# E&PDE 2024

# **Rise of the Machines**

Design Education in the Generative AI Era

Proceedings of the 26th International Conference on Engineering and Product Design Education

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# **Rise of the Machines: Design Education in the Generative AI Era**

Editors: Hilary Grierson, Erik Bohemia, Lyndon Buck, Jisun Kim, Ian Storer, and Timothy Whitehead.

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# Rise of the Machines: Design Education in the Generative AI Era

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#### E&PDE 2024 Foreword

#### The Rise of the Machines: Design Education in the Generative AI Era

The 26th International Conference on Engineering and Product Design Education (E&PDE) with the theme 'The Rise of the Machines: Design Education in the Generative AI Era' was held at Aston University, Birmingham on the 5th and 6th of September 2024. The conference was hosted by Aston University's College of Engineering and Physical Sciences, providing the principal locations and support for the conference. The conference was planned and arranged with the Design Education Special Interest Group (DESIG) of the Design Society, and the Institution of Engineering Designers (IED).

The E&PDE conference was initiated in 1999 in the United Kingdom and was consolidated as an international conference in 2004; alternately taking place in the UK and abroad. Its objective is to facilitate the bringing together of people from within education and industry who are interested in sharing expertise on the implementation and analysis of contemporary and developing methodologies in engineering and design education. It provides educators and researchers from product development, engineering and industrial design, together with industry and government representatives, with a platform for discussion on topical educational issues in design education and its future direction.

In 2019, the conference introduced visual papers where sketched images are essential in communicating the primary information, and text plays a supporting role. Visual papers aim to contribute new knowledge that have educational or research interest of the conference.

#### **Conference theme**

We are in the midst of a new stage in engineering and product design education and industry practice which will have a profound effect on how we teach, experience and do design - the era of generative AI. This is a rapidly accelerating field of machine learning that allows machines to generate or create new data and things that did not exist before. AI should cause all engineering and product design educators to consider how we should respond to this new era, how we can educate our students to flourish in an increasingly uncertain future, and how we can prepare them for careers in fields and roles that do not yet exist. Exploring and understanding these technologies may be the most critical challenge to engineering and product design education in the coming decades. While generative AI has been part of the digital ecosystem for a decade, it has only recently hit the mainstream. There is huge excitement around generative AI, yet it is raising concerns around information integrity and questions our ability to adapt to the pace of technological change. Therefore, we chose to dedicate the E&PDE 2024 conference to consider and expand the professional and pedagogic role that product designers and engineers have in engaging with Design Education in the Generative AI Era so as to ensure that we continue to explore the boundaries of engineering and product design education in an age of fundamental change.

These proceedings are based on a call for papers that aims to:

- Share, discuss and improve design and engineering education, and teaching and learning experiences
- Develop educational concepts and strategies to help staff, students and graduates address current and future challenges
- Provide a platform to engage a wide and diverse community of participants and explore the various themes from different perspectives

E&PDE 2024 brought together students, researchers, professionals and industry from the engineering and product design sector to exchange knowledge and experience, exploring sub-themes such as:

- The opportunities and pitfalls of AI for product design and engineering education
- Responsible innovation in design and engineering education
- Professional perspectives for design students in a pluralistic future
- International, multi-sectorial and transdisciplinary collaborations
- Ethical, social and/or environmental issues in design and engineering education
- Design and engineering as agents of regeneration and transformation
- Sketching and modelling design futures in the AI era
- Design sketching and modelling utilising immersive techniques and technologies
- Sustainable design and engineering education working towards the UN Sustainable Development Goals
- Established, alternative and emerging educational paradigms to equip engineers and designers for future challenges

During the conference over 140 participants from 26 countries delivered 4 workshops and 118 presentations. After double blind peer review process of the full papers, 123 contributions were selected to be included in the 2024 E&PDE proceedings.

The keynote for the conference was provided by Mandy Chessell CBE FREng. Mandy is a trusted advisor to executives from large organisations, working with them to develop their strategy and architecture relating to the governance, integration and management of information. Mandy worked for IBM for 35 years, the last 15 as an IBM Distinguished Engineer. She is now one of the founders of Pragmatic Data Research Ltd, dedicated to improving the transparency, security and efficiency of digital operations and data management. Mandy is also the honorary president of the Institution of Engineering Designers (IED).

Mandy has been developing integration software throughout her career. Her focus has always been on using and supporting open standards to achieve heterogeneous-interoperability. Today Mandy is the leader and top contributor to the Egeria Open Source project (https://egeria-project.org) which is part of the LF AI & Data Foundation. Egeria is focused on providing an open metadata and governance technology that is able to exchange, integrate and correlate metadata from different tools, engines and platforms.

Mandy is a Fellow of the Royal Academy of Engineering. In 2015 she received a CBE for services to software engineering. In 2000, she was identified as one of MIT Technology Review's hundred young people most likely to make significant 21st Century technical innovation. She is also distinguished as the first woman to win a Royal Academy of Engineering Silver Medal. Mandy has published numerous titles and has over 50 patents issued worldwide.

#### Acknowledgements

This 2024 edition of the E&PDE conference was made possible through the commitment and efforts of many people. We would like to thank Jo Winslow, Nadine Pearce, Lyndon Buck, Erik Bohemia, Hilary Grierson and Ross Brisco for their very effective and helpful collaborations. Thank you to all the members of the international academic review board who contributed to ensure the quality of

the papers and presentations and of course all colleagues and students at Aston University that contributed to the planning and running of the conference.

Dr Timothy Whitehead Associate Dean for Impact, Senior Lecturer in Design College of Engineering and Physical Sciences Aston University 6th September 2024



Established in 1945, Incorporated by Royal Charter in 2012, the Institution of Engineering Designers is the premier organisation in the UK to represent those working in the many fields of engineering and product design.

Our members enjoy a range of benefits, including mentoring and guidance to professional registration, exclusive access to our job board and newsletters to keep members up to date with relevant developments and events. We host regular events which offer our members the chance to network with other professionals and members receive the Institution's bi monthly journal – Engineering Designer.

We are committed to encouraging CPD for all our members and support ongoing training and skills development.

We offer a wide range of professional registrations: our own register for professional product designers includes the exclusive Chartered Technological Product Designer (CTPD) which is on a par with all other Chartered registrations and exists to provide professional recognition and standing to those suitably qualified and competent persons working in Product Design, with the sister grade of Registered Product Designer (RProdDes) for those not working at Chartered level.

We are licensed by the Engineering Council to assess candidates wishing to join the register of Professional Engineers and Technicians and we also accredit academic and training courses, for registration with either the Institution or with the Engineering Council. Those members who achieve the appropriate academic and competence standards receive Chartered Engineer, Incorporated Engineer or Engineering Technician status.

We are also a licensed body of the Society for the Environment and are able to register suitably qualified and competent members as Chartered Environmentalists (CEnv).

We welcome members from any organisation that has a design function and employs design engineers and we have many academic teaching staff in membership. To find out more about becoming a member of the IED and a professional registered designer go to <u>http://www.ied.org.uk</u>



The Design Society is an international non-governmental, non-profit making organisation whose members share a common interest in design. It strives to contribute to a broad and established understanding of all aspects of design and to promote the use of results and knowledge for the good of humanity.

The Design Society was founded in 2000, taking on the previous activities and responsibilities of the Workshop Design Konstruction (WDK) Society, especially the organisation of the International Conference on Engineering Design (ICED) series of conferences, which had been running since 1981. Since 2000 the Society has organised ICED conferences in Stockholm, Melbourne, Paris, Stanford, Copenhagen, Seoul and Milan. The upcoming 2017 conference will be hosted in Vancouver.

The Society has members from over forty countries and it organises very popular events such as the Engineering and Product Design Education conferences and the International Conference on Design Creativity among many other activities. The Society is very active in publishing papers and proceedings on design topics, and it has a developing portfolio of other design resources available to members including a repository of theses and collaborative agreements with a number of design research journals.

The Design Society concentrates on activities that transcend national boundaries, and, where possible, will seek to complement national activities. The objects of the Society are to promote the development and promulgation of understanding of all aspects of design across all disciplines by:

- Creating and evolving a formal body of knowledge about design
- Actively supporting and improving design research, practice, management and education
- Promoting co-operation between those in research, practice, management and education
- Promoting publications and their dissemination
- Organising international and national conferences and workshops
- Establishing Special Interest Groups and other specialist activities
- Co-operating with other bodies with complementary areas of interest

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The Design Society is open to new members. www.designsociety.org

### EXPLORING THE SYNERGY OF AI GENERATIVE FILL IN PHOTOSHOP AND THE CREATIVE DESIGN PROCESS UTILISING INFORMAL LEARNING

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#### ABSTRACT

This paper examines the emerging use of AI generative fill techniques in Adobe Photoshop (software, Adobe Inc, California, United States) coupled with informal learning situations, to enhance the creation of product posters for design exhibitions. By leveraging the capabilities of AI, designers can streamline their creative workflows, allowing for more efficient and innovative design outcomes [1]. The aim of this paper is to examine the benefits of Photoshop's AI generative fill in comparison to traditional manual methods for new graduates exhibiting at their first design show (New Designers, London), and to gauge the influence of informal learning settings in supporting designers' adoption of AI-driven design techniques. The findings of this research demonstrate a paradigm shift in the creative process, as AI generative fill in Photoshop emerges as a powerful tool for designers seeking efficiency, inspiration, and novel artistic directions. The findings also show how informal learning settings have played a vital role in nurturing new designers' adoption of AI-driven design techniques.

Keywords: AI, generative fill, photoshop, design process

#### **1** INTRODUCTION

In recent years, the emergence of Artificial Intelligence (AI) technologies in creative industries has led to ground-breaking advancements in design processes, enabling creative expression and expanding the boundaries of human imagination [2]. The integration of AI into the creative domain has opened new avenues for designers, empowering them with innovative tools to enhance their design capabilities [2]. Among these developments, the utilisation of AI generative fill techniques in Adobe Photoshop has emerged as an innovative creative tool, promising to enhance efficiency and enhance the creative design process. Photoshop's generative AI fill is a tool that uses machine learning to intelligently fill in missing or selected areas of an image with content that seamlessly matches the surrounding context, allowing for efficient and realistic image editing with minimal manual input. It analyses the image to understand its content and context, then generates new pixels to complete the area, blending seamlessly with the existing image.

Previously, the creation of product design exhibition posters by new graduates for exhibitions such as New Designers, involved laborious and time-consuming tasks, such as searching for an appropriate background image, perspective matching renders to chosen background images, and attempting to manually fix issues with tools such as clone replacement and content-aware fill. While these methods have yielded impressive results, they often require extensive effort and time, restricting designers' ability to explore multiple iterations and experiment with diverse design concepts. The use of AI generative fill in Photoshop has now opened new avenues for designers, enabling them to expand their creative process and streamline their workflow.

AI generative fill leverages sophisticated algorithms and neural networks to analyse and understand patterns, styles, and aesthetics from vast datasets of existing designs, and then venture into the realm of imagination and creation [2]. This technology allows Photoshop users to generate visually compelling elements, textures, and patterns automatically, reducing the need for manual input and repetitive tasks. As a result, designers can allocate more time and energy to the conceptualisation and ideation stages, developing innovation and creativity in the poster design process. However, the benefits that AI generative fill offers extend beyond just efficiency gains. By facilitating the rapid generation of design elements, it enables designers to explore diverse sources of inspiration, encountering numerous design

styles, and therefore pushing the boundaries beyond their traditional design conventions. By developing and integrating various design styles, social influences, and design trends, designers can create product design posters that deeply connect with target audiences.

The aim of this research paper is to comprehensively analyse if and how AI generative fill in Photoshop is being utilised to increase efficiency and improve the creative design process in the context of product design posters for exhibitions. By exploring real-world case studies, conducting user surveys, and assessing design outcomes, this research provides evidence of the tangible impact AI generative fill has on the design exhibition industry.

#### 2 RESEARCH METHOD

#### 2.1 Literature Review

Within the advancements of AI technology, generative AI has become a significant area of research [3]. Generative AI is an innovative technology that allows machines to surpass traditional tasks such as classification and predication and can generate novel and creative content automatically by utilising input data [2, 3]. Generative AI systems can produce novel outputs such as images, music, text, and more, that resemble human generated content [2]. Text-to-image AI models enable the creation of images from textual descriptions, and research into these models has been increasingly active [4]. Multiple approaches have been developed to create images from textual descriptions, including Generative Adversarial Networks (GAN), Variational Autoencoders (VAEs), and Diffusion-based Models (DMs) [5].

The literature demonstrates compelling evidence supporting the transformative role of generative AI in revolutionising the field of design [1]. Generative AI technologies have emerged as powerful tools that impact the design process positively, streamlining tasks, enhancing collaboration, and significantly improving efficiency [1]. The integration of AI tools in design has enabled automation of design recommendations, layout suggestions, and colour palettes, further augmenting designers' capabilities and creative output [6]. However, the literature also recognises inherent limitations of AI within the design domain [1]. While AI generative systems excel in analysing patterns and generating content based on existing data, they fall short in exhibiting innate creativity, emotional intelligence, and cultural context – qualities that human designers possess and infuse into their work [1].

#### 2.2 Primary Research/Methodology

This research is centred around the unique context of new product design graduates who had recently presented their final year projects at their degree show, being selected to represent their university and exhibit at the New Designers Exhibition in London. Following their selection, students were informed of the necessity to produce updated and enhanced posters within a remarkably short 2-day turnaround time frame. This rapid adaptation demanded not only creative agility but also a pragmatic approach to incorporate feedback they had received from the initial degree show presentations and subsequent design reviews conducted by members of New Designers team at the university. The graduates were introduced into an informal working group, through WhatsApp (Social Media Platform, California, United States), where they all shared their progress and updates, and received feedback from staff team members and the other graduates. The graduates were using Adobe Photoshop for the creation of their posters, with a notable adoption of Photoshop's AI generative fill that had only been released into the beta version that same month (June 2023).

To analyse the research findings a mixed-method approach was adopted, ensuring an in-depth understanding of the implications of Photoshop AI generative fill in this design practice. To gauge the effectiveness and implications of this tool within this setting, a questionnaire was developed and given to the graduates, comprising both quantitative and qualitative questions. The quantitative analysis, through a 5-point Likert scale questionnaire, focuses on evaluating efficiency, productivity, and creativity, measured through key performance indicators such as design iteration time, visual appeal, and user satisfaction, statistically analysed for comparison between AI generative fill and manual approaches. The qualitative evaluation delves into designers' perceptions and experiences with Photoshop's AI generative fill, exploring attitudes, challenges, and ethical considerations surrounding its implementation. By analysing both quantitative and qualitative data, this research aims to provide a holistic understanding of the implications and potential of Photoshop's AI generative fill in this realm of product design.

#### **3 RESULTS AND DISCUSSION**

#### 3.1 Adoption

11 recent graduates participated in this research study, and 8 (73%) of them used Adobe Photoshop's AI generative fill feature in their poster creation process. Notably, among the 8 participants who used generative fill, only 2 of them were using it for the first time, whereas the other 6 had prior experience with the feature. Adobe had released Photoshop's AI generative fill into their beta version 3 weeks before the creation of the New Designers posters. Meaning 75% of the graduates had actively sought out and leveraged Photoshop's AI generative fill within the first 3 weeks of its release. The participants with prior experience provided insights into their usage patterns. One participant mentioned using generative fill for editing images to rectify errors, while another utilised it for filling in background areas of composite images and scenery. Another participant utilised generative fill to widen images. Another experimented with generative fill upon its release, purely to explore its capabilities through test renders. While the last participant initially experimented with generative fill after encountering it on TikTok (Social Media Platform, Los Angeles, United States) and applied it purposefully for the first time in the creation of their New Designers poster. These varying experiences shed light on the diverse ways in which designers integrate new technological tools into their design processes and highlight the significance of adaptability and experimentation in navigating emerging design technologies.

The utilisation of Adobe Photoshop's AI generative fill feature by 73% of the graduates in this research project underscores the keen interest and proactive adoption of emerging technologies amongst the product design graduates. Despite being a brand-new tool, introduced merely three weeks prior to the project, a remarkable 75% of the graduates had already experimented with it. What is particularly intriguing is that this adoption was entirely self-driven, devoid of formal introduction or teaching within their university curriculum. This phenomenon reflects the students' intrinsic curiosity and eagerness to explore and harness the potential of AI advancements in their design practices. The high level of engagement with Photoshop's AI generative fill among the participants indicates a recognition of its transformative capabilities in streamlining and enhancing the design process. Beyond the immediate benefits of efficiency and creativity, the widespread adoption of Photoshop's AI generative fill among the graduates also prompts deeper reflections on the evolving role of designers in an increasingly technologically driven landscape and their proactive stance towards embracing technological innovation in design.

#### 3.2 Benefits of AI generative fill in comparison to traditional manual methods

The use of Photoshop's AI Generative Fill by the design graduates yielded significant benefits, as highlighted by both quantitative Likert scale responses (Figure 1) and qualitative feedback from participants. Quantitatively, participants overwhelmingly endorsed the effectiveness of Photoshop's AI Generative Fill in producing the desired outcomes, with every participant strongly agreeing or agreeing that it achieved the intended results. This result underscores the tool's capability to meet designers' expectations and deliver on their creative visions efficiently. Participants indicated that the AI outcome required minimal to no manual modifications post-generation, further affirming its effectiveness in streamlining the design process. This automation not only saves valuable time but also reduces the likelihood of errors, ensuring a smoother and more efficient workflow. Participants overwhelmingly agreed that Photoshop's AI Generative Fill saved them time compared to manual task performance, with all participants strongly agreeing with this statement. This unanimous agreement highlights the tool's efficiency in streamlining the design process, thereby enabling designers to allocate their time more effectively to other aspects of the creative process. Participants reported that the tool allowed them to achieve their desired outcomes more quickly and effectively, thereby enhancing overall productivity. Participants also rated the image quality of the AI-generated output favourably, with a majority agreeing or strongly agreeing that the output exhibited high image quality. This suggests that the tool effectively preserved the visual integrity of the poster elements, contributing to a professional and polished final product. Moreover, participants perceived moderate to high levels of creativity in the AI output, with the majority agreeing or strongly agreeing that it demonstrated creative potential. This indicates that the tool not only saved time but also facilitated creative exploration and experimentation, empowering designers to realise their design visions more effectively.

Photo	oshops Al Generativ	e fill produced the r	equired result I was	after		The image	quality of the AI ou	ıt was high	
Strongly Disagree	Disagree	Neither agree/disagree	Agree	Strongly Agree	Strongly Disagree	Disagree	Neither agree/disagree	Agree	Strongly Agree
0	0	0	5	3	0	0	0	3	5
T	ne Al outcome did n	iot require any man	ual modification aft	er		The creat	ivity of the AI outpu	t was high	
Strongly Disagree	Disagree	Neither agree/disagree	Agree	Strongly Agree	Strongly Disagree	Disagree	Neither agree/disagree	Agree	Strongly Agree
0	0	0	5	3	0	0	1	5	2
Photoshops AI G	ienerative fill saved	me time in compari	son to manually per	forming the task	My p	productivity was incl	reased utilising Phot	oshops Generative	Al fill
Strongly Disagree	Disagree	Neither agree/disagree	Agree	Strongly Agree	Strongly Disagree	Disagree	Neither agree/disagree	Agree	Strongly Agree
0	0	0	0	8	0	0	0	4	4

|--|

The qualitative results from the questionnaire, highlight the specific benefits derived from using Photoshop's Generative AI Fill. One notable advantage highlighted by participants was the substantial time-saving potential of the tool. By automating repetitive tasks and eliminating the need for labourintensive manual modifications, generative fill enabled designers to expedite the creation of exhibition posters significantly. Participants reported saving hours of work, which would have otherwise been spent on tasks such as adding details to render scenes or searching for suitable background images. This time efficiency proved invaluable, particularly when facing tight deadlines associated with exhibition preparations. The participants also noted that generative fill expanded their creative possibilities by providing greater flexibility and freedom in design exploration. The tool allowed designers to experiment with various concepts and iterate on design options rapidly, thereby fostering innovation and encouraging creative risk-taking. Participants reported that generative fill enabled them to add realistic elements to their posters, enhancing visual appeal and elevating the overall quality of their designs. Additionally, the tool facilitated the integration of objects and backgrounds seamlessly, contributing to a more cohesive and polished final product. Specific examples of how the graduates utilised Photoshop's AI Generative fill in their product posters for New Designers include creating a whole background image (Figure 2a), expanding an existing background image (Figure 2b), and to add extra products and content into the foreground of their image that was not in their original render (Figure 2c).



Figure 2. Product Poster Examples

Overall, the findings suggest that Photoshop's AI Generative Fill offers substantial benefits to designers in the creation of product exhibition posters. By automating routine tasks, reducing manual workload, and enhancing creative flexibility, this technology empowers designers to achieve their design objectives more efficiently and effectively. Future research could further explore the long-term implications of AI integration in design processes and its impact on designers' roles, workflows, and creative practices. However, it is essential to acknowledge and further research into the tool's limitations and continue refining its capabilities to address diverse design needs comprehensively.

#### 3.3 Informal Learning

Informal learning has played a vital role in nurturing the designers' adoption of AI-driven design techniques. The decision of students to independently learn and utilise Photoshop's Generative AI Fill reflects a broader trend of proactive engagement with emerging technologies within the design community. Motivated by a desire to enhance their skillset and streamline their design processes, the graduates sought out opportunities for self-directed learning, leveraging various resources and platforms available to them. Without formal instruction or guidance within their university curriculum, students took it upon themselves to explore the capabilities of Photoshop's Generative AI Fill, recognising its potential to advance their workflow and elevate the quality of their design outputs.

Social media platforms, such as TikTok and Instagram (Social Media Platform, California, United States), played a significant role in facilitating informal learning and knowledge dissemination among the graduates. Through TikTok, students encountered bite-sized tutorials, demonstrations, and showcases of Photoshop's Generative AI Fill in action, sparking curiosity and inspiring them to explore the tool further. The accessibility and diversity of content on platforms like TikTok provided students with a convenient avenue to discover and experiment with new technologies, transcending traditional barriers to learning. This research demonstrated the influence of social media on informal learning can be attributed to its ability to make knowledge easily accessible and develop a culture of continuous learning and innovation. By sharing tips, tricks, and insights on platforms like TikTok, individuals contribute to a collective pool of knowledge, empowering others to expand their skillset and stay in touch with technological advancements. The interactive and engaging nature of social media content creates a sense of community and collaboration, encouraging students to actively participate in discussions, share their experiences, and seek feedback from peers. The informal learning facilitated by social media aligns with the dynamic and rapidly evolving nature of the design industry, where staying ahead of emerging trends and technologies is essential for professional growth and competitiveness. By embracing informal learning through platforms like TikTok, the graduates demonstrated adaptability, resourcefulness, and a proactive approach to skill development, qualities that are highly valued in today's design landscape.

The establishment of an informal and supportive learning environment within a WhatsApp group among staff and student team members further enhanced the graduates' exploration of Photoshop's Generative AI Fill. By creating a sense of camaraderie and mutual support, the WhatsApp group encouraged active engagement and participation, creating a conducive atmosphere for learning and experimentation. The WhatsApp group facilitated ongoing dialogue and discussions surrounding the application of Photoshop's Generative AI Fill in their designs. Participants shared their experiences, exchanged ideas, and provided constructive feedback on each other's work, thereby promoting continuous learning and improvement. The iterative process of experimentation, feedback, and refinement produced an environment of innovation and excellence within the group, driving students to push the boundaries of their creativity and explore new possibilities afforded by the technology. The supportive and collaborative nature of the WhatsApp group nurtured a sense of belonging and community among the graduates. The group not only served as a platform for learning but also as a source of motivation, inspiration, and encouragement. The graduates felt valued, supported, and empowered to take risks and challenge themselves creatively, knowing that they had a network of peers to lean on for guidance and encouragement.

#### 4 CONCLUSIONS

This research paper has investigated the impact of Adobe Photoshop's AI Generative Fill on the creation of new graduate's product posters for their first external design exhibition, as well as the significant role of informal learning in developing designers' adoption of AI-driven design techniques. The integration of AI technologies into the design process represents a paradigm shift, offering new opportunities for efficiency, innovation, and creative exploration. The findings of this research underscore the proactive stance of recent product design graduates towards embracing emerging technologies. Despite the absence of formal instruction, the majority of participants independently sought out and utilised Photoshop's AI Generative Fill, demonstrating a keen interest in leveraging AI to enhance their design practices. This self-driven adoption reflects not only the students' adaptability and resourcefulness but also their recognition of the potential of AI to streamline workflows and unlock new creative possibilities. The informal learning environments, facilitated by social media platforms like TikTok and collaborative platforms like WhatsApp, played a crucial role in supporting the graduate's exploration of

AI-driven design techniques. The supportive and collaborative nature of these informal learning environments empowered participants to navigate the complexities of AI-driven design with confidence and creativity.

The implications of this research extend beyond the immediate context of product poster design, highlighting broader trends in the design industry towards the integration of AI technologies and the importance of informal learning in facilitating designers' adaptation to technological advancements. As AI continues to evolve and impact various parts of the design process, designers must remain proactive in embracing these changes and leveraging them to enhance their practice. Moving forward, it is essential for design education and industry stakeholders to recognise the significance of AI in design and provide the necessary support and resources to enable designers to harness its full potential. This includes integrating AI-driven design tools into design curriculum, developing collaborative learning environments, and promoting a culture of experimentation and innovation.

Further research could evaluate the effectiveness of formal educational interventions in preparing design students for the adoption of AI-driven design tools. Therefore, being able to inform curriculum development to better equip future designers with the necessary skills and knowledge needed to excel in a future technologically driven landscape.

In conclusion, the findings of this research underscore the transformative potential of AI in design and the critical role of informal learning in supporting designers' adaptation to technological advancements. By embracing AI-driven design techniques and fostering collaborative learning environments, designers can unlock new creative possibilities and shape the future of design practice.

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# EMBODIED DESIGN EXPERIENCES FIRST - BEFORE DESIGNING WITH(IN) AI

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#### ABSTRACT

Research on the 'materialising immateriality' design method and the related case studies have proven that hands-on designing with textiles, by humans belonging to different cultures and nations, provides an important tactile impetus and memorable senseful experience. Based on this knowledge, we can generate innovative, resilient textile habits, and develop design didactic approaches for the younger generations, from kindergarten on. In addition, collaborative, cross-generational and cross-cultural design doing provides resilience for the design community in terms of integration. The 'Materialising immateriality' design method with e.g. textile materials was developed over the course of collaborative, cross-cultural space and are showing that embodied experiences are the precondition for hacking digital tools, in designing and generating in virtual reality programs (with textile). Textile is only one example in designing with materials, architecture is another one, where first embodied experience is needed, before twice designing within digital tools, within AI will be senseful - in the meaning of designing resilient. Interdisciplinary materialising immateriality inhouse workshops are building instruments to proof innovative creating ways that we must shape our design tools with AI that will in turn shape us. And that is why hands on designing belongs relevant and as precondition for designing with AI.

*Keywords: Embodied experiences, materialising immateriality design method, tactile rebellion and remembrance, material memory, AI body and textile sketching* 

#### **1** INTRODUCTION

This research study focusses on the topic of 'advanced textiles materials and processes', by experimenting with hands on design and the idea of AI. The design method developed for 'Materialising Immateriality' [1] and the discussion of 'interlinked learning landscapes' [2] in cross-medial, non-hierarchical, interdisciplinary workshops – which first took place in 2019 in Germany and Great Britain – argue the importance of a re-valuation of human experiences with regard to manual designing – in particular that of children, e.g., by drawing in the sand, and adults [3]. At the same time, this holistically sustainable education gives us insight into the significance of good design within a **mixed reality space**, by using textiles. This research paper focusses on three significant didactic approaches to design sustainable textile products and sustainable cycles in the future:

First, the design didactic approach as applied in early education levels, particularly at primary school and before entering academic institutions (from both the children's as well as the educators' perspectives) looking for new textile partnerships in the field of 'Materialising Immateriality', expressed through collaborative hands-on designing – with TEXTILES. Hereby, the pedagogical implementation of tactile trigger points, like textiles, could **promote interlinked learning** and reflection, which would be beneficial to the upcoming textile experts as well a sustainable, circular textile economy, this will be showcased by a case study in cross continental conditions.

Second, it is about the collaborative approach of using different media and different tactile recognisable materials to 'designing experiences' [4] which are memorable. In this manner, corporal senses are a means of combining the design experience with design expertise to create sustainable textile habits – or, if nothing else, textile rebellion and textile remembrance. throughout embodied experiences.

And third, will be touched by looking at new field of cross collaborative experiences, the evolving field of 'interdisciplinarity', in that way Jan Cornelius Schmidt described in the year 2022 [5] that experiencing interdisciplinarity within a new field of research *today*, means generating a new *discipline of tomorrow*.

The 'Materialising Immateriality design process with textiles', like chapter two (2) outlines, – underlined by case studies (see fig. 1 – 3) and subsequent workshops – proves that different design methods impact the sustainable outcome not only for design languages, but in the form of pedagogical, economical, ecological and sociological benefits for society. The cultural mind [6] and the material mind [7] go hand in hand, forming a partnership to meet 3-dimensional (textile) media as an important tactile partner for all stakeholders to restore knowledge and rituals. To bridge the gap between reality and immateriality, when using digital design tools and AI, chapter 3 supports the motivation to understand world and complex systems by languages, codes and trigger points underlined by all senses, but in special by tactility. These holistically triggered experiences, embodied experiences, are essential trigger points to act. We need the motivation to act for a sustainable behaviour and sustainable design concepts. Chapter 4 formulates at the one hand a collaborative impetus of human embodied experiences WITH the 'AI body'– but important is the impact of manmade rebellions with hands on designing and materiality as trigger points. At the other hand, it demonstrates a strong believe, that we have to shape our (human body triggered) AI tools before AI shape us. This so called 'anti-paper' fights for behold on crafts technologies and hands on designing as embodied experiences FIRST – before designing with AI.

#### **2 MATERIALISING IMMATERIALITY – THE SIGNFICANCE OF TACTILITY**

# 2.1 'Materialising Immateriality' in context of design methods - TEXTILES as tactile trigger

Let me introduce how important the language of textiles is about the design and embodied learning process: In the year 2009, Matilda McQuaid wrote: 'Fashioning Felt examines the explosion of interest in recent years in the field as a design material and process. [...] Felt's first wave occurred as part of the fibre-arts movement of the 1970s. In 1979, British artist and scholar Mary Burkett produced an exhibition and book, The Art of the Felt maker (note: 'The Art of the Felt Maker'), which toured England and introduced to many people the felt making traditions of nomadic peoples. This served as a catalyst for two decades of intensive field research.' [8]. McQuaid described how textiles triggered the research by Canadian and British textile experts into the felt heritage found in North Africa, Mongolia and Japan. In the year 2019, ten years after McQuaid study, the research by Marina-Elena Wachs about **interdisciplinary industrial designing** with a focus on textile materials, created the framework for the 'Materialising Immateriality Workshop' practised with student group at RCA-UK and as well in Germany. This facilitated the collaborative design work of different students coming from a range of study levels, from bachelor and master students to PhD students, all of whom had different previous educational and cultural backgrounds. The textile media were fantastic trigger points that sparked the expression of their respective expertise.

Materialising Immateriality workshops are characterised by the following process: 1. A broader range of different textiles are given to the workshop participants as trigger-point. 2. The analysed functions, material-composition, construction parameters and narrative associations – related to individual experiences and to societies history at all – will than have an impact in the next design steps. 3. Mapping-Methods-Exercises in groups and for the individual design/-concept are than following. 4 Interim-Presentations and final presentation are coaching different didactical relevant results and competences. See the detailed process of 'Materialising Immateriality Method' within Wachs book about 'Design Engineering – sustainable and holistic from 2022 [9]. The academic benefit of learning through hands-on, collaborative designing is the acquisition of knowledge about textile applications and textile technological functions, while simultaneously learning about the textile heritage of different countries. The last element was beneficial for raising awareness about one's own cultural textile heritage and, at the same time, learning about the **textile languages** and the meaning of the textile codes of other cultures over the course of history.

The design method that we used within the workshop, 'Materialising Immateriality', has to be regarded as a design didactic approach for each group – in different languages and for different educational levels – which is communicated and related to the evolutionary development of design methods in Europe as listed below: (listed in a non-chronological order)

- Classical (linear) design process (original form of the term design; sketch based)
- Design driven by technology (first the development of technology form / design followed)
- Interactive design (abstract term elaborated and used for interactive, collaborative designing)
- Design thinking (mind-map based; reflective theory- and concept-based, collaborative ideating act)

- Integrative design (participants from different disciplines and different cultural backgrounds)
- Materialising immateriality (tactile materials create the process and the design object or a design concept, which is communicated and expressed via textiles within a designed 'form')

In the year 2019, 'materialising immateriality with textile methods' first was developed during intercultural workshops in Germany and Great Britain, within academic circles at universities. The use of different textile materials in various qualities provided important tactile triggers for creating a new process: using the textiles as an impetus for obtaining new perspectives by means of a manual act.







Figure 1. PhD Student is materialising the immateriality of 'illness dementia and the design concept of each individual involved in the care of the dementia patient'. 2019, London

Figure 2. Master student M.L., of course: 'Visual Language', designed: 'textile turn', 2023

# Figure 3. Bachelor student in study program 'Textile and Clothing Management', course design theory and history, student M.K. the concept: 'spiral of the textile industry', 2023

The freedom to experiment allowed participants to play with textiles in previously unknown associations - e.g., textile production and textile functions, textiles heritage - and in association with tactile experiences from the past; The textile experimentation took place after an introduction and comparison of textile furniture applications from different countries, cultural design heritages. Figure one shows the textile solution of a PhD student with the subject matter of his doctoral thesis about dementia, in the year 2019: By transferring the design concept of each individual involved in the care of the dementia patient, he integrated elements of empathy design, developed AND communicated by the 'textile concept'. Figure two and three shows comparable workshops with master and bachelor students in the year 2023. These covered a variety of topics, as follows. In the course Cultural Visual Language master students created visual textile language(s) that reflected culture. Master student M.L. created a concept based on the topic 'textile's doubts for the textile turn'. This involved doubting and questioning the given structures in the textile and clothing industry - not only to call for more transparency, but an active co-creation of the textile turning point, too. The open spaces and apertures of the draped textile can be individually designed so that everyone can incorporate their perspective and thus reveal more of the structures in the play of light and shadow. The interactive textile model symbolises the initiative to question and help shape the industry for more transparency as we find ourselves at a textile turning point. Two Bachelor students collaborated during the design theory course, which is part of the degree program Textile and Clothing Management and named their concept 'spiral up - the textile industry'. By expressing the hype of the fast fashion and the spiral of overconsumption and overproduction. With this, they intend to break this system, not only raising awareness about the problem, but also incorporating the element of a textile revolution, which should be transferred to other levels in the subsequent change process. All textile solutions were discussed, reflected and evaluated by all workshop participants. This kind of evaluation and self-reflection serve a resilient (didactical beneficial) learning loop in reflecting and guarantees remembrance.

#### 2.2 Textile rebellion and remembrance serve sustainable (textile) design strategies

Through the experimental possibilities, the playful atmosphere and sometimes the designers' and users' naïve views on unknown materials used within the interaction in Materialising Immateriality workshops, we are working with the ability of remembrance – the memory of preconditioned experiences from our own individual past within the framework of our own society (nation). The cultural memory and the material mind (Wachs) are aware of craft techniques, although we are talking about the loss of these knowledge heritages in design doing with textiles, ceramics and other resources. The initiation of the 'homo faber' event in 2022, which took place in Venice, Italy, is only one example of how to re-activate

and remember the value of a great textile past and other crafts – to inform us of the future. Perhaps we need more textile rebellion and textile interactivity through rediscovery [10] and by ensuring the textile education of all people our sense responsibility can be triggered. We must continuously provide answers for sustainable strategies, while also answering the needs of time and human beings. Juliane Kahl, a textile expert and teacher in Germany and at the London College of Fashion, organised the first fashion hackathon in East Africa as part of an academic research project. She argued that this was a 'Responsive Design project, within the wider development context of the global fashion industry, to which a sustainable strategy must respond and addresses local needs.' [11]. In relation to holistic textile design development and education, we would like to underline that sustainable textile strategies have to integrate textile rebellion, responsive design methods and tactile textile trigger points, such as the Materialising Immateriality Method that is beneficial for business applications and educational spaces.

# 3 CREATING WITH(IN) TACTILE SENSES – HUMAN MADE ACT OF REBILLION AND EMBODIED CONNECTION AS ANTI CHARACTER TO AI 3.1 The capacity of curiosity + revolutionary acts as manual experience is key – the

# 3.1 The capacity of curiosity + revolutionary acts as manual experience is key – t significance of 'reference letter(s)'

The capacity of curiosity and preference is an important factor in creating the new or seeing things as new. The unexpected influences the aesthetical and ethical creation and expressions in all times. Nowotny and Sennett explores the idea that innovation has to be seen through the unexpected intertwining of times and conditions of science, technology and societies. As Wachs declared graffiti, found in cities symbolising a 'reference letter' as cultural expressions of time as well as a self-expression of the individual relevant to that moment [12], this process of humans' self-discovery through hands on designing with different materials and through different senses can be seen today as anti-character of AI based (on) designing. This kind of designing could never be replaced by AI but is important for the designers' signature and ideating design power – and capacity.



Figure 4. Prerequisites for designing within the futures tools, 2024 thesis-by the author

Doing design by ideating with your hand are the '*Prerequisites*' [13] for creating and interpretating design codes, product languages as symbolically meaningful representatives, the beginning for societies reference letter and heritage, that ideates the new, unknown. The ability of coding with hand begins in free style designing as a child, developing in different steps, more or less influenced by cultural coding (see fig. 4). Today, at the beginning of the post digital era, 'patterns' are crying for attention, to feed the data collection of the AI-designing tools. Yet in the past, the meaning of ornaments was interpreted differently, and was viewed in different artistic, societal and design historical and ethical contexts. Like you have seen, with the help of the new experiences by the workshop 'Materialising Immateriality' the sociological and pedagogical and design didactical perspectives are telling us, manual experiences are key for the design act as well for restoring knowledge, knowledge of crafts, textile techniques or design didactical methods. This great archive of knowledge lay in all cultural by hands created and by hands evaluated design values and will have influence for the next design output of AI based designing [14].

#### 3.2 Textiles as trigger point for 'embodied social knowledge'

The experiences gained by the revolutionary act of designing is transferable to designing with textiles as a revolutionary and memorable 'all in' act. 'All in' means experiencing the individual acts with all senses – not only with the eyes and controller within the reduced frame of VR spaces, but also with acoustical and tactile approaches, smelling and tasting if possible, aligned with feelings and emotions. If you look at the process of 'Materialising Immateriality with textiles' (2019-2023) we have to reach a

culturally understandable interpretation of sustainable textile usage, to facilitate resilient habits for societies around the world. The act of creating together generates communities of its own: If we describe the revolutionary act as and 'all in' act, with all senses and a high motivation to act, the sociologist Richard Sennett explains as follows: 'In sum, the process of making and repairing inside a workshop connect to social life outside it. The pregnant world embodied helps make those connections. "Embodied social knowledge" is usually used, in the jargon of the social sciences, as a floating metaphor, though metaphors and analogies of course enable understanding [...]' [15]. Repairing, the act of doing with textiles, enables one to understand the world, to generate a sustainable world. But working with 3-d materiality is not only to design, to create, to gestalt, to know [16]. It is remembering by hands-on designing, using your material mind [17] in relation to the (textile) heritage and the knowledge archive of the societies - in line with the design methods, and co-creation in special [18]. Sennett argues again: 'Repair work suggests other ways to relate the physical and the social. Restoration, whether of a pot or of a ritual, is a recovery in which authenticity is regained, the damage of use and history undone; the restorer becomes a servant of the past.' [19]. Because at the end we have to evaluate the designed product or concept and the question arise: who will evaluate the result of designed goods, even it feed backs to the human's behaviour and habits? However, we see developments in AI collaboration be human beings [20], but it remains in our hands brain coordination and abilities.

#### 4 'MATERIALISING IMMATERIALITY' – A METHOD FOR COLLABORATIVE TEXTILE EDUCATION TO RESTORE & CREATE RESPONSIVE DESIGN

#### 4.1 Embracing unknown by designing solutions with(in) AI?

The 'embodied connections' (Sennett) could be the impetus and 'motivation to act' (Pelluchon) and bring about change in terms of sustainable solutions and behaviour: for this process textiles or the 3dimensional material, could be considered to be the tactile driver, for coming into action for the change. The textile design solution must be interpreted not only according to its ornamental beauty and the design codes employed, but also as cultural expressions with design didactical and art pedagogical significance. This allows us to learn from each other, cross cultural, cross continental, cross generational. At the same time, the significance of freely creating spaces with tactile materials, by 'Materialising Immateriality-Method' - which involves textile sketching that span cultures and generations - is providing a design theoretical and socially resilient and revived act of design doing that is good and reflected. The 3D-material, in this case textiles, promotes 'bridging the gap' [21] between the medium, which act, the actor of designing as co-designer: whether as human being or as AI based robot in optimised functionality. It promotes integration, and forms of integrative design [22] because it is embracing cultural codes and 'embracing the unknown' (Nowotny), which are viewed as 'differences' or 'otherness' in society. It is about understanding the otherness and the unknown, the unexpected. In the year 2020, Ashley Hall sees the 'Designs central value is dealing with the unknown and often the unknowable' [23] within the context of teaching Design AI. The human factor in designing good is precondition in designing resilient, meaningful, and this brings us to the Six (6) Characters in designing the future by human's hand different to AI Characters, that do not full-fill the same:

- Capacity of curiosity and preference as important factor in creating the new
- – as a cultural humanistic resource
- Reference letter self-expression of the individual relevant to that moment in time.
- Creating a knowledge archive to be used for tomorrow (– not losing the knowledge)
- Revolting moments against societies conventions...emotional act
- With the 'act' in relation to joy and self-discovery.
- Evolving own signature and ideating out-put.

Three-dimensional designing methods hand-made are good to restore textile techniques and textile heritage by remembering the value of design knowledge and hands on designing; evaluating the competences for the individuum and so it is for societies: As seen, textile rebellion and remembrance, by means of hands-on textile designing, is comparable to the act of sketching and designing with tactility, and should enable more sustainable design resilience for the future. Underlined by Nowotny, when talking about the unexpected intertwining of times and the standards of science, technology and societies, we have to 'embrace', or rather withstand this dilemma to create the new and different as something good through (textiles) design as 'natural embodied model' (the author) first, before shaping

(and feeding) our AI tools of the future. These results are underlining: we need embodied experiences first, before designing with(in) AI.

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## A COMPARISON OF ARTIFICIAL INTELLIGENCE IMAGE GENERATION TOOLS IN PRODUCT DESIGN

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#### ABSTRACT

Artificial intelligence (AI) image generators have seen a significant increase in sophistication and public accessibility in recent years, capable of creating photorealistic and complex images from a line of text. A potential application for these image generators is in the concept generation phase in product design projects. Successful implementation of AI text-to-image generators in concept generation could prove to be a cost and time saving application for companies and designers. Therefore, the aim of this paper is to investigate the integration of AI into product design and education. A literature review was conducted to gain a general understanding of what AI is and how AI image generators function. An experiment was carried out which used three different image generators: Stable Diffusion, DALLE 2, and Midjourney. Three images of dining tables were produced by each AI text-to-image generator and inserted into a weighting and rating matrix to be rated as concepts along with three real dining tables from IKEA. Within the matrix were four design specifications to rate the concepts against: aesthetics; performance; size; safety. The matrix was sent out to product design students and graduates to be completed anonymously. The highest scoring concept was one from IKEA, followed by one generated by DALL ·E 2. Based on the results of the experiment, it was concluded that AI image generators are not yet a viable alternative for concept generation in product design but could be a useful tool to spark new ideas for designers to use during the concept generation phase.

Keywords: Artificial intelligence, product design, text-to-image generation, concept generation

#### **1** INTRODUCTION

In product design, a project will typically require four stages: initial research, concept generation, concept evaluation & selection, and detailed design. Artificial Intelligence (AI) has the potential to support designers at each of these four stages. AI image generators is one promising tool which could support concept generation. These tools are capable of creating photorealistic and complex images from a line of text. However, the suitability of this technology to support designers is unclear. In this paper, the suitability of using AI image generators for the concept generation stage in student's product design projects is investigated. Although the incorporation of AI in product design is an emerging research area, successful implementation of AI text-to-image generators in the concept generation phase could prove to be a cost and time saving application for companies, designers, and design students. If educators have a better understanding of the value of these tools, and future successful and unsuccessful use cases then they can best advise students and educate them towards successful integration of these tools in the design process.

#### **2 LITERATURE REVIEW**

AI as a concept has been researched and developed since the late 1940's with its genesis attributed to Alan Turing who posed the question "Can machines think?" [1] and John McCarthy who invented the term 'Artificial Intelligence' and defined it as "the science and engineering of making intelligent machines, especially intelligent computer programs" [2]. In general, AI can be interpreted as creating a machine which is able to operate intelligently or even be able to think by itself, just as a human can.

#### 2.1 AI Text-to-Image Generation

AI text-to-image generators have seen a dramatic increase in sophistication and public availability in the last few years. Simply, they are programs/applications that present a prompt to enter a text description of an image and return an image that is accurate to the text description. There are multiple

methods that can be used to generate images; however, this paper will focus on popular methods of generative adversarial networks (GANs) and diffusion. This explanation is aimed to support the wider understanding of the types of technology used and how this works when using the label of AI.

#### 2.1.1 Generative Adversarial Networks

A GAN is comprised of two neural networks: a generator and a discriminator. The generator takes random gaussian noise and produces a fake image that is fed into the discriminator along with a real image of the same subject. The discriminator tries to identify which image is real, whilst the generator tries to fool the discriminator by making the fake image look real [3]. To begin, the generator may create an image where the discriminator has no trouble in identifying the real image. The generator uses the discriminator's identification and calculates a loss (generator loss) from it, where it undergoes backward propagation through both the discriminator and generator. The weights of the generator are updated, and this concludes one iteration of training for the generator [4]. If the discriminator misidentifies the real image as the fake and the fake image as real, the weights of the discriminator are adjusted based on the discriminator loss which is fed back through the discriminator network [4], concluding one iteration of training for the discriminator. The aim for training the GAN is to get to a point where the generator is able to consistently produce images where the discriminator cannot distinguish between the fake and real images. When the generator is fully trained, word embedding is used to ensure the generator represents the words used accurately. Word embedding is the process of training a network to recognise the meaning of a word and its relation to other words of a similar meaning [5] so the network knows what to use to represent these words.

Although GANs are capable of producing photorealistic images, training these networks can be very difficult because of a problem known as 'mode collapse'. This is when the generator creates the same image (with minimal changes) because it has worked out how to beat the discriminator and, therefore, has no incentive for creating interesting new images. It has found a solution for the problem it was given so it sees no need in finding other solutions for the same problem. Moreover, producing a photorealistic image with no blemishes from random noise is no easy task. GANs can suffer from obscurities and errors in their images when it comes to generating complex images. Diffusion can solve these issues.

#### 2.1.2 Diffusion

Where GANs generate images directly from random noise, diffusion models use a neural network that takes this process in iterative steps. Training a diffusion model involves taking an image and gradually adding gaussian noise to the image until it is complete random noise (forward diffusion). This process is then reversed, where the neural network tries to discern how much noise was added by calculating probabilities at each stage in order to recover the original image (denoising). This process is known as reverse diffusion. Once the diffusion model learns the reverse diffusion process and can denoise images accurately, it can be used to generate new images from random noise inputs [6].

Contrastive Language-Image Pretraining (CLIP) is a tool used in conjunction with the diffusion process to fine-tune images and make them as accurate to the text description as possible. It uses an image and a text encoder that have been trained to find which texts correlate to certain images within a dataset as described by Kim, Kwon and Ye; "The input image is first converted to the latent via diffusion models. Then, guided by directional CLIP loss, the diffusion model is fine-tuned, and the updated sample is generated during reverse diffusion." In this context, the "latent" is the random noise that the image from the dataset is converted to in the forward diffusion process. Using the loss function from CLIP the diffusion process is adjusted accordingly, and an optimised image is produced from reverse diffusion which should be more accurate to the initial image request [7].

#### **3 METHODOLOGIES**

To investigate whether AI text-to-image generators would be viable for generating concepts for student's product design projects, an experiment was created using three AI image generators to each produce three images of a dining table. These images were rated by participants as 'product concepts' using a rating matrix. Pugh's elements of specifications were used to establish generic design requirements. Four specifications were selected being: aesthetics; performance; safety and size.

Participants were 5th year students and graduates of the department of Design, Manufacturing and Engineering Management (DMEM) at the University of Strathclyde with experience from studying product design and with familiarity of the rating matrix used to collect data. The rating matrix was

created digitally using a survey tool (Qualtrics) and was emailed to participants. 12 participants took part in the study and were of ages between 21 and 24.



Figure 1. Image examples (from left to right) Ikea, Stable Diffusion, DALL ·E 2, and Midjourney

Participants were not made aware that three images of real dining tables available from IKEA were included in the evaluation with 9 concepts generated by AI. If the AI text-to-image generated images scored higher than the real tables, the AI will have succeeded in creating viable concepts for product design, otherwise, it will have failed. The AI text-to-image generators used for this experiment were Stable Diffusion, DALL $\cdot$ E 2, and Midjourney. Images of dining tables were selected from the IKEA website. Images from Stable Diffusion, DALL $\cdot$ E 2 and Midjourney were created in November 2022 using the text prompt "a dining table". Where AI tools generated multiple images, the first three presented were selected.

#### **4 RESULTS**

The sum of the ratings of the participants was calculated for each table and the results are presented in Figure 2. Tables 12, 8 and 3 are those created by Midjourney (Blue), Tables 10, 6 and 5 were created by DALL E 2 (Green), Tables 9, 7 and 2 were created by Stable Diffusion (Orange), and Tables 11,4 and 1 are taken from the Ikea website (Yellow).



Figure 2. Sum of rated AI generated images as dining table concepts

The concept with the highest score of 206 was Table 1 taken from the IKEA website. The lowest scoring table with a score of 90 was Table 12 generated by Midjourney. All 3 Midjourney tables were among the 4 lowest rated. The most consistently highest scoring set of tables were those generated by Stable Diffusion, with only a 4.5-point difference between the highest and lowest rated tables. The key result from this experiment was DALL  $\cdot$ E 2's Table 10 which rated higher than two of the IKEA tables with a score of 202.

#### **5 DISCUSSIONS**

Before discussing the results of the experiment, the understanding of what a concept is to the participants should be established. Our students are taught that a concept is a visual representation of an idea. These ideas can be expressed through various mediums such as 2D and 3D sketches, computer renders and physical prototypes. We teach our students to minimise the constraints on the generation of initial concept generation to support ideation. Only when evaluating concepts would they typically begin to introduce constraints in the form of product design specifications.

AI text to image generation tools do not currently have the ability to generate concepts based on design specifications which support creative ideation. However, where they are limited is in the data set used to train them. This may not support a wide exploration of ideas however there is evidence that datadriven design concept generation approaches have great value in supporting novice designers when incorporate novel technologies [8].

Beyond this, it should be noted that the ratings provided by the respondents are subject to the interpretation of the image as a concept. Each product designer will have their own interpretation of what a dining table should look like, the features and functionality the concept should have, and the same can be assumed for each of the design requirements used to evaluate the tables within the rating matrix. This may be a limitation of the study to not provide a design brief to the respondents, however, this may be authentic to the real-life process of evaluating and selecting concepts for some product design projects.



Figure 3. (from left to right) Table 4, 11 (Ikea) and 10 (DALL · E 2)

Analysing the results of the experiment, the AI has both succeeded and failed in scoring higher than the tables from IKEA. The outcomes of the images that AI created are inconsistent as concepts. Although DALL·E's Table 10 scored higher than IKEA Tables 4 and 11 (Figure 3), this should not be misconstrued as DALL·E 2 being the viable option for generating concepts suitable for product design. Table 10 is surrounded by chairs which mask the table's legs and makes it difficult to discern the chair legs from the table. This was a limitation of the AI, the ambiguity of the image concealing the table's legs has likely played to the interpretation of the concept.



Figure 4. Images generated by Midjourney (Table 3, 8 and 12)

Dining tables generated by Midjourney (Figure 4) were among the lowest rated of all twelve tables. When considering the images generated comparing them to Stable Diffusion and DALL E 2 it is clear why Midjourney had a lower score. The images are more artistic and abstract in nature and appear as though they have been drawn or painted. As a result, the dining tables generated made little sense in

terms of the design requirements in the matrix. The main reason for this is most likely due to Midjourney's training data consisting of drawings, paintings, and other artistic works. Whereas Stable Diffusion and DALL  $\cdot$  E 2 were, presumably, trained more with photographs which is why their images generated look photorealistic instead of hand drawn. This raises the question about the appropriateness of the training data to the use case of the AI text-to-image generator. If an AI text-to-image generator were created with product images, would it be appropriate and more successful for the purpose of evaluating and ultimately selecting concepts? Similarly, if a training set was created of a single product category would it be able to generate novel conceptual designs?

It may also be assumed that Stable Diffusion and DALL·E 2 have more images of dining tables within their training data compared to Midjourney which may have added to the odd and abstract look of the dining tables. Although detrimental to the outcomes of the experiment, Midjourney producing concepts through an artistic medium could be beneficial to some product designers since they would typically sketch initial concepts in an abstract way. If the training data was tailored more towards various objects and products that would be suitable for product design, then Midjourney could be a viable option for providing inspiration for new and innovative concepts.



Figure 5. Images generated by Stable Diffusion (Table 2, 7 and 9)

Stable Diffusion produced the most consistent high scoring images of dining tables (Figure 5), with only a 4.5-point difference between its highest and lowest rated tables. Compared to DALL $\cdot$ E 2 which had an 84-point difference and Midjourney which had a 37-point difference. Also, Stable Diffusion's Table 7 was 22.5-points lower than IKEA's Table 1 which was the highest scoring dining table. This may be another reflection of the impact that the training data can have on the outputs from the AI text-to-image generators.

#### 5.1 Reflections for educators

With the rate that acceptance of AI is growing, and how quickly it is advancing, the capabilities of AI image generation may soon be at a stage where it could become a common tool used by product designers to help with concept generation or even be the forefront of it in a range of roles [9]. Moreover, further advances in AI will allow for even more complex and sophisticated machine learning models to be created. An example could be a deep learning model built specifically with product design in mind. One that is incorporated with computer-aided design (CAD) and can easily create a wide range of concepts that take design specifications and engineering parameters into consideration with minimal input from designers. It could become common practice to use this model for the entire concept generation phase, saving designers a significant amount of time on the project. As new research on using AI in a product design environment begins to emerge, the likelihood of a deep learning model such as this becoming a reality increases.

If such a system were to exist, there may come a time where some everyday products have solely originated from artificial intelligence. As educators we cannot stop our students from experimenting with these tools and we should not discourage it. Once the capabilities of the tools catch up with the use case to generate product design concepts, our students need to understand how best to use these tools and we can begin to build their competencies in forming text prompts for these systems. As researchers we can support the understanding of the capabilities of current tools and drive the development of tailored tools to deliver solutions that are more accurate to the task. We should not encourage the use of novel technology without reason [10]. However, we can have a hand in supporting the evaluation of possible technologies from our investigations into their affordances.

#### **6** CONCLUSIONS

This paper aimed to investigate if AI could be integrated into student's product design process using text-to-image generation during the concept generation phase. An initial research investigation determined that the text-to-image generation method utilised, the training method and the interpretation of the images all play a significant role in the suitability of generated images as product design concepts. Tools such as DALL $\cdot$ E 2 were able to generate images that outperformed real world images which indicates a potential for this technology. However, the majority of concepts performed lower in a concept evaluation activity. There are still questions to be asked in the role that specifications and interpretation play in evaluating generated images. And if these challenges can be overcome with specific AI tools are created in the future which focus on inspiration of ideas or specific product categories.

Most text to image generation tools currently available are free to use, easily accessed, easy to use, and capable of generating images almost instantaneously, there are few reasons for designers within industry and education not to experiment with them, despite current limitations. As educators, we should communicate how best these tools can be used and when not to use them. For now, these tools have a place as inspiration when the design student has run out of ideas. However, currently they cannot replace the creativity of the designer, nor the intuitiveness of their response to design challenges within the conceptual generation phase of the design process.

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# IMPACTS OF GENERATIVE AI ON ENGINEERING AND PRODUCT DESIGN STUDENTS' PERFORMANCE

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#### ABSTRACT

There has been a growing interest in recent years in the use of artificial intelligence (AI) and computer science applications within the field of education. Previous systematic reviews and meta-analysis research has shown that use of AI and computer science can enhance students' performance in educational contexts. However, studies are mixed in their impressions of the use of Generative AI as a disruptive technology, with educators citing concerns over plagiarism and misuse of such technology by students. These tools represent a stark contrast to many traditional educational approaches and require reshaping of assessments to ensure that learning outcomes can still be measured. Nevertheless, there is still a significant lack of studies examining the students' perspectives on the use of these technologies and their impact on their academic performance. Therefore, the current paper aims to investigate how generative AI impacts upon product design and engineering students' performance within educational contexts in the UK. Through the distribution of an online survey, the study aims to assess student's attitudes, preferences, and challenges concerning the use of AI powered tools. Furthermore, it aims to capture valuable insights from students into how generative AI technologies can impact on various aspects of their academic achievement, learning outcomes, and engagement.

Keywords: Generative AI, education, teaching and learning, disruptive technologies

#### **1** INTRODUCTION

Recent developments in machine learning have resulted in improving technologies for generating digital content, such as generative artificial intelligence (AI) [8]. Generative AI models utilize smart algorithms to understand patterns and produce novel content such as texts, images, sounds, videos, codes, amongst others [4]. Previous literature has indicated two major types of generative AI, these are named as Generative Adversarial Network (GAN) and Generative Pre-Trained Transformer (GPT) [7]. The Generative Adversarial Network (GAN) is a type of generative AI framework which contains two neural networks, known as a generator and a discriminator, working in competition to generate realistic data [2]. Conversely, the Generative Pre-trained Transformer (GPT) models employ a neural network architecture which effectively captures and comprehends contextual relationships within data. These modes are based on diverse datasets meaning that they can learn from a diverse set of examples to understand the complexities of language and context. The importance of Generative AI in education cannot be emphasized enough. AI-driven tools have begun to transform the learning sphere, reshape the teaching paradigms, influence research productivity and present complex challenges. In higher education, Generative AI tools are widely used to improve students learning process by generating highly original outputs in response to user prompts [5]. For instance, ChatGPT, Gemini and Claude are text-to text AI generators which can support students, specifically non-native speakers, in brainstorming ideas and receiving feedback on their writing [1]. In addition, Grammarly improves written work with grammar checking and style suggestions, benefiting students' communication skills in different ways. Furthermore, text to images AI Generators tools such as Dall-E, Midjourney, Vizcom and Stable Diffusion, can be considered as valuable tools for teaching technical and artistic concepts in arts and design [6]. For instance, Vizcom enhances learning by improving comprehension by producing visuals like diagrams and videos, catering to diverse learning styles for more effective education. Despite the numerous advantages of using Generative AI tools, these tools can introduce certain challenges and raise
concerns in the academic community. One major concern involves AI-assisted cheating, where students using AI tools to write assignments and complete their exams [11]. Therefore, ensuring unbiased and fair outcomes in assessments and grading could be a big challenge for academic evaluators. In addition, some concerns may be associated with students depending heavily on AI tools instead of utilizing their analytical thinking abilities. This may result in a decline in problem solving proficiency and creativity among students as these tools often provide quick and automated answers, potentially discouraging students from engaging in critical analysis and fostering independent thinking [5, 10]. On the other hand, it's worth noting that these tools could also promote a deeper investigative approach to inquiry. Learning how to question AI tools effectively can be beneficial, but it requires a substantial amount of knowledge and training [9]. While extensive research has been conducted on Generative AI in recent years, there is still shortage of studies exploring its impact on educational settings, particularly from a student perspective of utilizing Generative AI tools in the UK. There. Considering the growing interest in the use of Generative AI tools among students, it is important to understand their attitudes and views on it. Therefore, the current paper aims to assess the influence of these tools on student performance within educational contexts in the UK. By employing an online survey, this study aims to understand how generative AI technologies influence academic success, learning outcomes, student engagement, and any potential impacts on the overall educational experience.

## 2 METHODOLOGIES

The current study gathered data from 110 engineering (55) and product design (55) students in the UK through an online Qualtrics based survey, distributed through social media platforms including Reddit, LinkedIn and through the researchers 'direct contact' using a snowball effect. The primary objective of the questionnaire was to assess engineering and product design students' views and perspectives on using Generative data Technologies. The study was approved by the Nottingham Trent University, School of Science and Technology ethics committee. Informed consent was acquired before each participant completed the online questionnaire. A questionnaire employed a mixed-methods approach, incorporating dichotomous, matrix table and multiple-choice quantitative questions and open-text qualitative questions. All data were coded and analysed using SPSS and NVivo software.

## **3 RESULTS**

## 3.1 Quantitative Findings

The sample comprised 79 males (71.2%), 28 females (25.2%), 2 other (1.8%) and 1 Prefer not to say (0.9%). Participants were aged 18 to 44 years old (M=23.61, SD=5.44). Out of 110 students surveyed, 59 identified themselves as UK home students, while 51 identified as international students. Table 1 displays the highest academic qualifications reported by participants.

	Frequency	Percent
PhD/doctorate or equivalent	2	1.8
Postgraduate/master's degree or equivalent	13	11.8
Undergraduate/bachelor's degree or equivalent	34	30.9
A levels, AS levels or equivalent	58	52.7
GCSE(s) or equivalent	1	0.9
None of the above	2	1.8
Total	110	100

Table 1. Academic Qualifications

Note. 'None of the above' could mean more specific international qualifications were not listed in available options and not those students had no qualifications.

81.8% of participants (90 people) indicated that they have used AI tools, while 18.2% (20 people) have not used them. It is important to note that use of AI was not restricted to students' studies and would include responses on personal use as well then. The most common AI tool used by participants was Chat GPT. Participants also mentioned other platforms such as Gemini, QuillBot, Snapchat AI, Vizcom, Auris AI, Copilot AI, Notion AI, Bing Chat, Dream image generator, Midjourney, Grammarly, Writesonic and

Adobe Firefly as other types of AI tools they used. Table 2 shows the frequency of using these tools among participants.

	Frequency	Percent
Daily	6	5.8
More than 3 times a week	18	15.9
1-3 times a week	21	19.1
1-3 times a month	21	19.1
Less than once per month	11	10
Few times a year	13	11.9
Total	90	81.8

Table 2. Frequency of AI Tools Usage Among participants

In addition, figure 1 illustrate the percentage of users who utilize AI tools for different tasks.



Figure 1. Diverse Applications of AI Tools Among Users

Furthermore, participants were asked a series of statements based on Likert scale to discover their opinions on the use of AI (Table 3).

	Strongly	Agree	Neither agree	Disagree	Strongly
	agree	e	or disagree	e	disagree
Generative AI tools could assist writing	34 5%	53 6%	0.1%	0%	2 70%
Generative Ai toois could assist writing	54.570	55.070	9.170	070	2.770
	10 70/	20.10/	22 (0)	0.10/	
Generative AI tools <i>should</i> assist writing	12.7%	39.1%	33.6%	9.1%	5.5%
Generative AI tools <i>could</i> autonomously	10%	58.2%	19.1%	9.1%	3.6%
produce writing.					
Generative AI tools <i>should</i> autonomously	5.5%	18.2%	35.5%	32.7%	8.2%
produce writing					
Generative AI tools could assist writing	24 5%	53 6%	14 5%	6 1%	0.0%
Generative AI tools could assist writing	24.370	55.070	14.370	0.470	0.970
programming code.	4 = 0.07		a = = a (		<b>a</b> <i>c</i> o <i>i</i>
Generative AI tools <i>should</i> assist writing	17.3%	38.2%	35.5%	5.5%	3.6%
programming code.					
Generative AI tools <i>could</i> autonomously	11.8%	54.5%	20.9%	9.1%	3.6%
produce programming code					
Produce Programming could.					

Generative AI tools <i>should</i> autonomously produce programming code.	7.3%	30%	33.6%	20.9%	8.2%
Generative AI tools <i>could</i> improve efficiency	43.0%	43.0%	9.1%	0.9%	2.1%
Generative AI tools <i>could</i> assist the researching process	0.9%	43.6%	11.8%	4.5%	2.7%
Generative AI tools <i>could</i> assist the data searching process	33.6%	50%	13.6%	1.8%	0.9%
Generative AI tools <i>could</i> be used as a replacement for in person teaching	10.9%	14.5%	16.4%	30%	28.2%
Generative AI tools <i>should</i> be used as a replacement for in person teaching	6.4%	5.5%	12.7%	30%	45.5%
Generative AI tools <i>could</i> help with the understanding of difficult concepts	25.5%	47.3%	17.3%	6.4%	3.6%
Generative- AI tools <i>could</i> have a negative effect on students' creativity	20.9%	33.6%	29.1%	15.5%	0.9%
Generative AI tools <i>could</i> have a positive effect	9.1%	40%	36.4%	10.9%	3.6%
Generative AI tools <i>could</i> be used to produce inaccurate information such as fake news.	31.8%	44.5%	19.1%	1.8%	2.7%
Generative AI tools <i>could</i> affect the quality of future academic publications	21.8%	45.5%	23.6%	5.5%	3.6%
Generative AI tools will disrupt existing higher education models.	9.1%	41.8%	31.8%	15.5%	1.8%
Access to Generative AI tools <i>should</i> be limited for students	4.5%	16.4%	31.8%	29.1%	18.2%
Access to Generative AI tools <i>should</i> be limited for academic staff	2.7%	10.9%	31.8%	33.6%	20.9%
Students who use Generative AI tools for their assignments <i>should</i> receive lower grades	7.3%	18.2%	33.6%	24.5%	16.4%
Generative AI tools <i>could</i> assist in assignments marking	5.5%	47.3%	28.2%	11.8%	7.3%
Generated AI information can be trusted?	4.5%	19.1%	50%	22.7%	3.6%

Table 3 shows that most participants think these tools can help with tasks like writing and programming (around 80% agree or strongly agree). However, fewer support the idea of these tools working on their own (around 60% agree or strongly agree). While many believe these tools can make tasks more efficient (around 87% agree or strongly agree), there's worry about using them in place of traditional education (around 75% disagree or strongly disagree with replacing in-person teaching). Some are also unsure about limiting access to these tools for students and academic staff (around 60% are undecided). Overall, people see benefits but are cautious about trusting (50% unsure) and using Generative AI in education and limiting access.

## 3.2 Qualitative Findings

In addition to quantitative findings participants were also asked whether they think Generative AI tools are useful or not. Out of 110 participants, 61.8% said Yes, 5.5% said No and 32.7% of participants elaborated further on their reasons, which are discussed below in more detail.

## 3.2.1 Positive and Negative Elaborations

These written responses were split into *positive* and *negative* remarks. The three main *positive* reasons for the use of AI were to improve efficiency and ease of completing work (15 references), idea generation (11 references) and to improve the quality of their work (4 references). With regards to the efficiency and ease of work completion, one student stated: "AI tools gives you a precise answer without any extra effort". Whilst other students stated: "It does it for you" and "Makes work easier". With regards to idea generation, students provided very similar feedback. One student stated: "It makes ideas easy to come by so as to build on those ideas in limited time". Many of the comments regarding the improvement of work related to spelling and grammar checking and included statements such as: "It allows me to see

my grammar mistakes and how to phrase things properly", "Really helps fix spelling mistakes in my academic writing" and "sometimes elevates the writing technicality". There were a few negative comments surrounding the use of AI with students stating: "I don't believe that using generative AI is acceptable in academia, because all the AI learning is done through other people's work and the use of AI makes it impossible to credit them", that [AI] "lacks creativity when asked for names and ideas" and they do not use it as "I like to understand exactly what I'm writing about". Other references in the student feedback state that AI commonly support their understanding of concepts and helps find references for the work.

## 3.2.2 General Feedback

Students were also given the option to provide any additional comments at the end of the survey. Some comments reiterated the comments given in relation to idea generation previously by stating that: "AI could help you in brainstorming" Comments were also made in respect to limiting AI should for use in just supporting learning by stating: "Generative AI, in my opinion, should only ever be really used as a support and not a replacement, it is well-known that the data it produces is not always accurate and its use should always take heed of this. It is not perfect, it is literally 'learning'', "It should be used as a supporting tool only" and "It's a useful tool – but should not be fully relied upon". One student also commented on the issue of AI hallucination whereby the AI generates incorrect or invalid information and responded by stating: "There should be another option giving a brief understanding of AI hallucination". However, others felt that AI was more important and responded by saying: "All people must and should learn the AI", "I think it's none the less a valuable tool, whether you agree with it or not" and "AI can be used as a second brain, to structure and provide information that otherwise would never have been found".

## 4 CONCLUSIONS

The results of the survey show a surprisingly strong preference and level of support towards AI from students particularly in respect to their existing use of AI and their opinions on the benefits of AI in respect to its capabilities to support their writing, programming, research, and their efficiency. This aligns with the findings from the literature, which also highlights diverse attitudes and uses of AI tools among students, categorizing them into different types using cluster analysis [3]. There was a distinct difference in the results however, between assistive and autonomous use, suggesting a conscious recognition of the distinction between an AI service that is viewed as a natural extension of a search engine and a tool that autonomously produces content. Thankfully students largely don't see AI as a replacement for in-person teaching ('our jobs are safe' and/or 'they like us') but students were surprisingly open to the use of AI to assess their work. However, the fact that 50% of students feel as that AI will disrupt, HE models and 50% were unsure (neither agreeing nor disagreeing) whether generated AI information could be trusted are key findings. This latter finding casts many of the other findings into reasonable doubt, mirroring concerns raised in Chan and Hu study [4] about the impact of AI on personal development and the ethical implications of its use. This point is particularly pertinent given that in the present study, over 80% of participants report having used AI. This uncertainty of the accuracy of the AI information provided could also explain the distinction between the could and should responses from the students in respect to its use for writing and programming. Furthermore, as educators it sheds light perhaps on our role in response to the proliferation of AI tools, to teach students to use them effectively and be able to critically review, consider and translate AI generated content. Giving students the tools and skills to discern between correct and incorrect AI responses and enabling them to become more discerning of AI use and recognise and understand the errors and causes of errors in data and information more generally, not just in relation to AI content.

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# AUTHENTIC VIDEO FEEDBACK FOR PRODUCT DESIGN STUDENTS

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## ABSTRACT

Since the COVID-19 pandemic and due to living in a digital environment, video feedback has become more prominent in higher education. However, it has not been as well adopted on product design courses due to the subjective nature of creative disciplines, and the unique challenges this constitutes in making it an authentic experience for students. This paper takes an influential framework for creating authentic feedback experiences and uses it to design a video feedback exercise for product design students. The framework presents five criteria relating to Realism, Cognitive Challenge, Affective Challenge, Evaluative Judgment, and Enacting feedback. From each of these criteria, the authors derive a set of propositions for video feedback and translate them into design features including: the use of discursive language, proportionate discussion to assessment criteria, the use of sensitive and empathic language, making visual reference to student work onscreen, and explanations of constructive actions. The video feedback exercise was then delivered to a cohort of twenty-eight, final year, undergraduate product design students. Both quantitative and qualitative datasets were collected through Likert scale and freetext questions in a survey completed by all twenty-eight, students and semi-structured interviews with five students. A statistical and thematic analysis developed an understanding of the video feedback exercise as an authentic feedback experience, highlighting some of its strengths and limitations as a teaching tool. The paper concludes with several recommendations to improve and develop the design of the video feedback exercise.

Keywords: Authentic feedback, video feedback

## **1** INTRODUCTION

Video feedback has become more common place in a post-digital environment, with many seeing it as a necessity within higher level education due to the popularisation of hybridised courses [1] [2]. However, there are few examples of this type of feedback delivery on creative courses [3]. An explanation for this may be that creative courses face challenges when it comes to video feedback due to the subjective nature of creative disciplines [3].

Another explanation that the authors of this paper offer, is that it may be due to the difficulties in using video feedback to deliver an authentic experience. Authentic feedback is a growing field of research within pedagogy, that posits the importance of embedding feedback practices that replicate those used in the broader professions of the subject [4]. The belief behind this pursuit is that delivering authentic feedback 'creates a measurable connection between the academic context of the subject and the practical application of the subject in a professional context, improving lifelong learning skills of students' [5]. Through assimilating concepts within literature addressing design pedagogies and authentic feedback, the authors of this paper have developed a video feedback exercise to try and create a method that embeds authenticity in the delivery of this type of feedback.

## 2 AUTHENTIC FEEDBACK AND DESIGN PEDAGOGIES

## 2.1 A Framework for Authentic Feedback

Dawson et al. [4] developed an influential framework for authentic feedback that can be used to embed authenticity into processes and practices involving feedback. The framework has five criteria:

• Realism: that the feedback is authentic to, and represents, the reality of the life graduates of the discipline will face and prepares the students accordingly.

- Cognitive Challenge: that the feedback supports engagement with high order thinking, problemsolving, and decision-making.
- Affective Challenge: that the feedback promotes engagement with challenging and potentially critical responses to work, recognising the occurrence of such practices in the workplace.
- Evaluative Judgement: that the feedback supports the development of capabilities to make decisions about the quality of your own, or other people's work.
- Enactment of feedback: that the feedback is engaged with constructively to support development of either the object of feedback, future approaches to work, or both.

The following sections will relate each of these criteria to design pedagogies and describe how the authors have used this assimilation to guide the design of video feedback creation and delivery.

## 2.2 Relating this Framework to Design Pedagogies

When considering Dawson's [4] first criteria for authenticity, 'Realism', there is much literature in the field of Design Pedagogy that examines the practice of design and posits understandings of its nature. Notably, Orr and Shreeve [6] suggest that design is a community of practice where standards of quality are arrived at through discussion. This posts various challenges when trying to embed design features into a video feedback exercise, as the assessor may be an individual reading from a script, as opposed to entering a discussion with a community. However, there are characteristics belonging to more discursive language that can be employed to emulate the type of conversation that occurs in a discussion. For example, Henderson and Philips [7], in their recommendations for creating video feedback within higher education, suggest the use of timely and plain language, due to its informal and discursive nature, and subsequent ability to project a more supportive and caring tone.

With respect to embedding design features in video feedback that look to support Dawson's [4] second criteria for authenticity, 'Cognitive Challenge', it is logical to consider methods that relate critique to specific assessment criteria, and that emphasise the need to use feedback as a means to consider alternative approaches to future work that may better meet the assessment criteria. This sentiment is also echoed by Henderson and Philips [7] in their recommendation that video feedback should be proportionate to criteria and phrased as an ongoing dialogue rather than an end point.

Concerning Dawson's [4] third and fourth criteria for authenticity, 'Affective Challenge' and 'Evaluative Judgement', it is reasonable to consider empathic approaches to feedback that invite students to acknowledge and take ownership of criticisms about their work, providing them with an accessible means to see why they have achieved their awarded grade and rationalise why others may have achieved the grades they have. Brown and Fridman [3] reference many pedagogies that align with this reasoning, in their assimilated list of recommendations for the creation of video feedback. They include Jones et al.'s [8] assertion that an assessor should be in the right frame of mind before recording feedback, and Cruikshank's [9] suggestion that styes familiar to students should be encompassed. They also highlight Hyde's [10], Williams and Askland's [11], and Orlando's [12] recommendations of providing visual examples where possible when creating content for video feedback.

Finally, when considering the design of video feedback to meet Dawson's [4] final criteria for authenticity, 'Enactment of Feedback', parallels can be drawn to his second criterion 'Cognitive Feedback'. It is the development of an understanding of how better to meet assessment criteria that will provide students with the means to act on feedback. Therefore, to build on the previous suggestion that feedback should be proportionate to criteria and phrased as an ongoing dialogue, it is also logical to suggest that this phrasing should also be constructive and explicitly reference action that can be taken the next time students are creating work for assessment.

## **3 DESIGNING AND DELIVERING THE VIDEO FEEDBACK**

The following table sets out the basic design for the video feedback exercise as derived from the previous section's literature review. The 'Theme' column references the criteria in Dawson's [4] feedback framework, the 'Proposition' column references the consequent intention for the students' experience, and the 'Design' column references the subsequent feature embedded in the video feedback exercise.

Theme	Proposition	Design
Realism	Students should associate the exercise with the experiences of practicing designers.	Set a discursive tone through using accessible language common in professional practice.
Cognitive Challenge	The exercise should encourage problem solving and decision making.	The length of discussion should be proportionate to the weightings of assessment criteria. Use phrases to indicate that feedback is an ongoing dialogue.
Affective Challenge	The exercise should support engagement with challenging and critical responses to work.	Sensitive and empathic language should be used when discussing critical responses to the student's work.
Evaluative Judgment	The exercise should help students to judge the quality of their own work and others.	An assessment of quality should be made against each criterion and referenced visually through indicating the relevant aspect(s) of the student's work onscreen.
Enactment of Feedback	The exercise should develop students' future approaches to their work.	An explanation of constructive action should follow each point of criticism.

Table 1. Video Feedback Design

To achieve each of these design features, onscreen recordings were created using Panopto [13], capturing the student's assessed work with a semi-scripted voice over delivered by the assessor. The cursor was used to reference the aspect(s) of the student's work being discussed onscreen. For consistency in approach, the same assessor constructed all the video feedback in this study. The assessed work submitted by the students was for the UK's Royal Society of the Arts competition briefs [14]. The video feedback exercise was delivered to a cohort of twenty-eight, final year, undergraduate product design students. Following the exercise, the students were asked to complete a survey to gather data on their perception of it. A survey is a well-established method for collecting data on social characteristics such as those present during feedback exercises; delivered with the intention of impacting future behaviour [15]. The survey included five closed questions to address each of the criteria in Dawson's [4] authentic feedback framework. They were phrased as 'to what extent' style questions, accompanied with a Likert scale response option of one to five, with one meaning 'not at all' and five meaning 'completely.' For example, question number one read: 'To what extent do you think video feedback is authentic to the design discipline? By authentic, we mean representative of experiences you may have as a practicing designer.' As well as this quantitative data, qualitative data was also collected through the survey with a final, free-text question, asking the students to describe their experience of the video feedback exercise, inviting both positive and negative points of reflection. The benefit of using a survey such as this meant that student perception could be captured in a consistent way across the entire cohort, allowing analysis of subjective opinion against the criteria used to design the video feedback exercise. However, limitations of this approach include 'dishonest or unanswered questions, issues with understanding and interpretation, and respondent bias' [16]. Therefore, to complement the survey, semistructured interviews were conducted with five students, using the topics within the criteria of Dawson's [4] authentic feedback framework as prompts for discussion. A thematic analysis was carried out on the free-text question of the survey and transcriptions of the interviews. Deductive analysis such as this is appropriate where conceptual frameworks are adopted, and a series of propositions are used to test effectiveness [17] [18]. The combination of these data sets and their analysis will provide insight into the student perception of the exercise's authenticity, and how and why they hold these perceptions. This will develop an understanding of the exercise's effectiveness in providing an authentic feedback experience and suggest steps that may be taken to improve its delivery.

## 4 FINDINGS AND DISCUSSION

## 4.1 Realism

As stated previously, in testing the first proposition of the video feedback design, students were asked to what extent they believed the exercise was authentic to the design discipline. The mean score (m) across the cohort was 3.86, with a standard deviation (SD) of 1.19. This indicates that a small majority of students agreed that video feedback exercise is authentic to the design discipline. However, the high degree of variability across the cohort demonstrates that there is a considerable number of students who do not believe video feedback is authentic to the design discipline.

When looking to the qualitative dataset, an emergent theme in response to this proposition was that for it to feel more authentic, the feedback should include more comparison to other examples of work submitted. All five interview participants discussed how they believed that the culture of a design studio included discussion around the comparison of multiple concepts, and that "rarely are ideas talked about in isolation of others."

#### 4.2 Cognitive Challenge

In testing the second proposition, students were asked to what extent they believed the exercise encouraged problem solving and decision making. The results of the statistical analysis were m=4.29 and SD=0.52. This indicates that most students agreed that the video feedback exercise encouraged them to solve problems and make decisions.

When looking at the qualitative dataset, emergent themes in responses to this proposition included the usefulness in having the ability to rewatch the video feedback, and how this can act as a prompt to thinking through problems and making decisions when creating future work for submission. One student described "I always have trouble with the communication bit, and my video talked through how I could take better photographs that explain how someone would use my product. I can't remember what it said exactly, but I am going to watch it again before I decide what to do next time." Similar statements were made across the interviews, and in six of the responses to the free-text question in the survey.

#### 4.3 Affective Challenge

In testing the third proposition, students were asked to what extent they believed the exercise supported engagement with challenging and critical responses to work. The results of the statistical analysis were m=4.50 and SD=0.50. This indicates that most students agreed that the video feedback exercise supported their engagement with challenging and critical responses to their work.

When looking at the qualitative dataset, there are several emergent themes in discussion that contradict this finding. For example, one student proclaimed that "If [I had made] a big mistake, or overlooked something, I could say why face-to-face. With a video, you don't get a chance to explain yourself." Similar remarks were made in the other interviews. Although this is something we offered alongside the video feedback, this response is indicative of a need to emphasise that this is not the only opportunity for feedback, and that discussion around the critique can be followed up face-to-face should the student feel it necessary. Although this theme was apparent in the semi-structured interviews, it did not feature in the free-text responses to the survey question.

#### 4.4 Evaluative Judgement

In testing the fourth proposition, students were asked to what extent they believed the exercise helped them to judge the quality of their own work and others. The results of the statistical analysis were m=4.61 and SD=0.49. This indicates that most students agreed that the video feedback exercise helped them to judge the quality of their own work and others.

When looking at the qualitative data set, emergent themes in discussion supported this finding. Similarly to the proposition for the theme 'Cognitive Challenge,' students re-emphasised the usefulness in having the ability to rewatch the video feedback. One student pointed out "Sometimes when you chat with a teacher, you forget what they said." Similar remarks were made in the other interviews, and as stated previously, in six of the responses to the free-text question in the survey.

#### 4.5 Enactment of Feedback

Finally, in testing the fifth proposition, students were asked to what extent they believed the exercise helped them to develop future approaches to work. The results of the statistical analysis were m=4.75

and SD=0.43. This indicates that most of the students agreed that the video feedback exercise helped them to develop future approaches to work.

When looking at the qualitative dataset, emergent themes were similarly supportive of this proposition. Many students across both the interviews and free-text question included in the survey referenced the specific design feature derived from the proposition. For example, one student wrote "I liked that every time you pointed out something that I didn't do well in, you told me what I could do next time." Similar reference to the constructive actions suggested in the video feedback exercises were made by all interviewees and seven other responses to the free-text question in the survey.

## 5 CONCLUSIONS

This study provides a meaningful contribution to understanding video feedback, more specifically, the perception that the cohort of product design students had of it with respect to its ability of delivering an authentic feedback experience. When considering the quantitative dataset across all propositions that derive an authentic feedback exercise, we can see that although not immediately identifiable as authentic to the discipline (Realism), it was unanimously perceived as authentic for Cognitive and Affective Challenge, Evaluative Feedback and Enactment of Feedback.

When considering the qualitative dataset across all propositions that derive an authentic feedback experience, further support was discovered in its perception as authentic to Cognitive Challenge, Evaluative Feedback and Enactment of Feedback.

However, despite this positive perception of the video feedback exercise, there are several considerations that can be made in bolstering its perception as authentic to Realism and Affective Challenge. Several observations were made that suggested concepts being discussed in isolation was not reflective of typical disciplinary practices. Several observations were also made that referenced the benefits of face-to-face feedback to provide an opportunity to respond to critique. Taking these findings into consideration, the following recommendations are designed to develop the video feedback exercise in the hopes of strengthening its perception as authentic to Realism and Affective Challenge:

- Include examples of previous cohorts work in the video, to draw comparisons between the work the student has submitted.
- Record group feedback with multiple assessors, that compare various pieces of work submitted by the students.
- Include reference to other forms of feedback that will be delivered, highlighting the opportunity for further face-to-face discussion around the video feedback.

Further iterations of this research project will include these modifications to the video feedback design and seek to include greater sample sizes of level six undergraduate product design students, from a wider range of cohorts belonging to a wider range of national and international higher education institutions.

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# TRANSFORMATIVE COLLABORATIONS FOR SUSTAINABLE MATERIAL SELECTION PRACTICES

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#### ABSTRACT

In an era characterized by the pressing need for environmental sustainability, educational initiatives that empower students with the knowledge and skills to engage in sustainable practices are crucial. This paper presents a case study of a Collaborative Online International Learning (COIL) project that explores the transformative potential of intercultural collaborations in the context of sustainable material selection practices. The project, involving students from University of Monterrey (Mexico) and Oakland Community College (USA), challenged participants to research and specify sustainable materials for residential interiors while incorporating local artisanal, handcrafted elements. This collaborative approach transcends geographical boundaries, enabling students to delve into the complexities of sustainability, examine materials through a global lens, and consider cultural and environmental impacts. The project aligns with the United Nations Sustainable Development Goals (SDGs), specifically SDGs 9, 11, 12, 13, and 17, by incorporating international perspectives. The paper explores how the project's objectives, methodologies, and outcomes, nurtured the development of intercultural competence and collaborative partnerships while teaching responsible consumption, mitigation of climate change, and preservation of local traditions and cultural heritage. The findings demonstrate that such collaborative initiatives hold the potential to catalyse sustainable transformations in material selection practices, preparing the next generation of designers to contribute to a more environmentally responsible and culturally inclusive future. This case study serves as a valuable model for educators and institutions seeking to integrate intercultural collaboration and sustainable design into their curricula, offering a blueprint for addressing the pressing global challenges of our time.

*Keywords:* Collaborative Online International Learning, sustainable material selection, intercultural collaborations, transformative learning, learning experience

## **1** INTRODUCTION

In an era characterized by the pressing need for environmental sustainability, educational initiatives that empower students with the knowledge and skills to engage in sustainable practices are crucial. The reorientation of education towards sustainable development gave momentum in the early 1990s with UNESCO's Agenda 21 [1]. Among its objectives were to achieve environmental awareness, responsibility and commitment towards sustainable development at all educational levels. Recognizing the role of education as a means for creating a more sustainable future, the pivotal initiative United Nations Decade of Education for Sustainable Development (DESD) (2005-2014) followed by the Global Action Programme (GAP) (2015-2019) aimed to integrate the principles, values and practices of sustainable development into all aspects of education and learning. With its focus on nurturing a critical thinking and responsible citizenship, Education for Sustainable Development (ESD) is more than proposing add-ons to existing curricula but requires a fundamental change in mind-sets and behaviours. "Sustainable development can only be progressed – or indeed achieved – through a critical understanding of its complementary parts – such as how environmental, socio-political and economic factors influence our lives, the impact our choices and actions have on sustainable development – and a commitment to make a positive difference in our world." The current global framework for EDS 2030 [2] emphasizes the transformative power of education and its contribution to the achievement of the 17 Sustainable Development Goals (SDGs). It advocates for a holistic approach to learning to ensure that individuals understand sustainability challenges, become aware of their relevance to the surrounding realities and take actions to shape a different future [2].

## 2 THE CULTURAL DIMENSION OF SUSTAINABILITY

Though grounded in environmental concerns, sustainability is interpreted holistically to encompass economic and social dimensions or 'pillars' [3, 4] alongside emerging aspects such as institutional [5], and cultural [6]. Culture, in particular, is increasingly acknowledged as a distinct pillar of sustainable development [6, 7, 8]. It is considered as both "a driver and an enabler of sustainable development" [9]. Culture-led development influences people's lifestyle, behaviour, consumption patterns and interaction with the natural environment. It leads to greater social inclusiveness, resilience, innovation, creativity and entrepreneurship through the use of local resources, skills and knowledge. Moreover, culturesensitive development approaches, which consider the needs of people and the cultural context, have a transformative power and are more likely to achieve sustainable, inclusive and equitable outcomes [10]. Hawkes defines culture as encompassing values and aspirations (content), the processes and mediums through which they are developed, received and transmitted (practice), and their tangible and intangible manifestations (results). He argues that sustainability "can only be achieved when it becomes an enthusiastically embraced part of our culture" [8]. Soini and Birkeland analyse the scientific discourse on cultural sustainability and organize it around seven story lines (heritage, vitality, economic viability, diversity, locality, eco-cultural resilience, and eco-cultural civilization) [6]. This framework highlights the diverse roles that culture plays in achieving sustainability, the complexity of the problems cultural sustainability addresses and its transdisciplinary character.

#### **3 SUSTAINABILITY IN DESIGN**

In the field of design, the discourse on sustainability started in the mid-twentieth century with the pioneering work of visionaries like Rachel Carson, Buckminster Fuller, Victor Papanek, and E. F. Schumacher [11]. In the 1980s design for sustainability (DfS) emerged as a design approach integrating the principles of sustainability into the entire design process from conceptualization to end-of-life scenarios. Throughout the years its field has evolved from focusing on the improvement of existing products (product innovation level) and services (product-service system innovation level) to encompassing broader considerations such as the various scales of human settlements (spatio-social innovation level) and transitions to new socio-technical systems (socio-technical system innovation level) [12]. With its core intention to generate sustainable outputs, DfS serves as a catalyst for shaping new directions, lifestyles and approaches to satisfying people's needs [13].

Vezzoli and Manzini summarize designers' efforts to interpret sustainability into four categories - selection of resources with a low environmental impact, design of product life cycle, system-design for eco-efficiency and design for social equity and cohesion [14]. While the level of consolidation of the first two levels is high and has already permeated design practices, the third level remains inferior and sporadic, and the fourth level has not yet received sufficient research attention, resulting in inadequate implementation in both design practice and education. The implications for design extend to the principles and rules of democracy, human rights and freedom, achievement of peace and security, reduction of poverty and injustice, improved access to information, training and employment, respect for cultural diversity, regional identity and natural biodiversity.

Adding the cultural perspective to sustainable design entails a commitment to fostering wellbeing, cultural diversity and social inclusivity. It also involves strengthening cultural identity, community resilience, and innovation while preserving cultural capital for future generations.

#### **4 "SUSTAINABLE MATERIAL SELECTION" PROJECT**

Given the significant influence designers play in shaping every aspect of the built environment, from the materials utilized to the processes of manufacturing and consumption patterns, the importance of educating design students on sustainability cannot be overstated.

Material selection in particular plays a critical role in the pursuit of sustainability. It is considered as one of the most important principles in the DfS approach [15]. The choice of materials directly affects the environmental, economic, social, and cultural dimensions of a product's lifecycle. Selection of sustainable materials extends beyond mere consideration of factors such as resource availability, energy and carbon footprint of the production process, and end-of-life disposal. It requires strategic decision-making that takes into account the context of use, aiming to cultivate environmental awareness among users and potentially create new scenarios for more sustainable lifestyles and consumption patterns within the broader socio-technical system.

The project 'Sustainable material selection' was elaborated as a Collaborative Online International Learning project (COIL) with the participation of interior design students from University of Monterrey in Mexico and Oakland Community College in the United States. The virtual exchange format involved students in experiential cross-cultural learning for a duration of five weeks. Launched in 2022, the project was subsequently implemented in 2023 and 2024. Over the course of three consecutive years, a total of 125 students have been engaged in the initiative.

## 4.1 **Project objectives**

The objectives of the project were divided into two categories – subject-specific and intercultural. The subject specific objectives were further divided into five categories – define, identify, examine, justify and develop. They focused on acquiring integral competencies in identifying and evaluating sustainable materials, applying sustainable design principles effectively, recognizing the cultural significance of artisanal products, and making informed decisions that contribute to the quality of life, health, and wellbeing of users in interior design practices. Additionally, the intercultural objectives emphasized creating connections and understanding cultural diversity within design practices. It involves applying culturally respectful decisions, developing intercultural sensitivity and work ethics, fostering positive relationships in diverse groups, enhancing global competence, and broadening perspectives through exposure to international viewpoints and educational systems (Table 1).

Subject specific	objectives			
Define	- the benefits of incorporating sustainable materials and artisanal products in interior design			
	- the use of traditional handcrafts for establishing sustainable cultural connections and preservation of			
	cultural heritage			
Identify	- what constitutes a sustainable material choice			
	- green, sustainable and Fair Trade (GSFT) products for interior design			
Examine	- sustainable design principles and strategies for using sustainable materials in interior design practice			
Justify	- how the selection of sustainable materials and the integration of artisanal products in interior design			
	can improve the quality of life, health and well-being of the users			
Develop	- comprehensive understanding of environmentally responsible materials mindset for eco-conscious			
	design			
Intercultural objectives				
- Create connections and discover shared similarities and differences within different cultural and geographical				
experiences.				
- Apply culturally respectful design decisions.				
- Develop intercultural sensitivity, respect, and work ethics.				
- Foster positive working relationships in a culturally diverse group.				
- Enhance students' global competence, including their ability to adapt to a new cultural context and effectively				
communicate across cultures.				
- Broaden students' perspectives by exposing them to international viewpoints, alternative solutions to problems, and				
different educational systems.				

Table 1. Project objectives

These objectives aimed to provide students with a global perspective on the significance of sustainable practices, to enhance their critical thinking and problem-solving skills and to foster a sense of global responsibility. The COIL project exposed students to diverse perspectives and cultural backgrounds, enriching their understanding of sustainability and material selection in interior design. In this collaboration, students not only developed professional competencies, values, and attitudes preparing them to excel in a global job market, but also had the opportunity to establish friendships that can potentially lead to the creation of cross-border professional networks.

## 4.2 Project implementation

The project comprised three activities – an intercultural introductory activity, project development, and post-COIL critique and reflection. The intercultural activity titled 'Cultural sustainability showcase' served as both an icebreaker and a platform for introducing the topic of sustainability by engaging students in cross-cultural dialogue. Working in intercultural teams, students were tasked with exploring and sharing sustainable design practices from their respective countries. They could focus on historical examples, contemporary projects, or emerging trends in order to discover relevant examples of eco-friendly materials application, energy efficiency, waste reduction etc. The activity concluded with a

discussion and individual reflection on the importance of intercultural collaboration in sustainable design education.

The project 'Sustainable material selection' required students to research finishing materials and two artisanal products (furniture/textile/fixture/decorative object, etc.) representing each country to be installed in the kitchen and bathroom of a client located in the US. The analysis began with an exploration of the raw materials used, their extraction, processing, and energy consumption. Subsequently, students investigated the environmental impact throughout the complete material/product life cycle, including transportation, production, installation, maintenance, removal, disposal and opportunities for recycling. To justify why the material/product can be considered sustainable, they evaluated their environmental value and overall eco-efficiency. Additionally, to delve into the social and cultural impact, students conducted a survey to assess how the material embodies sustainable design qualities. Another aspect to explore was the perceptions of individuals from both countries on how the materials and artisan products represent their own culture and that of the opposing country.

The collaboration terminated with a reflection, where the participants contemplated on their journey throughout the COIL experience. Students shared their opinions and described their experiences, providing insights into the project's impact on their perspectives and sustainability practices, challenges faced, criteria prioritized in material selection, skills and knowledge gained and implications of the project's emphasis on sustainable materials within the broader field or industry.

#### **5 PROJECT IMPACT AND SIGNIFICANCE**

Among the benefits of the project is that it enriches the educational experience by providing students with unique learning opportunities that go beyond traditional classrooms and prepares them in a very effective way for a globalized world. 'Sustainable Material Selection' is a formative and educational project. The students who participated developed fundamental skills in selecting sustainable materials, understanding eco-friendly practices, and the principles of the circular economy.

In addition to this profession-specific knowledge, they had the opportunity to learn about other cultures, establish cross-border partnerships and exchange knowledge to achieve sustainability goals in a cross-cultural context. The relationships established between students from the two neighbouring countries facilitated a dynamic exchange of ideas, cultures, and perspectives, providing a valuable learning experience. They became familiar with other cultures, thereby promoting their identity as global citizens who are open-minded and respectful towards the different. Furthermore, the project aligns with various sustainability goals by emphasizing responsible material selection, eco-friendly design, cross-cultural collaboration, and the promotion of sustainable practices in artisanal production, all of which are critical for addressing global challenges and building a more sustainable future (Table 2).

SDG	Description
Responsible Consumption and Production	The project focuses on identifying sustainable materials that incorporate recycled, reclaimed, or locally available resources. This approach encourages
(SDG 12)	responsible consumption by choosing materials with a reduced environmental footprint.
Climate Action (SDG 13)	By researching and selecting materials with lower carbon footprints and sustainable practices, the project supports efforts to mitigate climate change.
Sustainable Cities and Communities	Sustainable materials, when incorporated into building and design projects,
(SDG 11)	contribute to the development of more sustainable and eco-friendly living
	spaces, aligning with the goal of creating sustainable cities and communities.
Partnerships for the Goals	The project encourages international collaboration by incorporating an artisanal
(SDG 17)	element. It promotes cross-border partnerships and knowledge sharing to
	achieve sustainability objectives.
Circular Economy Principles	The emphasis on materials that are recycled or reclaimed supports the transition
	to a circular economy, where resources are used efficiently, and waste is
	minimized.

The conclusion that the 'Sustainable Materials Selection' project was beneficial for the students is based on a comprehensive evaluation of the project-related learning outcomes and feedback received from the students. To determine the project effectiveness the following evaluation indicators were implemented – quality of the research, technical proficiency, level of detail, team collaboration, presentation and communication. Firstly, the evaluation of the design outcomes presented by the students revealed the successful application of the knowledge acquired through the project development. Students' final submissions reflected a strong focus on sustainability, with the innovative incorporation of sustainable materials into interior spaces. This indicated that the students had internalized sustainability concepts and could creatively apply them in real design contexts.

These observations were confirmed with the positive results obtained in the post-COIL survey. These results underscore the effectiveness of collaborative international learning initiatives in enriching students' education and preparing them to face challenges in an increasingly interconnected world. Students from both countries expressed that they had gained valuable knowledge and skills in the field of sustainability and had experienced significant growth in their ability to collaborate with peers from different cultures. Furthermore, they highlighted that the project had inspired them to consider sustainability and cultural heritage in their future designs and professional careers.

Students shared the following opinions when asked to describe the experience of the COIL project:

"Honestly, I found it to be a very interesting and interactive project from which I learned a lot. I was excited to meet classmates from another country who are in a completely different environment from ours. They told us about themselves, and we also shared our interests, hobbies, etc. It was challenging because you don't really know the people in your team, but I also learned that communication is key to solving team projects." In my opinion, the COIL project was challenging but rewarding. It opened my eyes to new perspectives on sustainable materials and design practices. While it demanded hard work, collaborating with my international peers was an enriching experience."

The COIL project demonstrated a clear impact on learning outcomes, as participants improved their understanding of subject-related topics, such as the selection of sustainable materials.

"Before the project, I had a basic understanding of sustainability. However, focusing on sustainable material selection made me realize the significant environmental impact of material choices and the importance of responsible consumption in everyday life".

"We as designers have a really important responsibility when selecting sustainable materials, which I wasn't aware that there are a lot of good options for it, so from now on I will start implementing this type of materials and techniques in future designs and will share it with my classmates".

"Before COIL I didn't know a lot of sustainable materials and artifacts and now, I know a lot because of the efforts of my team and from the projects of the other teams".

Additionally, an assessment of the students' intercultural skills showed significant development throughout the project. Students reported a better understanding of cultural differences and an increased ability to work effectively in international teams. This suggests that the project contributed to their intercultural growth, which is crucial in a globalized world.

"The most significant experience for me was learning to work with other people, with a culture totally different from ours, and being able to get the work done".

The project also influenced students' self-perception and cultural identity. During the process, students had the opportunity to reflect on their own cultural identity and how it relates to their personal and professional values in the context of sustainability and design. For many students, this experience led to a greater appreciation of their own cultural heritage and the importance of preserving and promoting sustainable practices rooted in their culture. They understood how traditional materials and artisanal practices from their home countries could play a crucial role in promoting sustainability in interior design. This generated a stronger sense of cultural pride and a deeper connection to their roots.

"Reading about the cultural history of the artisanal object made me feel very inspired, since it is something we as Mexicans see as something 'ordinary' while it is something unknown for all others that are not from Mexico. Mexican culture and history are one of my favourite things about being a Mexican, I feel very honoured and proud to be a part of this enriched cultural country".

"I got inspired looking for the artisanal element because I realized how great it is to find beautiful and at the same time sustainable art for a design. Also, made me fall in love even more with the art and culture of my country".

Generally, the COIL project on sustainable material selection can be considered as a transformative learning experience. According to the transformative learning theory, transformative learning occurs when individual's frames of reference (the assumptions through which the surrounding world is understood) are effectively changed [16]. It became evident from student' self-reflection that their mind-set about sustainability and culture underwent a significant transformation. Firstly, students' perspective on sustainable material selection practices were shifted. Moreover, they demonstrated an increased awareness of their responsibility as designers to preserve cultural heritage and safeguard the environment. Through active participation in intercultural discourse on sustainability, they realized their

ability to make a difference in both their lives and their community. Furthermore, they showed a deeper understanding of the complex character of sustainability practices and its cultural implications.

Finally, students became critically reflective on the assumptions about cultural diversity fostering mutual understanding and respect for others. As they went through the challenges of the collaboration, they actively engaged in discourse, critical reasoning and consensus building to collectively make decisions.

## 6 CONCLUSIONS

The project 'Sustainable materials selection' fostered a sense of responsibility toward the environment and cultural heritage. Students benefited significantly from the intercultural and collaborative experience, developing effective communication skills, adaptation to cultural diversity and problem solving related to the selection of sustainable materials in a global context. They developed a commitment to making sustainable and culturally respectful design choices in their future careers. Through intensive research and practical application, they gained a deep understanding of sustainable material selection. They learned to distinguish and analyse eco-friendly materials, understanding their benefits, environmental impacts, and sources. The incorporation of artisanal, handcrafted elements exposed students to diverse cultural practices in sustainable material selection. Thus, they were able to recognize their role in contributing to global sustainability efforts. Interactions with international peers improved students' cultural sensitivity and intercultural communication skills. They learned to navigate differences in language, work style, and approaches to design.

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## EXPLORING THE IMPACT OF GENERATIVE AI ON CONCEPT GENERATION, IDEATION, AND DESIGN METHODOLOGY: IN PRODUCT DESIGN EDUCATION

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#### ABSTRACT

This paper presents an investigation into the utilisation of generative artificial intelligence (AI) by product design students in the concept generation, ideation, and design methodology of their final year major project. With AI's growing presence in the design field, its impact on the education of future designers requires investigation. This research aims to highlight the advantages and disadvantages associated with incorporating certain generative AI tools into the curricula of product design students. The study involves an in-depth analysis of how generative AI could be integrated into the design education process. It explores the extent to which AI-driven tools are employed by students to generate, refine, and iterate design concepts, and how it impacts their design methodology processes. By appraising and analysing the outcomes from AI creative design workshops and conducting surveys with final year product design students, this research sets out to determine the practical applications of generative AI in our future designers. By investigating the advantages and disadvantages, it equips educators and students with valuable knowledge to harness the full potential of AI in their design journeys. This paper contributes to the ongoing conversation on AI's role in design education, paving the way for informed pedagogical decisions and the education of future designers who can leverage AI as a powerful creative tool.

Keywords: Generative AI, design process, design methods, ideation, concept generation

## **1** INTRODUCTION

More than thirty UK universities deliver courses in the field of product design as of 2024 [1]. Over the years, these institutions have adopted new technologies to keep up with contemporary industry techniques and expectations. This includes solid and surface modelling CAD (Computer Aided Design) in the eighties, CAD simulation in the nineties, and more recently, 3D printing technologies. The advent of AI creative tools poses an inevitable area of special interest, worthy of consideration for inclusion within undergraduate Product Design courses. In 2002, an E&PDE paper [2] was presented, that discussed research being undertaken at the time into the potential role(s) of artificial intelligence (AI) as a creative capability within CAD software. The paper described how it could be possible for AI to produce highly detailed colour and form concepts more quickly than was humanly possible. Twenty years later, this prospect became a reality. Creative applications have swiftly become available, with software such as ChatGPT (Open AI Inc, San Francisco) and Midjourney (Midjourney Inc, San Francisco) demonstrating significant capabilities in the arts [3,4]. These software tools can create high quality, completed works of a level of detail that is both awe inspiring and startling when compared to that of human capabilities in a similar timeframe. The potential design applications are immediately apparent. A lot of a designer's time is used exploring possibilities, comparing alternatives, and breaking new ground. The iterative nature of designing new products can be labour intensive and resultantly carries significant financial risk [5]. As predicted in 2002, by exploiting the power of AI, we can, in principle at least, reduce this time to our advantage and ultimately deliver outputs faster and at a lower cost.

This research explores the utilisation of generative AI by final year product design students during their major project. While AI's influence in design has been increasingly recognised, its specific application within the educational context of being part of the concept generation phase of final year projects represents an emerging frontier. As the design field evolves in response to technological advancements,

this research offers an initial investigation into the suitability, strengths, and weakness of contemporary AI technologies for the purposes or concept generation within the product design process. The results of this research will allow educators to gain valuable insights into how to effectively incorporate AI into their teaching methods, enhancing the educational experience and preparing students for a technologically driven design industry.

## 2 RESEARCH METHOD

The rate of development of AI software has meant that the capabilities of the tools on offer have advanced significantly in a short period of time. Hence, a future market leader for Product Design applications seemed uncertain at the time of this research. Of those widely available in 2023, Midjourney was considered one of the most capable and frequently used for the purposes of creative visualisation, particularly when generating images solely from verbal descriptors. It also offered some enhanced capabilities, such as the use of control parameters (such as 'chaos' and 'weird', etc.) and syntax rules (such as 'multi-prompts') to allow the breadth of results to be fine-tuned. It was therefore chosen as a means of appraising the general suitability of generative AI tools for designers at the present time.

## 2.1 Methodology

To determine whether Midjourney might be a useful tool for design students at the early stages of the product design process, a study was devised that could be inserted straight into students' projects with minimal disruption to existing workflow. To this end, a group of Final Year undergraduate product design students was invited to generate preliminary design possibilities based on their final year project proposals. This way, they would be able to compare the results from their interaction with the software, with any early ideas that they might have conceived of their own. The study was split into two phases. Phase one was scheduled shortly after the students had submitted their final year project proposals. This phase was intended to determine the value of the software in providing the students with initial inspiration before they had spent time developing concepts of their own. Phase two was scheduled a few weeks later, giving the students time to reflect on the results of phase one and to develop their own ideas further, either in isolation or in combination with the results of phase one. Phase two was intended to explore the benefits of using the students' own sketches as prompts for further development within the AI software.

In the first phase it was anticipated that the students would use the software to ideate a broad range of initial ideas using verbal prompts only, when they had relatively little understanding of the design problem they were seeking to solve. The students were encouraged to identify relevant semantic phrases to describe their design aims in verbal form. The capabilities of Midjourney at the time of this study, enabled users to input their intentions using verbal phrases and images to prompt the AI software. Of particular interest, was the students' ability to control and refine ideas verbally to meet their design objectives, and their subsequent perceptions of the output results. The design students were given a brief overview of how to use verbal prompts and associated syntax. They were then given up to one hour to create as many ideas as they could, based on their individual design project briefs. During that time, they were provided with 1:1 tutor support on how to exploit features offered by the software to enhance its capabilities and to produce a wider or narrower field of results. At the end of this session, the students were asked to provide feedback on their experience via a 5-point Likert scale questionnaire.

In the second phase, the students were invited to use their own initial design sketches as image prompts. They were shown how to upload sketches, how to create image prompts and how to combine them with other images as well as verbal prompts to provide the software with contextual information to help refine the results (Figure 1). The ability of the software to produce meaningful results from what the students provided was of particular interest. Again, the students were given one hour to experiment with the software, during which they were provided with 1:1 technical support should they need it. At the end of the hour, they were asked to complete a follow-up questionnaire, to capture their opinions and experiences.

## **3 RESULTS AND DISCUSSION**

## 3.1 Application/Usability

Phase 1 of the study commenced shortly after the approval of the students' final year design project proposals. It was anticipated that these students would be open minded to a broad range of design possibilities. However, it soon became evident that they had yet to develop a deep contextual

understanding of their design problems, leading to some being frustrated at being unable to express their objectives effectively. Others found that Midjourney's tendency to prioritise broader scenes over the specific product design posed a challenge. It was apparent this was not due to the text prompts alone, but also the contextual information being provided and how Midjourney interprets that information and produces results. Midjourney creates groups of four results for every prompt. Using the same prompt never produces the same results twice, but rather, somewhat similar results conforming to the parameters set. The level of similarity and conformity could also be adjusted further, using the relevant control parameter (i.e. 'chaos'). However, few students entered the same prompts repeatedly, preferring instead to rephrase their prompts to try to refine the subsequent outputs.

Phase 2 took place three weeks later, giving the students time to work on their projects during the interim. This time the students were invited to bring sketches of their own that could be used as image prompts for Midjourney. The sketches provided by the students varied greatly in terms of detail, colour, and quality of line. However, the AI software seemed capable of interpreting their intentions surprisingly accurately, especially when verbal prompts were provided for additional context. Using more than one image prompt in combination with detailed verbal descriptors yielded some of the most promising results, due to the designer students' ability to home in on a particular intention. However, the degree of emphasis placed on a particular product's design was not always predictable or easily controlled, as illustrated in Figure 1 where the subject (lamp) is shown as part of the scene, rather than the focus of the scene.



Figure 1. Example result of combining image and verbal prompts in Midjourney (courtesy of student)

#### 3.2 Verbal Prompts

26 students took part in phase 1 during which verbal prompts were used by to communicate design intentions using Midjourney. These prompts consisted of written descriptions or commands, which served as an input for Midjourney to generate visual outputs. The findings from this research focus on 3 main areas from the use of image prompts within the concept generation phase of the product design process.

#### 3.2.1 Conceptual Inspiration

Questions were posed to understand the conceptual inspiration that Midjourney could offer during the concept development stage within the students' product design process. The findings aimed to understand how the AI-generated concepts sparked creativity and innovation and determine if the students believed Midjourney could produce innovative and original ideas. The students were also prompted to consider if the visualisation of the AI outputs were inspirational and if they offered an exploration into the design problem and potential solutions.

96% of participants agreed or strongly agreed that the AI concepts provided them with creative inspiration and were pleasantly surprising. This indicates that the students found Midjourney's outputs to be genuinely inspiring in terms of generating creative ideas, and that the outputs were perceived as

pleasantly surprising by majority of the students. 92% of participants agreed or strongly agreed the way the AI concepts were visualised was inspirational. 77% of participants agreed or strongly agreed that the AI design concepts were unexpected. This suggests that while the AI outputs were viewed as inspiring and visually appealing, they may not have consistently pushed the boundaries of expectation of the students or produced innovative concepts.

Students were also asked to consider what they believe Midjourney's main strengths in aiding their concept development could be. Exploring a broad range of useful design alternatives quickly emerged as its main strength with 92% of participants stating this. Visualisation of potential design solutions was stated as the second main strength with 88% of participants stating this. However, Midjourney's ability to inspire innovative approaches to design challenges was ranked comparatively low, with 77% of participants stating this as a strength. These results highlight both strengths and relative weaknesses in using Midjourney with regards to conceptual inspiration within the concept development stage of the product design process. Whilst the outputs were mainly seen as inspiring and visually appealing, more unexpected and innovative concepts would help to stimulate greater creativity amongst the students.

#### 3.2.2 Depth and Completeness

Questions were directed towards the students to assess the depth and completeness of their Midjourney outputs to understand if they considered them to be functionally suitable, relevant, and applicable for the intended application (as outlined in their project proposals). Questions regarding the completeness of the AI outputs sought to determine if the concepts presented a holistic and well-rounded perspective on the design problem. The students were asked to consider if the AI outputs explored design possibilities in depth, indicating the system's ability to perform exploration and ideation. The students were also asked to consider how Midjourney created outputs with the avoidance of preconceived design solutions, to evaluate its ability to generate innovative and unexpected concepts, free from conventional biases.

The responses indicate a generally positive perception of the functional suitability, completeness, and level of depth of the Midjourney concepts; however, this is far from conclusive. 58% of students agreed or strongly agreed that the AI design concepts were functionally suitable for the intended application, yet 15% disagreed. 69% agreed or strongly agreed that the outputs seemed generally complete, but 8% disagreed. 81% agreed or strongly agreed that the outputs explored design possibilities in depth, 4% disagreed. And 73% agreed or strongly agreed that Midjourney effectively avoided preconceived design solutions, however 8% disagreed or strongly disagreed. These findings suggest that the majority of students found the AI outputs to be comprehensive and suitable for supporting their concept development through depth and completeness of outputs. However, the significant presence of neutral, disagree, and strongly disagree responses highlights individuality of user experiences and perspectives when evaluating the effectiveness of using AI tools within the concept development phase.

#### 3.2.3 Interpreting Intentions

Questions were presented to understand how effectively Midjourney outputs interpreted the students' intentions using their verbal prompts. By understanding if it was easy for them to express their desired outcomes via verbal prompts, the research aimed to analyse Midjourney's ability to understand and translate their intentions and instructions accurately. This also allowed an insight into the synergy between the user and AI system, as well as the degree to which Midjourney effectively captured and understood the students' intentions during the creative process.

The results show a mixed perception among students regarding the ease of expressing their specific design objectives using verbal prompts. Only 9% of students agreed or strongly agreed that it was easy to express what they wanted to create, whilst 38% disagreed or strongly disagreed. Opinions were also divided regarding whether Midjourney interpreted their specific intentions as expected, with 48% agreeing or strongly agreeing and 32% disagreeing or strongly disagreeing. These findings suggest either a degree of inconsistency in Midjourney's ability to accurately interpret and translate user intentions from verbal prompts, or a varying level of ability amongst the students to use verbal prompts to articulate their intentions.

## 3.3 Image Prompts

Image prompts were used by 12 students as an input method for generating visual outputs in conjunction with verbal prompts. Image prompts provided the students with a more concrete and visually intuitive

input method compared to the use of verbal prompts alone. The findings from this research focus on 2 main areas from the use of image prompts within the concept generation phase of the product design process, and how the students' perception of the results of using image prompts varied from those of using just verbal prompts.

#### 3.3.1 Depth and Completeness

To assess the effectiveness of visual input in producing outputs that had practical relevance and applicability, students were asked to establish if they were able to explore initial concepts in greater depth using image prompts, if they believed the outputs were more functionally suitable, and if the outcomes were more complete. This gave insight into Midjourney's ability to provide holistic and well-rounded design suggestions based on visual inputs, compared to verbal inputs.

The findings demonstrate a generally positive opinion of the depth and completeness of the outputs generated with image prompts. 75% of students agreed or strongly agreed that they were able to explore their initial concepts in greater depth using image prompts, suggesting that sketches generally facilitated a more comprehensive exploration of their design ideas. However, opinions were divided regarding the functional suitability of the AI design concepts produced with image prompts, with 42% of students disagreeing that the AI concepts were functionally suitable. Similarly, 67% agreed or strongly agreed that the AI design concepts seemed more complete when generated with image prompts, 25% disagreed or strongly disagreed. These findings suggest that while image prompts may provide depth and completeness within their concept generation, improvements can be made to ensure the generated concepts are seen as functionally suitable by students. Further investigation into the factors influencing these perceptions, such as the quality of the original sketches from students and the resemblance of the AI outputs, could inform the use of image prompts within Midjourney for concept generation in product design.

#### 3.3.2 Interpreting Intentions

To investigate the ease and efficacy of expressing specific design intentions via image prompts students were asked how the outputs produced using this method compared to those generated using verbal prompts. This aimed to assess the clarity and effectiveness of visual communication versus verbal communication. The students were asked to consider whether the results produced using image prompts were more aligned with their expectations, indicating Midjourney's ability to accurately interpret visual cues. Additionally, questions about the productivity and value of using image prompts aimed to evaluate the effectiveness of visual input as a tool for concept development within the design process.

82% of students agreed or strongly agreed that it was easier to express specifically what they wanted to create using image prompts, indicating that visual prompts aided in articulating their design objectives effectively. 67% of students agreed or strongly agreed that the results produced using image prompts were more as they had expected than in phase one, suggesting that Midjourney was somewhat successful in translating their sketches into concepts. A significant majority, 90%, of students agreed or strongly agreed that the use of image prompts was a productive and worthwhile design method, highlighting the perceived value and effectiveness of incorporating original sketches in conjunction with Midjourney for concept generation in product design. These findings highlight the importance of visual communication in facilitating the students design intentions whilst using AI within their concept generation.

## **4** CONCLUSIONS

The findings from this research provide insights into the effectiveness of utilising Midjourney within concept development and demonstrate a strong positive reception to conceptual inspiration. The students believed their concepts to be creatively inspiring, visually pleasing, and enabling them to overcome creative blocks. However, the depth and completeness of the outputs provided mixed responses, with several students expressing neutral or negative opinions, and remarking they wanted more emphasis placed on the product rather than the user in the output. The results regarding Midjourney's ability to interpret the students' intentions through verbal prompts are inconclusive, suggesting varying levels of success in either Midjourney's ability to capture the students' intentions accurately, or the students' ability to precisely articulate their ideas verbally. It was evident that Midjourney could generate diverse and rapidly changing outputs. However, as students attempted to develop their verbal prompts further, they tended to find that superficial details would be added rather than the refinements they were anticipating. Furthermore, the software did not engage them actively as creative participants and it was

not possible for them to modify ideas or converge them to an optimum point. Judging by the results of the follow-up questionnaire, this was apparently seen as a significant limitation of the software (at this time).

The research highlights a significant difference in students' perceptions in Midjourney's ability to interpret their intentions effectively when using image prompts compared to verbal prompts. Students reported finding it easier to express their design intentions and that results aligned more with their expectations when using image prompts. This suggests that visual communication is a more effective way than verbal communication for design students to convey their design ideas and intentions. Given that design students are often more visually orientated, their preference for using image prompts is understandable. This positive response to using image prompts demonstrates the value of incorporating the use of visual AI tools within the design process, as it facilitates a creative and productive interaction between the designer and AI tools. This interaction between human designer and AI tools may be crucial, as designers often need to be immersed in the creative problem-solving activity in order to be effective and invested in the outcome. As new AI tools come to market with enhanced capabilities, this ability for designers to exploit them so that concepts can be fine-tuned towards convergent, meaningful solutions, may be a critical characteristic for success. The breadth and types of generative AI tools on offer is expanding quickly. Other platforms such as Vizcom (Vizcom Technologies Inc, Hanover), DALL-E (Open AI Inc, San Franciso), and Adobe Firefly (Adobe Inc, California), offer different and rapidly emerging capabilities, warranting further research into how and where they could be implemented into the product design curriculum most effectively.

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## HIIT 2.0: DOES BLENDED LEARNING STILL HAVE A PLACE IN POST-PANDEMIC COLLABORATIVE IDEATION?

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## ABSTRACT

In 2021 we proposed a novel way of teaching Design Sketch Ideation across a digital platform defined as High Intensity Ideation Training (HIIT). The COVID-19 pandemic precipitated a monumental shift in higher education, compelling educators to rethink traditional teaching methodologies and adapt to the demands of online learning. Now that we have returned to physical teaching environments, does the approach that we suggested still work? Or is there a better solution that utilises the learning from the pandemic, to further develop pedagogy? This paper outlines a framework for HIIT 2.0, utilising the originally digital structure of HIIT in a completely physical studio environment. This paper highlights that the original core benefits of HIIT in enhancing students' creativity, fostering collaboration, and promoting active participation are still achievable in a real-world environment. Through observations and comparisons to previous iterations, the authors found that this new approach outperformed fully digital models and allows for a more meaningful interaction within the student cohort. In this new era, the collaborative and creative skills developed through HIIT 2.0 will be instrumental in preparing students for the evolving demands of the design industry. This approach helps facilitate a future where creativity, collaboration, and innovation remain at the heart of design education, regardless of the challenges or opportunities in the educational landscape.

Keywords: Design education, pedagogy, creativity, community, belonging

## **1 CONTEXT**

The world may have changed post-pandemic, but the needs of the Product Designer and therefore Product Design Student have remained the same. Studies have focused on the Pandemic's effect on the various levels of Creativity, seeing both positive and negative effects surrounding student's creative ability [1], however the tools required to provoke these instances have not adapted to the changing needs of students. Regardless of the education stage the student was within during Covid, there was a significant impact on their development, especially regarding their creative ideation. The loss of the early interventions often causes students to be more unsure when creating novel ideas or forces them to rely more heavily on existing structures taught from A-Level/GCSE Education. To combat this tendency, University educators utilize numerous techniques to activate creativity within students. HIIT was developed specifically to promote this activation during periods of lockdown. Provoking creativity, building belonging through community and collaboration are still fundamental tools that students need to become great Product Designers, but these gaps in creative exploration affect students learning journeys in differing ways. The Author's intention was to adapt the existing successful online system, to an in-person experience, and build on the learning developed to produce the optimum implementation. An important consideration to ideation is team working, as most designers work collaboratively. A key component to successful collaboration is feeling you belong within the group [2]. This was a challenge to achieve during remote working, and perhaps was an area under-explored within the previous iteration of HIIT. Students were often working from isolated bedrooms, meaning creating a sense of belonging was extremely challenging. With a return to on-site teaching, there are opportunities to build community within the group, using HIIT 2.0 to facilitate this. The system can be adapted to utilize the shared space of the students, and actively help to build bonds between students. By using HIIT 2.0 as a scaffold, is it possible to promote inclusion within the group, supporting a student's sense of belonging and therefore encouraging them to collaborate?

## 2 METHODOLOGY

## 2.1 Framework Updates

Original paper recommended that the optimum iteration of HIIT would be a blended approach [3]. However, after subsequent years of testing and refinement in post covid teaching, we discovered that the blended approach became a limiting factor to ideation, as students tended to exist behind their laptops and collaboration was reduced. Therefore, for HIIT 2.0 we propose a return to a purely physical environment, utilizing the tools that were developed in a blended world. This paper looks to assess the success of this method and to validate its effect on not only creativity but students' sense of belonging within their cohort. This revised structure is outlined in the below table (1).

Stage	Description	Duration
Set Up	Creation and printing of grids (one set per group). Post-it notes.	
30 Insects	Using pre-printed grids, the groups begin to ideate around the concept of 30 different	10
	insects.	minutes
How Might	Pre-defined project brief in central grid. Task is to think of 8 themes associated within the	10
We Themes	brief as a group. An unrelated example is provided to demonstrate concept. This grid is	minutes
	utilized for ideas in the next two exercises.	
Group Idea	Each group member picks a theme and has 5 minutes to draw as many ideas as possible on	30
Rotation	post it notes and adds to themed grid. After 5 minutes move to the next theme and rotate	minutes
	until all themes are complete. Encourage drawing and being loose with ideas. Ideally 40	
	ideas per theme are generated.	
Cohort Idea	Student groups rotate around the room building on the ideas of other groups. 5 minutes	20
Rotation	per group.	minutes
Cluster	As a group, the students cluster their ideas within each theme highlighting shared	30
Rumble	characteristics. Encourage all to participate in discussion.	minutes

Table 1. HIIT 2.0 Session Framework

The revisions made to the framework were intended to streamline the ideation session, adapting to barriers identified during previous sessions. The session requires some basic resources to be printed, such as the original HIIT template grids [3] and the "30 Insects" template. Beyond this, the sessions simply require a method for collating and categorizing the generated ideas. In this process, Post-it notes were used, but paper or physical modelling could be used depending on the project requirements.

During the HIIT 2.0 session, we utilized the '30 Apples' process first created by Johannsson et al. [4] but added a variant as the cohort had previous experience with the activity. Instead, we utilized '30 Insects' where students used the same template to rapidly generate 30 different insects. The content of the warm-up activity is secondary to the process of rapid ideation. It is the speed and freedom that creates the activated flow for ideation [4].

The overall concept of the HIIT 2.0 session remains the same, again being driven by the fundamentals of the Lotus Blossom technique. However, there were some important modifications made, based on the findings of the previous running. The HIIT 2.0 session was used within a specific project, where the students had been originally world-building in teams. This gave a direct link to the project the students were working on, allowing more linked learning to take place. This linking to the current project allowed for a much more structured approach to the initial theming of idea directions, and thus gave the students more tangible directions to explore. This was a key insight from previous sessions, as the theming became pivotal to ensuring the groups could generate a comprehensive quantity of ideas. If these themes were ill-defined or ambiguous, the students tended to struggle with generating ideas beyond the obvious first links.

The second biggest change to the system, made possible by the session now being in person rather than virtual, was the physical rotation of the groups around the room. This additional step, taking place between the final rotation and the Cluster Rumble (Table 1) allows the other student groups to look at themes and ideas created by the groups in the room, with the intention of the fresh sets of eyes adding value to the ideas. The students rotated several times to add ideas to differing groups, however the time taken at each group was reduced each rotation in an attempt to promote the rapid ideation approach. By this time in the workshop, the students are often running out of ideas and fatiguing, so the movement and reduced time limit aimed to rejuvenate their creativity. Following the Cluster Rumble students took ideas created as a team and began their own project ideation.

## 2.2 Introducing a Project Brief



Figure 1. Moodboard Generated During "Dreamworlds" Project

Unlike previous HIIT iterations, this version was carried out as a starting point for a specific project. Prior to the HIIT 2.0 workshop, student groups had been working on a project entitled "Dreamworlds", using text-to-image AI to develop speculative worlds [5]. Project outcomes were videos and Moodboards (Figure 2) introducing these "speculative worlds" to the cohort. These deliverables were then used as starting points to inspire an individual toy design project, taking the themes and characters from these worlds and developing them into toys suitable for children aged 4-5. The HIIT 2.0 session provided a starting point for this, with groups using these Moodboards as visual cues for coming up with HMW Themes. These Moodboards were available throughout the HIIT 2.0 session as a reminder of the project brief and a source of inspiration.

## **3 DISCUSSION & FINDINGS**

## 3.1 Set Up

In contrast to HIIT, the implementation of HIIT 2.0 significantly reduced the setup time required by staff. Unlike the previous iteration, there was no need to establish individual Miro Boards for each student group, as all participants shared a single workspace, the design studio. Additionally, the use of printed templates proved to be timesaving, eliminating the need to recreate them for subsequent sessions. Another efficiency was observed in the process of grouping students, particularly to ensure that each group focused on Moodboards relevant to their own "*Dreamworlds*" projects. In addition, running the session in person contributed to less waiting time for students to come online, which allowed for more meaningful engagement during the HIIT 2.0 session. Furthermore, running the session in person meant that student groups could work through the full HIIT 2.0 session without the potential for technical difficulties such as loss of internet connection. Overall, the streamlined setup process of HIIT 2.0 facilitated smoother workshop execution, enabling staff to dedicate more time to the workshop content and interactions with students.

#### 3.2 HIIT 2.0

The adaptability provided by an in-person experience added value to the process overall, allowing for modifications to be made reactively during the session. As the workshop progressed, the Authors noted a gradual decline in students ideation ability, with some groups stagnating due to a drop in attention or mild creative burnout. Once this was noticed in the room, the Authors combatted the decline by modifying the rotation system. The groups were asked to physically move around the room, swapping ideas with other groups. This was highly successful, as the physical movement provoked a reactivation of motivation [6] and added a wider diversification of ideas through a 'fresh pair of eyes' approach. The physicality of the workshop also added several benefits to the process. Student groups were able to collaborate much more effectively and efficiently as they could build on each other's ideas in real time and seek clarity from unclear sketch work. Whilst this was possible utilizing the method online, the

nature of talking over Teams/Skype created a roadblock to the free flow of ideas. Conversation could remain informal in person, and students could build on each other's ideas in a wider collaborative way. It was also easier to encourage students to participate in the session, as being in the same physical space allowed for tracking of disengagement by staff. If they weren't interacting with their team, or their ideation had slowed down it was simple for staff to reengage them or help with a creative prompt. During HIIT, less involved students remained unengaged online, as they were easily hidden behind closed webcams or the anonymous Miro space.

The refinements within HIIT 2.0 provided a wider oversight of the whole session. In the original HIIT format, Teaching staff were assigned to several isolated groups and whilst they could maintain oversight on this selection, it was more difficult for them to see how their group's progress related to the whole cohort. Again, the physical studio environment allowed for Staff to observe all groups and react to slow downs or earlier completions as they arose. This in turn promoted a more dynamic pacing to the workshop, as it could be easily tailored to the development of the method.

#### 3.3 Cluster Rumble

The main aim of the" Cluster Rumble" is to encourage students to highlight key ideas and themes that they can further develop later. In the original HIIT workshop, the cohort worked on a HMW question unrelated to their current studio project, meaning similar ideas could be clustered together and that there would be clear ideas for group development. As HIIT 2.0 was run as part of a larger individual project, the "Cluster Rumble" became more of a challenge, students used the HIIT 2.0 session to come up with initial project ideas. As groups clustered the most suitable options to develop, it became clear that individual projects might become similar. This was observed during the final project hand-in, where although suitable; multiple projects had outcomes with shared characteristics. In future iterations of HIIT 2.0, it is suggested that students share their initial ideas within their groups to understand what others are working on. This would help to ensure there are a variety of project outcomes and encourages students to explore different options, reducing the chances of final project outcomes being too similar and encouraging a wider range of design opportunities.

#### 3.4 Community & Belonging

Both HIIT and HIIT 2.0 help to encourage community building and a sense of belonging amongst the cohort. However, after running HIIT 2.0 it became clear that this is much more achievable in physical sessions. The real-world interaction during the HIIT 2.0 sessions enhanced connection among the students and provided more meaningful opportunities for collaboration and communication, in addition to further inclusivity than the original method.

A level playing field was established through students only needing to bring a pen to participate in the session. This setup is notably more inclusive than original HIIT workshops, which required students to own a digital device to participate, due to Covid restrictions. Removing the need for a laptop/tablet minimized barriers to participation and ensured that regardless of access to technology, students could fully engage in the workshop. This meant that students had equal opportunity to contribute and benefit from HIIT 2.0.

In addition to a more inclusive environment, working in themed groups during HIIT 2.0 allowed students to share ideas and gain feedback from peers on a shared brief. In grouping the cohort in this way, it was observed that there was a greater sense of "team working", as student groups ideated around the same brief, knowing that this would contribute to individual projects once the HIIT 2.0 session was complete. Throughout the session, students were able to bounce ideas off each other, exploring different points of view to improve their ideas. Not only did this benefit the whole cohort in terms of idea exploration, but this approach also provided a starting point for students who felt less confident with the brief to begin with. In working within a group setting, individual pressure to come up with ideas was alleviated, allowing groups to come up with ideas more freely and confidently. By working together in a collaborative setting, student groups were ultimately able to approach their projects with greater confidence and creativity, making for a more inclusive and productive learning experience.

Conducting HIIT 2.0 in the same physical space allowed staff to offer more timely guidance and motivation than was possible online. Staff were able to personalize parts of the HIIT 2.0 session more easily due to being able to monitor the whole cohort's progress, compared to online sessions where staff could only monitor one group at a time. This meant that students who needed additional support and encouragement were still able to participate in the sessions alongside their peers. This not only

strengthened student groups but developed a bond between staff and students. Additionally, these faceto-face staff-student interactions created opportunities for more spontaneous discussions than the previous iteration, meaning that students benefitted from more organic input from staff. In the previous iteration, staff interaction was more focused on ensuring student groups were staying on task, mainly due to staff having to jump between multiple Miro boards and groups. Overall, HIIT 2.0 allows for a more cooperative atmosphere amongst students and staff, promoting teamwork and collaborative problem-solving more effectively.



Figure 2. Students Collaborating in 30 Insects and Cluster Rumble

## 3.5 Tools for Creativity

The HIIT 2.0 method acts as a key activator to creativity within the physical space. The method is a useful tool in early project stages, as it actively promoted creative collaboration through the sharing of ideas. Students are encouraged to produce sketches quickly, with a reduced focus on quality, which reduces barriers to creativity by negating the 'I'm not good a sketching' mentality. A focus on quantity over quality ensures that all ideas are equal, and students do not become precious of their ideas. The early-stage implementation also ensures that ideas can be built on by several students after the workshop but directed into different areas of exploration through tutorial. This democratization of the ideas allows for a wider set of students to build on initial ideas in a similar way to a team design consultancy and helps to support those weaker Ideators who in traditional methods may have just focused on their first idea. Generating a wider sample of initial ideas allows for a more diverse iterative process and gives those less creatively minded a point to develop from.

A key failing of the original HIIT method was within the digital tools usable within Miro. At the time of writing the original method, the Authors believed this was a useful feature of the workshop, as it provided a more level playing field of ideation by students. With the implementation of HIIT 2.0 it was clear that this was in fact a negative levelling tool, as it caused all ideas to be drawn poorly (due to the nature of the mouse-pen interaction). By running the workshop in person, the sketching ability of others helped to lift the ideas of everyone, as a particularly strong sketcher could redraw an idea presented in another way. Combined with the focus on quantity over quality, as well as the instant Tutor input, any negative feelings towards poor sketching could be quickly addressed and mitigated. This became a key differentiator between the two approaches and provided a benefit to all participants.

## 4 CONCLUSIONS & RECOMMENDATIONS

Overall, the Authors feel HIIT 2.0 was a more successful implementation than the previous HIIT framework. In the original HIIT sessions there were spaces left within the Cluster Rumble template. In HIIT 2.0, 574 ideas were collectively generated within 1 hour by 52 students. These ideas were also

much more visible to the whole cohort, as in HIIT online the ideas were restricted to individual Miro boards. The physical space enabled the room to be effectively filled with ideas, allowing all students to engage with the process more fully. This shared space and idea generation, also enable stronger community links to be created, ever building on senses of belonging, as well as a deeper activation of creativity through the fast-paced, in-person 30 insects.

Practically, the sessions were more efficient to set up and easier to facilitate. There was less administration required, with printing being the only prerequisite to the session, compared to online set up which required multiple Miro boards being set up and managed.

The speed and pacing of the workshop allow staff to take a more reactive approach, allowing timings to be adapted to suit the needs of the students within the space. A result of this was that a wider oversight of the learning of whole cohort was possible, as there was much less chance of students or groups becoming isolated. This in turn promoted greater staff and student relationships, further embedding the collaborative qualities required to be a designer.

The belief from HIIT was that the digital tools were enablers to creativity, in effect 'levelling the playing field' for all students. However, the tools themselves were limitations as they restricted everyone to the level of drawing with a mouse/finger. HIIT 2.0 demonstrates the power of physical sketching, from the quantity of ideas created, to the collaboration of the students in developing the ideas. It also provided many opportunities for peer learning, as those with stronger skills could advise those with weaker ability, and they could also learn from the techniques the excellent sketchers were using.

Students were polled after the session to gauge their response to it, and 85% of participants scored the session a 3/5 or above for how satisfied they were. This highlights a limitation with the original study, as no feedback was received from it, whilst demonstrating the success of this current iteration.

With both iterations of HIIT there are limitations, particularly when considering the type of project students are using it for. Following HIIT 2.0, students took ideas from the sessions to use in their own individual projects. As a result of this, final project outcomes were similar, as all students had taken the best ideas from the HIIT 2.0 session forward individually. Therefore, it is suggested that HIIT 2.0 either be run as part of a group project where students can collectively develop ideas, or be delivered as a stand-alone workshop, giving students the skills for rapid ideation outside of assessed projects. A further iteration that could be students completing HIIT 2.0 as individuals, however this risks the loss of collaboration inherent in the group project style.

Overall, there are arguments for using both versions of HIIT, depending on need and circumstance. There are clear added benefits to HIIT 2.0, promoting student creativity and a sense of belonging, which the Authors believe make it the optimum iteration.

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# HOLISTIC SYNTHESIS OF THEORY AND PRACTICE IN CAE EDUCATION FOR ENGINEERS

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## ABSTRACT

In recent years, the landscape of engineering and design education has witnessed substantial changes owing to the heightened utilization of Computer-Aided Engineering (CAE) tools. This shift has necessitated a further development in educational approaches, emphasizing the seamless integration of theoretical knowledge with the practical application of CAE tools. This trend is reflected in university curricula that aim to teach the use of CAE tools.

Crafting effective courses in this context is a multifaceted challenge, demanding the simultaneous delivery of theoretical foundations and the application of CAE tools to real-world problems. Notably, many courses tend to focus on a singular CAE tool, neglecting the diverse array available in the market. Recognizing this limitation, an innovative teaching concept was designed for a CAE course, with a specific emphasis on multibody simulation (MBS), at Graz University of Technology.

This paper provides an overview of the teaching concept's structure, resulting from insights collected from diverse CAE courses and the integration of various didactic measures and methods. The primary objective was to enhance the overall learning experience for students, ensuring adaptability and alignment with rigorous academic requirements.

The validation of the teaching concept is based on evaluation results, indicating increased satisfaction of students over the past years. Beyond the specific use case of the CAE courses, the transferability of the teaching concept to other disciplines that combine theoretical knowledge and practical software application is evident. In conclusion, continuous evaluation of the teaching concept and monitoring of students' learning progress remain essential for constant improvement.

Keywords: Teaching concept, MBS, machine dynamics, CAD, CAE, finite element analysis

## **1** INTRODUCTION

In recent years, the working environment for engineers has undergone a significant transformation, with traditional tools such as calculators, pens, and notebooks being replaced by computers equipped with advanced CAE tools [1], [2] [3] [4] [5]. This shift has impacted engineering education, leading to an increased focus on integrating courses that emphasize the practical application of CAE tools. In the 1960s, using CAE tools for finite element analysis (FEA) simulations in education was considered exceptional and confined to research applications. However, nowadays, it is firmly established and included in almost every curriculum at technical universities. [5]

The scenario differs when it comes to simulations in the field of machine dynamics. Even today, only a few universities have incorporated their application into their curricula [4].

The CAE course at Graz University of Technology strives to enhance traditional Finite Element Analysis (FEA) education in mechanical engineering by integrating Multibody Simulation (MBS). This integration is imperative, considering the increasing significance of MBS as a simulation methodology in contemporary engineering practices. This presents a challenge that extends beyond only imparting software usage: it requires establishing a connection between practical application and the underlying theoretical principles. In addition to fostering a thorough understanding, the course places special emphasis on imparting practical applicability and familiarity with various modelling approaches. An innovative approach has been developed to delve deeper into this aspect.

In contrast to many CAE courses that focus on a single tool, the TU Graz course adopts the use of three different CAE tools in the field of MBS. This approach intends not only to teach students the use of various software tools but also to cultivate an awareness of the diversity of modelling approaches in the MBS domain (see section 3.1 for details).

The objective is to make students more sensitized to selecting a suitable tool and its specific capabilities. This, in turn, equips them with the ability to differentiate variances in both structure and results when utilizing different CAE tools. From the authors' perspective, this is a crucial factor in today's era, where an increasing number of diverse CAE tools are available and some of them, according to the developer's descriptions, encompass the same range of functions and capabilities.

Drawing insights from other CAE courses and synthesizing various didactic measures and methods (*Figure 1*), an innovative teaching concept has been developed, combining all these aspects. This concept not only aligns with the content requirements but also considers the students' needs. Adjustments have been made to optimize the course for the students and thus improve their learning success, which is monitored via annual evaluations.

## 2 STATE OF THE ART – DIFFERENT CONCEPTS OF CAE COURSES

The following chapter presents the current situation at other universities, outlining the approach in CAE education and introducing various didactic measures and methods. The design of courses focusing on the use of CAE tools can vary in terms of the scope of teaching materials, as well as didactic measures and methods employed. In the selection of literature, courses were chosen which use several cad tools or also deal with multi-body simulation.

Cavacece, Pennestri, and Sinatra discuss an approach from the early 2000s in [4]. In this case, multibody simulations and numerical methods were conveyed through traditional lectures. Due to licensing costs and limited resources at the time, practical sessions were not feasible, restricting the application of simulations to homework assignments.

[5] present an educational concept that integrates multibody simulation within a project-based learning approach. This approach strongly emphasizes practical implementation and application but requires a foundation in theoretical knowledge.

In addition to separate presentations of theory and practical implementation, as seen in the previous examples, there are concepts that propose a combination of both. Examples include [1], [6] and [7]. These concepts commence with traditional lectures to impart theoretical fundamentals, succeeded by a practical section where students acquaint themselves with the simulation software.

Beyond the shared structure of theory input and practical application, [1], [6] and [8] present the combination of various teaching methods. Common learning approaches include project-based learning and group work. An observable trend is shifting away from a rigid separation between theory and practice to a more integrated approach, placing particular emphasis on project-based learning concepts that foster experimentation and exploration. [5] and [9] demonstrate that engineering students, in particular, benefit significantly from receiving educational content through different learning layers, adhering to the motto: "Tell me, and I forget; teach me, and I remember; involve me, and I learn" [10]. [4], [10] and [8] emphasize that, in addition to using simulation programs/CAE tools, group work and project-based learning serve to critically discuss modeling approaches and evaluate results. Learning how to effectively model these systems and analyse results correctly is an objective that cannot be achieved with traditional instruction alone [5].

## **3 TEACHING CONCEPT**

In this chapter, the CAE teaching concept of the Institute Logistics Engineering from Graz University of Technology is presented. The structure of the course was derived from insights gained from the stateof-the-art section and the combination of various didactic measures and methods. After the concept was developed, industrial partners were involved. This involved identifying the skills that industrial partners expect from graduates in this field. Accordingly, the content was shaped to meet these requirements, aiming to enable students to independently develop solutions for given problems and interpret the results accordingly. This emphasis is particularly evident in Section 3.5 Exams, where the focus is placed, and the performance assessment is adjusted accordingly. Figure 1 attempts to clearly show the various components of the course.



Figure 1. Structure of the CAE Teaching Concept

#### 3.1 Software Selection

An innovative approach pursued by the authors is not only to use a single simulation software for teaching MBS but to incorporate three different software solutions. This approach aims to convey to students that not every problem is solvable with any software and that different levels of abstraction are required. It also illustrates that both the model development and the quality of results can vary significantly.

The first software solution<sup>1</sup> is Creo by PTC, serving as a comprehensive software that provides not only an MBS environment (Creo Simulate), but also features for FEA and geometry generation (Creo Parametrics). This kind of software suite can accompany almost the complete design process. The implemented multidirectional associativity allows the user to always edit the same model, regardless of the program component in which the changes are made. This means that changes made to the geometry of a component are also applied directly to the MBS model, which can help to reduce development time. But this advantages also entail drawbacks: the multi-body simulation (MBS) capabilities are reduced in comparison to dedicated MBS tools like Hexagon Adams. For instance, as outlined in the product descriptions, both tools support the utilization of 3D contacts<sup>2</sup>, but MBS in PTC Simulate is only capable of mapping a 3D contact between special geometry pairs.

The second software is SimulationX by ITI Software, functioning as MBS software that enables simulations at various levels of abstraction. Mechanical models can be abstracted using simplified signal flow-oriented modelling up to physically object-oriented modelling. A notable aspect of this simulation software is the multiphysics approach, allowing the expansion of mechanical models into different domains such as electrical engineering, hydraulics, or pneumatics, thereby enabling the representation of interactions within entire systems and control loops. Even though this tool has extensive capabilities for mapping three-dimensional multi-body systems, there are no options for mapping a 3D contact, to stay with the example of the 3D contact.

The third software, Adams by Hexagon, positions itself as a high-end MBS software. For example, Hexagon Adams offers the most advanced implementation of a 3D contact and the ability to create sub models automatically. In addition to these functionalities, this software offers a wide range of options for intervening in the solving process of the multibody system, from the selection and configuration of the solver used to deep interventions in the solving process itself, which make it possible to change the behaviour of the model during the calculation or to reduce the calculation time by selectively deactivating irrelevant constraints. While the modelling and solving capabilities of MBS systems exhibit notable strengths, the MBS software suffers drawbacks in other areas. In Hexagon Adams, the functionalities for geometry generation are limited, adopting a basic approach. This constraint is offset to a certain amount by the system's ability to import a diverse array of supported geometry formats but also shows room for improvement.

<sup>&</sup>lt;sup>1</sup> The program components listed only include those that are necessary for the CAE course. PTC Creo, ESI SimulationX and Hexagon Adams also include other program components, but these are not relevant here.

 $<sup>^{2}</sup>$  A 3D contact is a kinetic constraint that is only activated when a geometry collision occurs between two components. If a geometry collision is detected, the reaction force is calculated using a non-linear spring-damper system and friction.

The information presented in this section is not intended to pass judgment or endorse any specific software. Its purpose is to highlight the distinctions among them, which may not always be immediately apparent, and thereby raise students' awareness. This awareness is crucial not only in the decision-making process when choosing among these three tools but also in a more holistic context to assist students in selecting a suitable CAE tool for a specific simulation task in general.

## 3.2 Course Structure

The course structure unfolds in three distinct blocks, each focused on a particular simulation software. To set the stage for the entire course, an initial theoretical session provides a comprehensive overview of MBS modelling. This session delves into the foundational concepts and principles applicable to MBS. Following this general theoretical session, the course progresses into software-specific theory sessions tailored for each simulation software. These sessions are meticulously designed to highlight the unique features, capabilities, and methodologies associated with modelling in the respective software platforms. Emphasis is placed on elucidating the fundamental distinctions between the software options, ensuring students develop a nuanced understanding of the intricacies involved.

## 3.3 Teaching Method

The pedagogical framework of the CAE course's teaching concept is woven around the principles of blended learning, aiming to synergize the advantages of both online and in-person instructional methods. Central to this approach is the simultaneous recording and transmission of lectures, providing students the flexibility to engage with course content both remotely and in traditional classroom settings.

A wealth of instructional videos complements the theoretical aspects, which have been adapted to the lecture content, meticulously guiding students through the intricacies of practical exercises. These videos, offering detailed insights into the usage processes of the tools, serve as valuable resources for independent learning. To foster a dynamic learning environment and ensure personalized support, weekly open tutorial sessions are conducted, allowing direct interaction between students and instructors.

Within these tutorial sessions, a flipped classroom methodology is employed to deliver course content. Students independently engage with learning materials, including worksheets and videos, prior to the tutorial sessions. During these interactive sessions, the instructors provide in-depth explanations, clarify doubts, and facilitate discussions, promoting a deeper understanding of the subject matter.

## 3.4 Resources

This section introduces an array of resources and tools meticulously developed to enhance the learning experience for students. The strategic development of these tools was a central focus in shaping the teaching concept, considering that the CAE course attracts students from diverse backgrounds, including mechanical engineering and biomedical engineering<sup>3</sup>. The inherent challenge is to bridge the gap in prior knowledge among students, fostering a shared understanding that accommodates the diversity of their academic backgrounds.

All foundational theory lectures on essential topics are recorded and made readily accessible to students. Complementing these lectures, a series of video tutorials is provided, addressing problem scenarios to those encountered in the worksheets. These video resources serve as valuable supplements to support self-study initiatives.

Beyond videos, practice examples are presented wherein complete solutions are withheld, offering hints and results instead. This intentional approach encourages students to independently review and refine their problem-solving skills. Furthermore, detailed click-to-click guides are available to elucidate the operational intricacies of each software, providing step-by-step instructions for efficient software utilization.

To foster meaningful interaction among students and between students and instructors, a dedicated online forum has been established. This platform serves as a hub for addressing and discussing queries.

<sup>&</sup>lt;sup>3</sup> The Program in Biomedical Engineering provides a comprehensive foundational education encompassing technology, medicine, and the natural sciences. This program's uniqueness lies in the combination of engineering and natural sciences, a fundamental understanding of biology and medicine, and essential computer science principles. The curriculum also covers an introduction to safety aspects and necessary regulations in the field of medical technology. Details can be found under the following URL: https://www.tugraz.at/en/studying-and-teaching/degree-and-certificate-programmes/bachelors-degree-programmes/biomedical-engineering

Additionally, a weekly Q&A session is conducted, offering a direct opportunity to collaboratively tackle specific problem scenarios. As an extra resource, a comprehensive wiki has been curated, documenting problem scenarios from previous years. This serves as an initial reference point, capturing recurring issues and their solutions.

#### 3.5 Exam

The assessment framework for this course is structured into three pivotal domains, providing a comprehensive evaluation of students' capabilities. Firstly, the semester is punctuated with seven worksheets, strategically spaced throughout the term, each subject to independent assessment. These worksheets present students with small projects<sup>4</sup> aligned with specific focal points, deliberately designed to be open-ended. The intentional flexibility of these assignments aims to stimulate creativity and hone problem-solving skills, fostering a dynamic learning environment. Emphasis is placed not only on the solution but also on the interpretation of results, as this is deemed a significant key competency, alongside proficiency in software modelling and operation.

In the culmination of the semester, a practical examination unfolds, challenging students to solve specific problems in a real-time, on-site setting. Tasks include, for example, the analysis of the driving dynamics of a car axle or the vibration behaviour of an overhead crane. The application example and the desired output variables are provided. The modelling must be chosen accordingly by the students to derive the required results from the modelling. Following the practical examination, a structured oral examination is conducted, delving into students' comprehension of the underlying theoretical principles and their adeptness in tackling practical tasks. There are questions regarding the modelling, and students must justify how they arrived at their choices. Subsequently, the interpretation of the results is also examined. It is not sufficient to only generate results; an important aspect of the examination is also the interpretation of these results. This oral assessment component completes the evaluation cycle, providing a well-rounded measure of both practical skills and theoretical understanding.

By incorporating diverse assessment methods, ranging from open-ended projects to on-site problemsolving and theoretical comprehension checks, the evaluation process ensures a nuanced and thorough understanding of each student's proficiency. Ultimately, this multifaceted approach aims to foster a wellrounded set of skills and knowledge, preparing students for the challenges and demands of real-world applications in the field of computer-aided engineering.

## 4 RESULTS AND CONCLUSION

The CAE teaching concept, introduced and implemented at Graz University of Technology, has undergone significant success in recent years. The thoughtfully designed resources and teaching format have demonstrated their efficacy, successfully bridging the knowledge gap for students with diverse backgrounds, bringing them to a common and proficient level.

Recent evaluation<sup>5</sup> results over the past six years bear testament to the positive impact of the program. Approximately 60% out of 153 students expressed a very high level of satisfaction with the course, indicating the effectiveness of the teaching methodologies and the overall learning experience. Moreover, a substantial 75% of these students found the workload to be reasonable, suggesting a well-balanced and manageable academic environment that accommodates the varied needs of the student body. This evaluation is based on qualitative factors and reflects student satisfaction. Quantitative factors such as grades are not considered, as they cannot be used as indicators of good teaching quality. The noteworthy achievement of the CAE teaching concept is further underscored by its nomination for the "Prize for Excellence in Teaching"<sup>6</sup> in 2021. This recognition not only confirms the positive feedback from students, but the learning concept is also examined and assessed by external experts. The nomination is proof of the commitment and innovation of the teaching approach.

<sup>&</sup>lt;sup>4</sup> The projects in the worksheets, for example, address the modeling and analysis of the dynamic behavior of a single-cylinder engine under given operating conditions or the vibration analysis of drive shafts.

<sup>&</sup>lt;sup>5</sup> Cumulative result of the course evaluations provided at TU Graz, carried out electronically, by the CAMPUSonline system. Details can be found under the following URL: https://mibla-archiv.tugraz.at/09\_10/Stk\_1/Lehrveranstaltungs\_Evaluierung.pdf

<sup>&</sup>lt;sup>6</sup> The "Prize for Excellence in Teaching" is an award recognizing outstanding teaching at Graz University of Technology, with nominations being made by the students themselves. Details can be found under the following URL: https://tu4u.tugraz.at/en/students/our-tu-graz/teaching/prize-for-excellence-in-teaching

On a technical level, students have demonstrated through the completion of worksheets and exams that they possess the necessary knowledge and skills in handling CAE tools upon completion of the course. It is particularly encouraging that many students, after completing the course, go on to write bachelor's and master's theses in relevant areas at the Institute of Logistics Engineering by using CAE. This suggests that the course has inspired students for these topics.

Another significant point is that students, after the course, are capable of navigating in three different simulation domains. It is noteworthy that earning the title of an expert in using a specific software would require years of practical experience. Therefore, the authors consider it more beneficial to develop a broad understanding of the world of simulation programs rather than limiting oneself to a single software.

In conclusion, this teaching concept can serve as a template for various instructional formats that require the integration of theoretical knowledge with the practical application of simulation programs. The diversity of tools employed, along with the approach of providing different strategies through various software solutions, can serve as inspiring models for future teaching concepts.

Despite the success of the teaching concept, there was a fluctuation in the evaluation results after the year 2021. This is attributed to the fact that, following the COVID-19 years, fewer Q&A sessions were offered, and students expressed a desire for more support. This feedback needs to be incorporated into a continuous improvement process. Alongside student feedback, this optimization process should consistently align with the current suggestions and needs of students while reflecting the technological state of the art. The integration of modern teaching and learning methods, as well as the regular update of course content in accordance with the latest developments in CAE technology, is essential. Through surveys, evaluations, and close collaboration with students and subject matter experts, successful evolution and adaptation of the teaching concept can be ensured.

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## INDUSTRIAL EDUCATION ECO-SYSTEM – AN APPROACH TO ENABLE THE TRANSFER BETWEEN SCIENCE, EDUCATION, AND INDUSTRY

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#### ABSTRACT

The manufacturing industry is constantly facing multiple trends and challenges – globally and locally. Technologies, like Artificial Intelligence (AI) or Machine Learning are key enablers for companies to increase the ability to react and adapt. No matter if those technologies are part of products for end-consumers, or part of machines which produce the products for the end-consumers – those technologies need to be innovated, designed, produced, maintained, serviced, and recycled. For all those activities people with the right skillset are key.

This paper presents an approach of an industrial eco-system and provides industry-leading-practices. This eco-system allows people in different phases of their educational life to continue their learning path. Moreover, multiple partners in science, education and industry bring their input and opportunities into this eco-system. And one of the key benefits for all participants is the transfer of latest knowledge and technology into the industry.

The presented industrial eco-system is an open and flexible network of multiple partners on the one side, and on the other side a constant commitment and line-organisation. For many industrial companies this is an innovative concept to ensure the transfer in both directions: from science and education into industry – but also getting feedback and open topics from industry back to science and education. By this, the presented approach can be considered relevant for representatives from universities, institutes, and industry.

Keywords: Industrial eco-system, transfer, knowledge and technology transfer

#### **1 INTRODUCTION & MOTIVATION**

Engineering and Product Design Education from a global, industrial perspective has the purpose: to educate the next generation of engineers for successful products and services.

Today, the Engineering and Product Design Education typically is performed at universities, research institutes or educational institutions. Very often the foundation of this education is based on traditional subjects like mechanical engineering, electrical engineering, or software engineering. Interdisciplinary subjects are getting more and more relevant, like Systems Engineering. This education today is often mainly driven by academics only, with limited interaction with industrial practice and companies.

This educational situation is impacted by mega trends across society and industry. Those megatrends are transforming the society and industry eco-system [1]. By this, products and the related manufacturing systems need to transform as well. – For this reason: also, the Engineering and Product Design Education needs to be transformed (Figure 1).

Since the frequency of change of those trends has been increasing over the last several years, the need and speed of transformation is also increasing. Hence, the Engineering and Product Design Education needs to adapt transformation at the same pace.


Figure 1. Situation & Motivation of an Industrial Education Eco-System

To address those changes and the increasing complexity, Engineering and Product Design Education needs to operate in an eco-system. This eco-system consists of multiple partner and institutions and should be able to adapt according to the specific situation or context. Since multiple partner and institutions are involved, the eco-system needs to operate as a network organisation.

# 2 RELATED WORK AND INDUSTRIAL REQUIREMENTS

This paper is based on long experience in industry and educational environments and part of a series of papers reflecting those experience and introducing approaches to bridge existing gaps from science, education, and industry [2] [3].

With focus on Germany and Europe the engineering education at universities is still mainly driven by engineering disciplines like electrical, mechanical or software engineering. Students typically learn specific terms, methodologies, and way of thinking – specific for one of those engineering disciplines. At the same time, the structure and content of lectures very often are not driven by or related to current trends or problems of industry.

When it comes to any kind of technology used in education, very often universities struggle to keep state-of-the-art industrial technology up and running for lectures, laboratories, and research projects. Since those technologies were invented for industrial-daily-operations, those technologies require substantial effort in configuration, installation, operation, and maintenance.

Moreover, based on industrial-daily-operations questions and demands of the industry for further research and education in Engineering and Product Design can be derived. Today, industry is operating in a constantly changing environment with new technologies and products which require new business models [4]. Addressing those questions and demands in a closed loop, is a key success factor for future design education – from an industrial point of view.

# **3 APPROACHES**

The presented approach intends to leverage synergies for science, education, and industry by establishing a permanent network-organisation in the considered company, which allows to establish, orchestrate, and maintain multiple institutions and partners in an Industrial Eco-System.

To unleash those synergies, this approach fosters the collaboration in both ways, as depictured in Figure 2. New topics of innovation need to find their evolution from Science to Education into Industrial Transfer. As well as relevant topics or open questions from Industry need to find their way back into Science and Education.



Figure 2. Approach to transfer between Science, Education & Industry

#### 3.1 Frame and Building-blocks

Beside those relevant topics and open questions, the industry can also provide additional elements, which can be leveraged in education (Figure 3).

**Industrial Technologies** can be a profound platform to enable state-of-the-art Engineering and Product Design Education: from latest versions of assets for digital engineering with multiple design simulation features, to collaboration technologies like Virtual Reality glasses. To increase the learning experience for students, appropriate information and **Industrial Data** needs to exist.

Since those technologies always follow an engineering intend and to not come without engineering processes and methods, the elements of **Industrial Processes & Methods** – as well as **Industrial Use Cases** need to frame the building blocks of Engineering and Product Design Education.

Industrial Education Eco-System | Framing



Figure 3. Building blocks of Engineering and Product Design Education in an Industrial Eco-System

The described elements frame the following core building-blocks:

- **Research Projects:** Typically, there are two types of research projects: The first one is industrial research with support of external institutions like universities. The second one is publicly funded research project in a consortium of universities, research institutes and companies.
- Lecturer: In lectures at universities or educational institutions representants of dedicated companies can be invited to provide insights and perspectives from industry. Moreover, a permanent lecture-contributions by company representants can be part of the lecture-concept.
- Laboratories: Often in combination with ongoing lectures, laboratories are part of the educational schedule. The involved use-cases and technologies can cover industry-specific topics. Furthermore, those laboratories can be extended to facilities or demonstrators of involved companies.
- **Demonstrators:** A sequence of use-cases with relevant technologies involved can be set-up as demos for regular usage. The usage of demonstrators can be across all building blocks of education (see Figure 3). The involved use-cases and technology can be provided and supported by the companies of the eco-system.
- **Technology Transfer Centre:** Multiple demonstrators combined and framed in an educational approach, can be established as Technology Transfer Centre. Those centres can be leveraged in educational building blocks for students and industrial practitioners. This can help to ensure the transformation from Science, Education and Industry very much.

- **Partner Visits:** Partner in the Industrial Eco-System can for example be from other universities, research institutes, government, associations, or industrial companies. Those visits typically happen in both directions invite for a visit and visit the partner in their location which very much helps to get a broader perspective during education.
- **Communities:** Based on so called "multi-channel communication" the eco-system needs to have the opportunity to exchange information and to keep each other up to date on new trends and technologies. Publicly available information as a low-barrier entrance helps to share information and to involve more partners in the eco-system.
- **Student Competitions:** There are many established formats of student competitions at universities and educational institutes, such as Hackathons or Formular Student programs. The engagement of the eco-system in those competitions can help to set those activities and events in a more comprehensive context of Engineering and Product Design Education. For example, seeing Formular Student teams engineer their race cars, using CAD and Simulations based on industrial-standard IT solutions.

The main **impact on Design Education** of the presented building blocks is that on the one hand research and innovation topics are constantly brought into engineering education (universities and industrial education). On the other hand, currently existing challenges or research questions are brought up by the industry and find their way back to universities and research institutes.

#### 3.2 Organisational Set-up & Implementation

**Company-internal** organisations typically are structured in hierarchies and line-organisations. Those line-organisations are needed to structure business operations and responsibilities within companies. At the same time this structure sometimes generates internal boundaries, when topics need to be addressed which require skills and resources across the structure. Alternative organisational structures are partially established in industry which help to bridge those boundaries or silos [5].

Those **network organisations** are part of the approach presented in this paper. A network organisation is centred around functional-oriented groups – called **domains** (Figure 4).

In industrial Research and Development departments, those domains typically are centred around technical and engineering topics: such as Systems Engineering, Lifecycle Management or Sustainability Engineering. Very often those topics are defined to connect existing or traditional topics, disciplines, or technologies. Moreover, domains bring together relevant skills and resources to address a certain task or challenge. Those skills can be distributed in various departments and teams across the line organisation – or even outside of the respective company.

**Company-external** Networks following a similar intend. Skills and resources of multiple partners or elements of this network are pulled together based on a specific demand or activity. In this approach this network brings together the company with its industrial knowledge and technologies and Universities and Educational Institutions. Moreover, to have a wide perspective on education this network typically also includes governmental institutions, associations, and up-to representatives of society.



Figure 4. Internal and external network-structure of an Industrial Eco-System

The benefit of such network structures is, that they are more flexible and more dynamic in comparison to the hierarchies. At the same time, establishing a Domain Network Organisation within a companyorganisation – in parallel to the well-established and legally required hierarchical structure – allows to constantly drive the Domain Topics – such as Systems Engineering or Sustainability Engineering.

**Organisational Implementation** of described organisational set-ups typically requires two different strategies in parallel. On the one hand a domain core-team needs to be defined, which gets a high-end education of the respective topic. As an example of Systems Engineering, this team is educated along the certification levels of the International Council of Systems Engineering (INCOSE). This strategy can be described as **"frontloading education"** for the domain core-team, to increase their knowledge in an early phase of the upcoming transformation of the industrial eco-system. On the other hand, the domain focus or domain topic, such as Systems Engineering, need to break down into **"steps of education"** for the respective industrial eco-system. In industrial practice, often those steps are defined along: basic, advanced and leading. In the context of Engineering "basic" could be defined as "Engineering Excellence" with focus on System Lifecycle Management, the "leading" could be defined as "Engineering Innovation" based on technology-enabled system development (Engineering Intelligence). [6]

#### 4 INDUSTRIAL EXAMPLE

The following example shows how the presented approach is used and how it impacts the Engineering and Product Design Education [7]. The engineering of an **industrial machinery context** is in focus. Around this context the entire education concept was developed: Lectures, Laboratories and Research Projects. The set-up of this industrial machinery context is equipped with industrial leading technology for information technology (IT) and operational technology (OT).



Figure 5. Example: integrated education concept for industrial machinery engineering [5]

#### 4.1 Lecture approach

The lecture approach covers multiple perspectives of engineering and integrates those perspective in physical demonstrators and virtual representations (Digital Twins) at the same time.

**Product Engineering** is one of those perspectives, leveraged in the lecture approach. The simplified electronic device in this context is made of different electrical components such as resisters or switches. With this device the use case is defined, where the industrial machinery needs to replace an electrical component and test the electrical component at the end of the manufacturing line.

**Manufacturing Layout Engineering** is another perspective where the product use case needs to be operated. In this perspective all components of the industrial machinery need to be engineered.

**Manufacturing Process Engineering** is also a perspective which needs to be engineered. The production line, high rack excavator or the robot arms need to be programmed to fulfil the required activities in the right sequence and quality.

Students in this lecture learn different perspectives of engineering based on industrial leading information technology and are also able to transfer this to the physical world by applying their engineering results on the physical demonstrator.

#### 4.2 Laboratories and research projects

In addition to the lectures, it is possible to conduct laboratories and research project based on the industrial machinery context. Students are constantly working in small projects to enrich or improve the industrial machinery context. This gives different generations of students a great opportunity to learn from former projects and bring-in innovations to expand the existing set-up. The research projects can be scaled according to the type of project, such as master thesis or publicly funded research projects.

#### 4.3 Demonstrators & Partner Visits

The industrial machinery context can also be leveraged for transfer. In this scenario the machinery with its different use cases can be utilised as demonstrators for students during their education. Moreover, it can be used for knowledge and technology transfer during partner visits with other universities, research institutes or industrial companies. This typically can be a great scenario for new projects or input to further evolve the overall educational approach.

#### 5 SUMMARY AND OUTLOOK

The approach, introduced in this paper, describes how the transfer between science, education and industry can be established and impacts the Engineering and Product Design Education. It is covered under the name "Industrial Eco-System".

The motivation of this approach covers both, educational and industrial demands, as described in the beginning of this paper. The major building-blocks of this approach were introduced. Moreover, the organisational set-up was described which covered the concept of network-organisation, called domains. Finally, an industrial example showed specific impacts on Engineering and Product Design Education with one of the partner education institutes of the eco-system.

In future, this approach will be leveraged with our existing and new partners in the eco-system and will constantly be further developed. Moreover, the focus on transfer will be fostered by new ways of technology transfer centres. This will also help to address the education of employees in industry, which needs to handle the constant change in technologies and engineering methodologies.

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# IS AI 'JUST' A NEW TECHNOLOGY? ON INTEGRATING AI EDUCATION IN DIGITAL DESIGN CURRICULA

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#### ABSTRACT

Design schools in digital media and interaction design face the challenge of integrating recent artificial intelligence (AI) advancements into their curriculum. To address this, curricula must teach students to design both "with" and "for" AI. This paper addresses how designing for AI differs from designing for other novel technologies that have entered interaction design education. Future digital designers must develop new solution repertoires for intelligent systems. The paper discusses preparing students for these challenges, suggesting that design schools must choose between a lightweight and heavyweight approach toward the design of AI. The lightweight approach prioritises designing front-end AI applications, focusing on user interfaces, interactions, and immediate user experience impact. This requires adeptness in designing for evolving mental models and ethical considerations but is disconnected from a deep technological understanding of the inner workings of AI. The heavyweight approach emphasises conceptual AI application design, involving users, altering design processes, and fostering responsible practices. While it requires basic technological understanding, the specific knowledge needed for students remains uncertain. The paper compares these approaches, discussing their complementarity.

Keywords: Artificial Intelligence, digital design, interaction design, design education

#### **1** INTRODUCTION

Many design schools struggle with how artificial intelligence should be taught in their curricula. This is particularly challenging for programs with a substantial digital design component, such as media or interaction design. All design schools must incorporate in their curricula novel AI-based design tools, future work processes, new design jobs, and work environments for designers – but interaction design students must also be prepared for a role as (interaction) designers of AI-based systems.

In a way, this is business as usual for digital design schools. In the past two decades, novel technologies have been introduced every couple of years. Schools have had to adapt to the rise of the internet, mobile technologies, embedded media [1], and extended realities (XR), to name a few [2]. However, this time, it seems to be different. Unlike the other technologies, AI is considered a 'system technology'. System technologies are ubiquitous, subject to constant change, and enable complementary innovation [3]. Therefore, AI is expected to have a much more profound impact on the industry than other technologies that have entered the field.

As such, introducing AI has sparked more heated discussions in teaching institutes. Staff in our institute, for example, wonder how much students should know about the underlying technology, whether they need to gain 'hard' knowledge about AI, acquire coding skills, develop a particular attitude towards such technologies or work more on '21st-century skills'. Additionally, the rationales for selecting skills to be taught vary widely. Questions such as whether future students need to be able to conceptualise systems using AI or to what extent conversations with programmers require programming skills lead to fierce debates among the staff. We cannot disentangle all aspects of these discussions in a single paper; many depend on the programs' details, the teaching teams, and other institutional-specific aspects. However, in our experience, it already helps to identify and clarify the fundamental choices that educational teams face. Our aim in this paper is to bring some structure to the debate that is going on in our school and other schools like ours.

# 2 FOUR WAYS IN WHICH NEW TECHNOLOGIES IMPACT DESIGN EDUCATION

In general, discussions on curriculum design tend to be chaotic and based on staff members' private views rather than a thorough analysis of the changes that warrant curriculum change [4]. Interaction design education is no exception; academic discourse on interaction design curricula tends to focus on generic didactic principles [5], or to favour a very specific approach in response to an external development [6]. Our experience is, however, that creating an overview of external developments can be incredibly helpful to guide curriculum level decision-making. We analysed discussions on the redesign of curricula in Dutch institutions for higher education in The Netherlands and summarised our understanding of those discussions in Table 1 below. It lists the four primary ways, educational staff considered AI to change the work of future interaction designers. Even though all four can be shared under the heading 'impact of AI on design education.', they inherently spark different discussions. Identifying which of the aspects is the focus of a discussion may lead to tidier arguments and swifter closure. We will discuss and illustrate each aspect below.

How design is done	Design Outcomes
Different work processes	Different interface design challenges or control of AI
Designers will use different tools and approaches to design.	Designers will be asked to shape the interactions with AI-based applications.
Different work environments	Different types of applications or capabilities of AI
Designers will take on new roles, new companies hire designers, designers work with other people (i.e.) data scientists.	Designers will be asked to conceptualise novel AI- based applications.

Table 1. Four ways in which AI could have an impact on digital designers

#### 2.1 Different work processes

The first change is not unique to digital design education and relates to the fact that AI-based tools alter designers' work processes. Designers will use generative AI to create content or as a source of inspiration. They might engage in AI-based research of target groups and rely more on data-driven decision-making. Many of these changes already have entered and will continue to enter the workspace. Earlier examples are tools such as Google search and 'context-sensitive fill' in Adobe software. Newer tools are potentially more disruptive to the extent that they inspire worries about how AI might replace design jobs. We believe, however, that cost reductions through AI-based tools translate, at least partly, into increased demand. Nevertheless, students do need to be prepared to increase their efficiency with novel AI tools and to find means to convince others of the added value of their human touch.

Discussions among teaching staff on using AI-powered tools focus on the juxtaposition between craftmanship (artisan work) versus the value of being able to work well with the new tools. They also sometimes touch identity questions: 'what sets me apart as a creative mind who can design beautiful and effective interfaces, if anyone can ask AI to design that as well'. Teachers are aware the landscape of AI tools is constantly changing, so they also want to teach students how to educate themselves on new tools. Finally, students need ways to assert themselves as people who bring more to the table that just someone who works with AI-tools. Not only can this support their value as a designer, but it will also reinforce their self-perceived professional identity.

#### 2.2 Different work environments

If AI is a system technology, it is bound to impact the economic structures in which design takes place. Different companies will feature design in their product portfolio, and design companies will hire people in new roles to solve tasks for clients together with designers. These changes are much more complex to monitor and more challenging to predict than changes in the work processes of existing roles. However, it does seem plausible that the relationship between digital designers and programmers will intensify. IT companies currently identify interaction design as part of their value proposition and, as

such, invest more in-house designers rather than outsourcing design to agencies. Design agencies, in turn, acknowledge that they need more skills in data-driven design and AI to compete with IT companies. For prospective students, this means they need to be prepared to have meaningful and fruitful discussions with data scientists and AI specialists, and they need to be taught processes [7] and models that can cross the epistemic and cultural boundaries between these fields, such as the data-driven feedback loop [8]. A common discussion within our teaching staff is whether learning to code is essential to improve communication between programmers and designers. Although there are valid arguments to include coding – as one teacher put it, 'coding is also a communication skill' – much communication between stakeholders in the development of AI-based systems is not related to actual code. Much more then coding, stakeholder management seems to be essential.

#### 2.3 Different Design Challenges for Al-based applications: interface v. concept design

Whereas the first two developments probably apply to all design fields, the second two are particularly relevant to digital design. For digital designers, AI is not only a means to an end but also a desired outcome of a design activity. In other words, designers may be asked to design AI-based applications - ranging from designing the interface to the entire ai-concept - and different knowledge and skills are needed to prepare design student for these tasks. When engaging in discussions about these skills, in our experience, it is vital to distinguish between front-end design and concept design. Front-end design includes the design of an interface of a system for which the functionality and expected performance of the system is more or less given. The designer's task is to develop an interface that harnesses this functionality in a way that the user can work with it. Most tasks in the industry that focus on front-end design are carried out by bachelor students. In our view, even if schools focus on interface design challenges, they need to consider certain particularities of AI-based applications. We will elaborate on these and our efforts to address them in section 3.

Concept design, in contrast, also includes the design of the system's functionality. This requires a much more thoughtful exploration of an application's technical, economic, and ethical aspects and arguably requires a deeper understanding of the underlying technologies and their limitations. Because we believe that it is the more senior designers who will generally work on this aspect, we teach conceptualising AI-based systems mainly in the Data-Driven Design master program [8]. Nevertheless, in our experience, unpacking the requirements of such roles is also beneficial for bachelor teachers, if only because the contrast with the challenges in interface design brings clarity, also when it comes to designing a curriculum. We will elaborate on this in section 4.

# 3 THE 'LIGHT' APPROACH TO INTERACTION DESIGN OF AI APPLICATIONS: FOCUS ON CONTROLS OF AI

Many of the design skills that interaction designers are already taught in curricula can be directly transferred to the design of AI-based systems. Human-computer interfaces aim to make a system's functionality accessible for users, and there is no *a priori* reason to expect this goal to be any different for systems based on AI. Below, we list however four considerations that do have an impact on the design process and results.

First, as it is, interaction design is an overlooked area in creating responsible AI. Designers should step up to ensure human agency within AI-based systems [9]. Human action possibilities within such systems determine, to a large extent, whether users feel control over the outcomes of a system and therefore can be held accountable for how they use the systems and its outcomes. Devising such interaction possibilities and using them to increase the accountability of ai-supported human decision-making is a significant developmental area within interaction design of AI-based systems. Students need to be aware of their responsibility and need training in the potential for human agency they could unleash.

Second, while traditional systems, too, need to acknowledge and design for their users' mental models, working for the mental model of AI-based systems is particularly hard. Typically, users build their models upon a mix of signals, thus feeding into a hybrid of how laymen tend to reason about such systems [10][11]. How user interfaces are designed, in turn, impacts this mental model formation [9]. Students should, therefore, know how (1) humans generally reason about AI-based systems, (2) how users may incorporate emerging behaviour of the AI into their mental models, and (3) how interaction designs could course-correct faulty mental models or reinforce helpful ones. Although work on explainable AI gives us some sense of direction [12], more effort is required to support designers' a deep understanding of these mechanisms in order for them to work confidently on AI-systems.

Third, as with other new technologies, novel interaction languages are emerging, specifically tailored to the possibilities that AI-based systems offer. Hekman et al. [13] coined the term *algorithmic affordances* to cover this emerging area of interactions with algorithms. Such interactions go beyond *explainability* and include all ways users could influence (the outcome of) algorithms through interaction possibilities. Students focusing on AI's front end should be familiar with this emerging solution repertoire [14]. Research has shown that beginning designers are empowered by exploring collections of such materials [16][17].

Fourth, interaction design students need to consider the impact of AI within the more extensive work context in which these systems are used. For example, consider the situation where AI-generated credit scores play a role in loan applications. Ethical and interaction design considerations would be pretty straightforward if the credit score were the only indicator in the decision process (assuming the creation of the score is unbiased). However, loan application decisions take many other factors besides credit score into account and reside within a collaborative work environment. Such embedding of an AI-based system in the broader work and decision context is much more complex than simply providing an explanation or an algorithmic affordance for the AI-based component. Students must be trained to consider all aspects of these contexts and how they influence their approach to transparency, explainability, or control [18]. Furthermore, they should confidently be able to test their designs.

### 4 THE 'HEAVY' APPROACH TO INTERACTION DESIGN OF AI APPLICATIONS: FOCUS ON THE CAPABILITIES OF AI

The conceptual design of AI-based systems encompasses interface design, including algorithmic affordances, but it entails also other design challenges. Some of these are related to the complex settings in which responsible AI systems will be developed. First, many stakeholders are involved in the design of responsible AI, with divergent knowledge and perspectives on the system under design. Designers, being generalists, can take a role in facilitating design-oriented conversations among non-designers, addressing complex questions such as shifting power distributions in the envisioned AI system. More than technical knowledge about the AI system, to play such a role, they need facilitation skills and an overview of different perspectives on and attitudes towards AI and their corresponding limitations and blind spots.

Second, as a concept designer of novel AI-based systems, students must be able to envision such systems. From our experience, students find it quite hard to conceptualise 'intelligence' in novel systems [16]. Their points of reference are human (or animal) intelligence or systems they know well, such as Google or Netflix. Neither suffice as models of artificial intelligence. As a generative concept, human intelligence encourages students to envision systems as other humans, focusing on general rather than special-purpose intelligence. Netflix and Google, in contrast, embody a specific purpose intelligence, but students find it hard to translate these to novel application areas. Even with the help of various AI ideation toolkits [19][20][21], students can get stuck on building a dashboard. As one student proclaimed, 'It has data, so it is an AI-concept'.

Third, designers conceptualising novel AI-based systems need to envision the capabilities of such systems. Apart from finding appropriate metaphors, this entails understanding the characteristics of AI-based systems. Yang et al. [22] suggest two dimensions of AI-based systems that are particularly difficult to design: *capability uncertainty* and *output complexity*. With capability uncertainty, Yang et al. refer to the intrinsic difficulties of estimating the performance of AI-based applications. AI-based systems are typically trained on certain materials but then used in different contexts. For example, face recognition software may perform relatively good in the lab, with fair lighting conditions and 'single face' images, but much worse in the wild, where conditions are different and images to be judged may not even contain a face. The differences between training and usage conditions are inherent to AI-based systems, and designers need to find means to deal with such uncertainties. This should be part of their curriculum. The second dimension is output complexity. Output complexity refers to the situation where human input can lead to many systems' responses, and the designer cannot reasonably envision them all. A classic example is chatbot design, where the diversity of human responses can lead to infinite dialogs that need to be 'designed'. Designers cannot design all possible paths and need more abstract means of exercising control over the emerging dialog.

Although all these challenges require some knowledge of AI, it seems that the conception of AI systems does not necessarily require students to understand the inner workings of AI systems. It does, however, require them to get a sense of their outer workings, whether it be its capability uncertainty, output

complexity, its intelligence characteristics or its embedment in societal systems. These aspects are qualitatively different from the challenges involved in the front-end design of AI- systems.

Discussion among teaching staff on incorporating AI-concept design reveal a varying degree of ethics in the curriculum. While some feel that ethics are taken care of with a course on GDPR and the AI-act, others include psychological aspects of human-AI-teams [15] and ideas like Contestable AI. More marked, however, based on complaints on the lack of originality and the 'AI-ness' of their concepts, students need to receive thorough training in concept development. Experience has shown, furthermore, that students' feasibility assessment (what can AI do now, and when can it reasonably expected to do more?) should also receive attention. Our master students have a hard time estimating to what extent their ideas can be executed.

#### **5 CONCLUSIONS**

In this paper, we have examined the impact of AI on digital and interaction design education. Unlike previous new technologies, AI is a system technology [3] with set of unique characteristics that impact design. Interaction design programs need to adapt to these developments. While the field has earlier needed to adapt to technological developments, the advance of AI brings qualitatively different challenges. Much more than in earlier developments, designers need to adapt to uncertainty in the system output: output complexity and capability uncertainty; much more than before, designers need to see how designs impact different sets of stakeholders and how these technologies impact their relations. Although these elements have been at the heart of interaction design from its beginnings, AI -as a development- profoundly steps up both the game's speed and impact.

Discussions on how to accommodate AI in design curricula, as for all curricula redesigns, have been muddled. In our view, it is beneficial for design curricula to distinguish four separate approaches to involving AI, thereby focusing the discussion, the questions, and the potential curriculum interventions better. The four approaches were presented in Table 1, and are reiterated in Table 2, this time supplemented with related discussions and potential curriculum design choices.

Approach	Discussions	Curriculum Interventions
Designing with AI: Different work processes	<ul> <li>Craftmanship vs. user of AI-tools</li> <li>Identity as a designer</li> <li>Value of design and dire job perspectives</li> </ul>	<ul> <li>Using AI tools critically and efficiently</li> <li>Assessing and learning new tools</li> <li>Presenting the value of a human designer</li> </ul>
Designing with AI: Different work environments	<ul> <li>Do designers need to be able to code?</li> <li>Do designers need to master advanced data science techniques?</li> <li>Is coding a communication skill?</li> </ul>	<ul> <li>Introducing specific models that smoothen communication</li> <li>Co-design strategies are more emphasised</li> <li>Stakeholder management</li> </ul>
Designing for AI: interface design of AI systems (control)	<ul> <li>Are students concept designers or interface designers?</li> <li>Identity as a designer</li> <li>What level of ethics?</li> <li>How do we foster the communication with engineers (data scientists, developers)</li> </ul>	<ul> <li>Algorithmic affordances and their impact</li> <li>Roles of AI (coach, decider, etc.)</li> <li>Understanding needs of decision contexts and varying roles of AI</li> <li>User testing on complex constructs such as <i>trust</i></li> <li>Ethical design</li> </ul>
Designing for AI: Concept design of AI systems	<ul> <li>What level of ethics?</li> <li>Students can/cannot be expected to develop novel AI-concepts</li> <li>Students have a hard time assessing the feasibility and future developments of AI.</li> </ul>	<ul> <li>Ethical design (responsible AI)</li> <li>Contestable AI</li> <li>Human-AI collaboration/hybrid teams</li> <li>Concept development skills, fostered by courses on feasibility assessment, high-level domain and user research, Prospective design</li> </ul>

Table 2. Common discussions on AI in digital design curricula

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# A HOLE IN ONE: BREAKING BARRIERS & CREATING COMMUNITIES BY ENGAGING PRODUCT DESIGN STUDENTS WITH CREATIVE MODEL MAKING & COLLABORATION EVENTS

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#### ABSTRACT

Within product design education, encouraging collaboration, creativity, and a sense of community among students is vital, especially during the first few weeks of undergraduate study. Creating a student community in the early weeks is crucial for students to adapt to course cultures, adjust to new environments, and establish friendships. This is essential in creative disciplines where students must collaborate, serve as critical friends and network in a professional practice setting. Post-COVID-19 pandemic, students are increasingly anxious in new environments and often reluctant to engage in large events, which is problematic in a sector where 'community' is essential. Thus, it's important to create a collaborative culture quickly within undergraduate programs, however, this is a challenging task with large student cohorts. A strong design community can serve as an incubator for creative ideas, peer learning, and emotional support, helping students thrive in an academic environment that often demands intense problem-solving and innovation. This paper introduces 'A Hole in One,' a Welcome Week project designed to promote student engagement through competitive model-making. Using unique innovative approaches, we introduce a set of core values to first-year Product Design students through experiential learning and collaborative design making. The core aim is to break down barriers and cultivate student communities by challenging student groups to construct a unique crazy golf hole in groups. The collaborative effort resulted in a crazy golf course being assembled for an end of welcome week student competition. Our findings offer educators/institutions guidance in promoting communitybased teamwork within design programs, suggesting innovative pedagogical approaches to elevate the educational experience for product design students.

*Keywords:* Community building, creativity, experiential learning, collaboration, creative modelmaking

#### **1** INTRODUCTION

The early days/weeks of higher education for incoming undergraduate students are often identified as a pivotal point in a student's education. The friendships established within courses, societies and student accommodations often create the support systems, student communities, and social connections necessary for students to be successful in a higher education environment. Engaging with university initiatives and course programs in the early days/weeks in higher education is also essential. Minimizing early negative experiences, difficulties settling into university communities, financial issues, dissatisfaction with course programs/initiatives and attachment issues can all be attributed to student engagement issues/withdrawals [1]. Furthermore, engagement in the first three weeks of UK higher education has also been proven to predict subsequent activity and attainment in first year undergraduate students [2]. The importance of community in education cannot be overstated. Helping facilitate the creation of a student community is no easy task, particularly in the context of product design courses where students are often focused on individual projects, sticking to tight schedules, and working in isolated student accommodation with students from other courses university wide. Minimizing student non-engagement is therefore critical as this can pose problems later within degree program when summative assessments occur.

Historically within UK higher education, student activities outside of the classroom environment often involves alcohol consumption, this culture has been embedded in how students build social connections,

with many first-year students enlisting in the consumption of alcohol to create social bonds in order to get to know one another in key spaces of student life, including student housing and the social events of student societies [3]. However, the decline in certain activities and the number of students consuming alcohol within the associated social activities has meant students are seeking different ways to establish key friendships/communities. Within university environments, academics have been employing strategies to enhance engagement with courses for years, including creating creative spaces, monitoring/responding to demographic subgroup differences, creating stimulating intellectual environments, focusing on engagement, fostering social connections in different classroom environments, amongst others [4]. It is therefore essential that equal emphasis is placed on successful integration into the social world of a university as much as the academic environment [5].

In recent years, Product Design staff at Nottingham Trent University (NTU) have observed that engagement with Welcome Week/Freshers Week course activities correlates to student engagement, student progression and course cohesion. As such, we sought to create an engaging, collaborative, competitive and course community driven project that runs for the duration of Welcome Week to help break down barriers and facilitate/establish course communities. To maximize student engagement, this project focused on creative model making providing students with the opportunity to get hands on immediately. Learning by doing is an essential teaching methodology employed and is an essential part of modern-day design education [6]. Creative students often prefer to learn via this method and as such this formulates a large part of our teaching philosophy.

This paper takes a holistic view on the impact of how creative model-making and collaboration events can harness the concept that designing in a collaborative environment can benefit students through the application of learning by doing. The next sections of this paper discuss the methods used and the student outcomes, whilst reflecting how the 'A Hole in One' project has influenced students' creativity, communication skills, and overall sense of belonging in the design community at NTU. Our findings provide valuable insights for educators and institutions seeking to promote community building and teamwork within design programs providing the potential to inspire innovative pedagogical approaches and enhance the overall educational experience of product design students.

#### 2 LOGISTICS

During the students first week at NTU, 151 students across three undergraduate Product Design courses (BA Product Design, BA Furniture and Product Design and BSc Product Design) and a group of students from our International Exchange Program were set the challenge to design a Crazy Golf Hole primarily from corrugated cardboard and an assortment of other materials such as foam, paper etc. A short project briefing was provided to all students and post the project briefing, students were asked to get into groups of 6 to 10, this varied based on the size of the cohorts of the respective courses. The project spanned the entirety of welcome week, with designated times allocated for designing/making their imaginative crazy golf holes; this was supplemented by other welcome week activities linked to university initiatives. This ensured that all students had time to explore their new city, join societies and participate in other social events.

To encourage the students to get know other members in their group and the rest of their cohort, the students were taken to a social evening at Nottingham Bowl, where NTU had reserved bowling lanes and time slots on an existing crazy golf course. This not only facilitated group interaction in a more social setting but also provided an opportunity for primary research, enabling students to draw inspiration and gather insights for their own designs. This was organised on the evening of the students first day to reduce any first day nerves and therefore provide a strong platform for group interaction for the rest of the week. For the next three days, students were given access to their respective course design studios for a couple of hours every day to meet up with their group and construct their crazy golf holes. This ensured the students were able to get used to their studio environment which will be their course home for the next few years, whilst also giving them a chance to ask questions and get to know their lecturers for the year.

To end the week, a social gathering in an open area on campus was facilitated. Each group were asked to set up their crazy golf holes and receive a scorecard, a pen, and a putter before navigating through the course. Students not only played their own designed hole but also the other 20 holes crafted by different groups. To encourage equal participation, staff members and student mentors assigned to support welcome week monitored the rotation through the crazy golf holes, completing scorecard signoffs thus ensuring every student within each group took turns playing the holes. Whilst students were playing the golf course, chosen staff judges walked around the course picking their chosen designs for each course that aligned to following awards; the most creatively designed crazy golf hole and the best considered and well-made golf hole. Additionally, there was also awards for the lowest score from each course and an overall group winning score.

#### **3 METHODS**

The brief for the project had specific parameters to ensure both socialization but also a soft introduction to some of the core design methods to be used in the coming weeks. Also, group projects formulate a core aspect of the start of the product design courses at NTU, so this group activity is designed to help with the experiences. Overall, the project would expose the students to key themes within the design process, ideation, prototyping, testing, and, eventually, the creation of a functioning golf hole prototype. The collaborative nature of the project would require effective communication, problem-solving, and the ability to synthesize ideas. The parameters for the golf holes that the students could create were given a maximum size restriction of either 3m x 1m or 2m x 2m. The size was determined by staff for several reasons. This would effectively be two sheets of cardboard laid out but the size and time-frame available also meant the groups would be encouraged to work together to meet the finale deadline at the end of the week. The size of the holes would be too big for an individual to complete on their own, but not so large that it becomes overwhelming and stressful for a group. Students were encouraged to think of a theme for the crazy golf hole. This would allow the group to align their ideas to a clear direction they have decided but also encouraged the students to get to know each other to identify a theme they could all agree on.

Each group was given a plastic cup to act as the golf hole itself. The cup was chosen for a couple of reasons. Firstly, as it was the same for every group it meant parity across all golf holes on the course but the second was the introduction of a fixed component that the students would have to creatively consider how to integrate into their designs. Exposing the students to working with constraints and considerations was also critical. Furthermore, each group was given a golf ball at the start of the week and putters were available in the studio. This pushed the students to work in 3D and therefore prototype and test their ideas, something that is a key skill as a designer and encouraged throughout their time on the course. The limitations of just being able to make their crazy golf holes from the corrugated card provided meant modelling was easily accessible, whilst also getting the students to consider the strengths and limitations of the material.

#### **4 OUTCOMES**

On many levels the project can be viewed as a success. The primary objective of the project was to encourage new students to socialise and get to know each other whilst having fun. It also provided an opportunity for students to very early on get hands-on using their problem-solving skills but also use collaborative model making to bring together a diverse student pool to present an outcome within a few days. Critically the students felt that the collaborative model-making focus of the welcome week project encouraged them through brainstorming, problem-solving and discussion to create a fun interactive outcome. It can be seen from the student comments below how successful this was. From a teaching point of view, the project successfully introduced students to some of the key ideas and methodologies they will be exposed to in the course.

"It helped integrate people with each other and relax and be themselves. Creating a relaxed environment, breaking down any initial Barriers between each other"

"It helped build and form Friendship groups, and it allowed individuals to come out of their shells and interact with each other"

"The project was really good, and it helped us get to know each other naturally and easily. Despite working in small groups, we all got to know each other well which made it enjoyable".

"I really enjoyed the fun atmosphere it created, gave everyone chance to connect with one another, our group are all close friends and some of us are even going to live together next year". "It really helped to bond us as a group and has formed friendship a group that has lasted throughout the term, it was a great way to learn design skills and bond as a course".

### **5 DISCUSSION & RESULTS**

#### 5.1 Breaking the Ice

Icebreaking is a key component within "Welcome Week", extending beyond simple introductions. The "Hole in One" project integrates icebreaking through collaborative model making, recognising its potential to develop friendships and a sense of belonging amongst students whilst working in a relaxed and inclusive environment. This was key in developing a design community within the cohort, where students were able to feel empowered to express themselves creatively and engage in collaborate problem-solving. Whilst icebreakers are typically brief activities, the project served as an extended icebreaking activity, evolving over the week to deepen student relationships and promote peer and staffstudent connections. Rather than focus on structured introductions, the project allowed students to interact organically, gradually breaking down barriers and working towards a shared goal. By engaging in a competitive and collaborative project, students were not only able to familiarise themselves with their peers and university environment but also, they were able to develop a sense of course belonging. For first-year students, navigating higher education for the first time can be challenging, and icebreaking activities offer an opportunity to overcome some of these challenges. By providing a platform for students to connect, this project facilitated a smoother transition into university life, instilling confidence and easing anxieties. Moreover, their shared experiences contribute to the development of a support network, essential not only for academic success but for overall well-being. Overall, the ice-breaking nature of the "Hole in One" project aided in enhancing student engagement and nurturing a positive journey into Higher Education.

#### 5.2 Building Community

Community building lies at the heart of effective higher education, encouraging a supportive and inclusive learning environment where students can succeed both academically and personally. In the context of product design education, cultivating a strong sense of community is critical, as it encourages collaboration, innovation, and peer learning, all important skills needed in a professional design context. This project shows how collaborative model-making initiatives can serve as a catalyst for community building within a cohort. By working together to design and construct a crazy golf course, students not only developed their technical skills but also form meaningful connections with their peers. These connections extend beyond the confines of the project, laying the foundation for a cohesive academic community. Community building initiatives promote active engagement and participation among students, fostering a culture of collaboration and shared responsibility. Through collaborative practices, students learn to appreciate diverse perspectives, communicate effectively, and work towards common goals. Additionally, a strong sense of community provides students with a support network that they can rely on during challenging times, further enhancing their academic resilience and well-being.

#### 5.3 Fostering Competition

Four course cohorts took part in the "Welcome Week" activity, including first-year students from BA Product Design, BSc Product Design & BA Product and Furniture Design, in addition to a group of Students on European Project Semester (EPS). In addition to each team being in competition with each other, each course was competing as a full cohort. Introducing an element of competition into educational activities can have profound effects on student engagement, motivation, and learning outcomes. In the context of this project, the competitive aspect added an exciting dimension to the experience, fuelling students' enthusiasm and creativity. By challenging student teams to design and construct a unique crazy golf hole, the project fostered a spirit of friendly competition that drove innovation. Competition serves as a powerful motivator for students, encouraging them to strive for excellence and push the boundaries of their creativity. Throughout the week, the prospect of designing the most impressive and functional crazy golf hole spurred student teams to invest extra time and effort into their designs, often spending time outside of timetabled sessions working on their models. This heightened level of engagement not only enhanced the quality of the outcomes but also instilled a sense of pride and achievement among student groups. Moreover, competition cultivates important skills such as teamwork, time management, and problem-solving. As student teams worked collaboratively to

design and make their golf holes, they encountered various challenges that required innovative solutions, for example, limiting material usage. By navigating these challenges together, students honed their collaborative skills and developed a deeper appreciation for the value of teamwork in achieving common objectives. Overall, the competitive aspect of the "A Hole in One" project not only enhanced student engagement and motivation but also provided a platform for students to demonstrate their creativity, teamwork, and problem-solving skills.

#### 5.4 Developing Skills

The project not only served as an icebreaker and community-building initiative but also provided a platform for students to begin developing essential skills for their academic and professional journey in Product Design. Throughout the project, students engaged in hands-on activities that required them to employ various design techniques, problem-solving strategies, and communication skills. Throughout the week, students enhanced their design skills through ideation, prototyping, and iteration processes. Furthermore, the friendships created in this initial week helped formulate lasting friendships for the course and beyond, including some groups signing up to second year houses together.

The project facilitated the development of critical thinking and problem-solving abilities among students. As they encountered challenges during the design and construction phases, students had to think creatively to overcome obstacles, adapt their designs, and find solutions to meet project requirements. Overall, the project provided students with a holistic learning experience that went beyond traditional classroom instruction. By engaging in practical design challenges within a collaborative and competitive framework, students began to develop the foundational skills necessary for success in both their academic studies and future careers in product design. This section highlights the transformative impact of experiential learning initiatives in equipping students with the skills, knowledge, and mindset needed in the field of product design.

#### 5.5 The Final



Figure 1. The Final

During the final day of the project, all 21 golf holes were assembled in a shared space, providing a platform for the end-of-project finale (*Figure 1*). This not only facilitated a reunion of all students but also welcomed additional staff members, encouraging a sense of inclusivity and collaboration within the academic community. Playing all the holes offered an opportunity for students to observe and appreciate the techniques used to construct each hole, enriching their understanding of design processes and skills. Furthermore, student groups were able to observe the various themes of the golf holes, including a "Barbie" themed hole and holes themed around personal interests or experience, for example, "Anime", or in the case of EPS students, a hole themed around the different countries they had travelled from. Not only did the variety in themes create a dynamic and exciting atmosphere, but the theming of the holes also highlighted particular interests and hobbies, allowing students to form further friendships based on shared interests. Prizes were awarded for the most creative and best-constructed

holes per cohort, as well as for the team completing the course with the fewest shots, further enhancing the atmosphere of friendly competition. This served as a conclusion to Welcome Week, reinforcing the bonds formed within cohorts.

### **6** CONCLUSIONS

In conclusion, the "A Hole in One" project exemplifies the impact of creative model-making and collaborative events on the landscape of product design education. By strategically incorporating experiential learning into Welcome Week activities, this project successfully breaks down barriers and encourages community building amongst students. Through collaborative model-making, students not only demonstrated their creativity and innovation but also developed essential teamwork and communication skills necessary for success in the design industry. This approach not only enhances students' design abilities but also instils a collaborative mindset essential for navigating the complexities of modern design practice. By encouraging a strong sense of community, the project serves as an incubator for creative ideas, peer learning, and emotional support, empowering students to succeed in an academic environment that demands intense problem-solving and innovation.

By engaging students in hands-on activities from the outset, staff can create a dynamic learning environment that inspires creativity, collaboration, and engagement. This project underscores the importance of integrating practical experiences into design education, providing students with opportunities to apply theoretical knowledge in real-world contexts. Furthermore, the collaborative nature of the project develops a supportive and inclusive culture within the design community.

Overall, the "A Hole in One" project offers valuable insights for educators and institutions seeking to enhance community building and teamwork within design programs. By prioritising experiential learning and collaborative activities, staff can elevate the educational experience for product design students, equipping them with the skills, knowledge, and mindset needed to succeed in the ever-evolving field of design.

#### 7 RECOMMENDATIONS

Despite its success in facilitating the creation of strong friendships early on, it has been observed that students arriving late to the courses encountered challenges integrating into the courses due to bonds established through the "Welcome Week" activity. Whilst these students cannot avoid missing "Welcome Week", future iterations of the project should aim to prioritise ways to support the integration of latecomers. Furthermore, whilst the project aimed to promote sustainability by using cardboard for construction, the disassembly process proved challenging in many cases. To address this, future iterations of the project should emphasise the importance of designing the holes so that they can be easily taken apart and reused in future projects, emphasising long-term sustainability.

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# EXPLORING THE CHALLENGES TO INTEGRATE VR MODELLING IN PRODUCT DESIGN EDUCATION

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#### ABSTRACT

Over the past decade virtual reality (VR) headsets have become increasingly affordable and available. This in turn, has made virtual reality tools more accessible. Within the context of product design, one of the possibilities opened with VR, is the creation of 3D models within a 'virtual/immersive' environment. This has several advantages in the realm of product design education, including increased student engagement due the novelty of the approach and the appeal of the physical immersive experience. How to incorporate this type of 3D modelling in the curriculum however, remains rather unclear.

While there is continued interest on VR from segments of the academic community, its adoption within the context of product design education is still in its infancy. Moreover, because of the many different variables involved, and the differences inherent to any design project, the experience from a larger and wider variety of case studies is necessary. This paper reports from a case in which VR has been incorporated into a design project in a first-year course which is part of a product design degree course.

Keywords: Virtual reality, VR modelling, CAD, design education

#### **1** INTRODUCTION

Over the past decade, virtual reality (VR) has experienced significant growth and evolution, driven among other by advancements in technology and increased adoption across various industries [1], [2], [3], [4]. The development of more powerful and affordable VR hardware has made it more accessible to a wider range of users, and an increasing variety of VR software apps have appeared on the market. VR modelling or virtual reality modelling involves the creation and manipulating of 3D objects within a virtual environment using VR technology [1]. This typically includes VR headsets and hand motion controllers. This approach allows for a more immersive and experience compared to traditional computer 3D modelling methods. In the context of product design, VR modelling enables designers to explore and refine their concepts in a highly immersive environment, delivering an experience that is difficult to achieve with models represented on a traditional computer screen. This approach is increasingly being integrated into product design processes in various industries [5], [6], [7], [8]. Designers can use VR modelling to quickly create and visualize product concepts in a virtual environment. A footwear designer for example, can quickly start laying out three-dimensional geometry over the 3D model of a foot. This is in principle similar to sketching over a drawing of a foot in 2D. By experiencing their designs in virtual reality however, designers can understand spatial relationships, and ergonomic considerations better [3].

As the role of VR modelling becomes prominent in industry, there is an interest from the academic community to integrate VR modelling into product design curriculum. Despite this interest however, its integration into the product design curriculum is for the most part, yet to happen [2], [4]. And while there has been research looking at the incorporation of VR into design education, literature documenting attempts to implement this integration from different perspectives remains scarce.

# 2 BACKGROUNDS

This paper investigates the challenges and considerations that educators must address when integrating VR technology into the curriculum. This is done by examining the experience of incorporating VR modelling into a design project. Through a thorough analysis and investigation of this experience, best practices for educators seeking to do the same are revealed. In this sense, the paper can be considered to be autoethnographic in its approach. Autoethnography is a common method of inquiry in the education research and pedagogy [9], [10], [11].

A VR modelling activity was introduced as part of a first-year module within an undergraduate product design degree course. In this module students work on a term-long project where they are tasked with designing either a doorknob or a perfume bottle to be manufactured using moulds. Students follow a traditional design process, starting by doing research, subsequently generating ideas through sketches, they then move on to create CAD models of their designs, and finally 3D-printing these models to produce casts (figure 1).



Figure 1. General project stages and VR modelling integration

For the VR activity, students were invited to three additional sessions held outside the regular schedule of the module. The sessions were an hour long, and due the headset-to-student ratio, three similar sessions were run on the back of each other. In total each student took part in two sessions, one each week. These sessions took place in the two following weeks after students completed their CAD modelling. Incorporating VR modelling in combination with traditional CAD modelling has the advantage of a scaffolded approach for students [1], [5]. Students were instructed to bring their laptops to the VR modelling sessions. This was essential to facilitate guidance and feedback during the sessions as will be discussed later. Students were given a feedback questionnaire by the end of the session.



Figure 2. Students during VR modelling session

The headset selected for this activity was the Meta Quest 2. The selection of this headset over other alternatives such as the HTC Vive, HP Reverb, or Pico VR, was primarily based on popularity, affordability, and versatility. The Meta Quest 2 works as a standalone device, eliminating the need for a high-performance PC. Moreover, there is an extensive library of apps on the Meta Quest store and a wealth of online resources and tutorials.

Gravity Sketch was chosen as the software for the VR modelling activity. There are other similar tools available on the market, such as TiltBrush and Masterpiece Studio, however, Gravity Sketch is specifically tailored towards product design. And being the first mainstream app of its kind, there is a substantial amount of learning materials and support available online, making it the best choice for educational purposes [3]. Moreover, as opposed to some of the other options, Gravity Sketch is free on the Meta Quest store.

# **3 SUMMARIES OF ISSUES**

Although expected, it was impossible to anticipate the issues that would emerge as a result of integrating VR modelling into this design project. Therefore, the issues presented in this section were identified as the integration exercise took place and categorized afterwards. For discussion, these issues have been arranged in seven categories: Connectivity, File-Transfer, Account Management, Service Time, Suitability of models, Development of teaching support materials, and Curricular Integration.

#### 3.1 Connectivity

A critical consideration for lecturers, is the need for real-time monitoring of students' activities within the VR environment. To provide guidance and feedback, lecturers must be able to observe what students are seeing. For this reason, the implementation of screen-casting is essential. This allows the student's view within the VR headset to be mirrored onto a computer screen for the lecturer's observation. In practice however, this requires that both, the VR headset and the computer are in the same Wi-Fi network. It is important to consider that most higher education institutions use Eduroam to provide Wi-Fi access to students and faculty. To gain access to the network however, Eduroam requires the installation of a certificate in the user's device. Institutions generally support this process by providing ready-made installation packages and guides for the most common device types such as Windows and Mac PCs, and Android and iOS mobile devices. However, support for VR headsets is less common if at all available.

Furthermore, information found online quickly made evident the challenges to connect VR headsets to Eduroam. Some comments found on forums and discussions boards even suggested that it was not possible at all. It was almost by chance, and aiming to exhaust all possibilities before giving up, that success was achieved to connect the headsets to Eduroam using manual configuration settings. It must be pointed out however, that this was only possible by inputting network details during the initial device setup. Subsequent attempts to do the same via the settings panel did not work.

### 3.2 File-Transfer

This case study also showed the importance of understanding the intricacies involved in moving files to and from the VR headsets. An important consideration, particularly when VR modelling is used in addition to traditional 3D/CAD methods, is that while it is possible to transfer files by connecting the headset to a PC, this method presents inconveniences, especially if students have been working on their models using university computers. Just as an example, this would imply collecting all student's files before copying them on to the headsets, or even having to physically connect the different headsets to several different computers. Moreover, files must be copied to a specific location within the headset folder structure, a task that may be challenging for students with limited computer skills. A situation that is not uncommon.

Files can be transferred online by uploading them to LandingPad, Gravity Sketch's proprietary platform. The files can then be accessed directly within the Gravity Sketch app on the headset. This approach however, presented several issues that lectures ought to be aware of when guiding students through this process. First, to use LandingPad, it is necessary to create a separate account with its own login credentials. This can be done directly on the LandingPad website, and from within GravitySketch in the headset. The later however, did not work for the students in this case. While students were asked to register at LandingPad in advance, several did not, and because they only needed the account at the time of importing their models, and because the account in principle can be registered from within Gravity Sketch on the headset, it seemed the simplest option to do it that way. Attempts to register for LandingPad directly within the headset failed. Several students were unable to log in after receiving a Single sign-on (SSO) code via email. Moreover, it was not easy for students to know whether the registration had worked within the Gravity Sketch interface.

Registering for a LandingPad account on the website using a PC and subsequently logging in on the headset proved to work. Nonetheless substantial time was spent while trying to sort out these issues, causing further delays and disruption of the sessions.

### 3.3 Account Management

Another critical consideration for lecturers interested in implementing VR modelling, is the limitations the number of user accounts that a single headset can hold. Thereby constraining the seamless rotation of students in and out of the VR modelling sessions. This is an important consideration, particularly as the ratio of students to headsets increases, requiring that several students share the same headset.

To set up the Meta Quest 2, it is necessary to use a Meta.com account without which the headset cannot be used. While in principle it is possible for different users to use the same headset without switching accounts once it has been set up, this is impractical in a scenario like this for several reasons. The first, is that as previously mentioned, screen-casting is essential for guiding students throughout the activity, and this requires that both, the headset, and the PC to which the headset is casting, are logged on the same account. In practice this means that each student must use an individual account. Furthermore, sharing accounts presents additional issues, such as the fact that all settings within the headset, including those associated with LandingPad and Gravity Sketch, are tied to the current user.

The Meta Quest 2 headsets can accommodate only three distinct user accounts besides the administrator account. In this case, the lecturer's account served as the administrator account, with three students subsequently added to each headset. While manageable within the scope of this trial, the inconvenience of identifying and managing student accounts on each device surfaced as an issue that would have to be addressed if more students were involved in the activity and had to share the headsets available.

### 3.4 Service time

Another issue evidenced through this experience, is the service time of the battery, a factor that becomes particularly important when consecutive VR modelling sessions must be scheduled back-to-back due time constraints. In this case, it was observed that the Meta Quest 2 headsets offer approximately one and a half hours of continuous running time on a full charge. This became an issue during the first week, as the need to recharge the headsets between sessions resulted in delays and the disruption of the overall flow of the sessions.

The headsets are equipped with a charging cable; however, its short length made it impossible to recharge the headsets while being used, because students are constantly moving around. This issue was addressed by purchasing three-meter-long charging cables; however, these were only available for the second round of sessions the second week. The longer cables made it possible to recharge the headsets during the activity itself and allowed the students to continue working seamlessly in subsequent sessions.

#### 3.5 Model Suitability

While it is possible to export models from most popular CAD packages that can then be imported into Gravity Sketch, this experience highlights that the exported models are not ideal for manipulation within Gravity Sketch. Models to be imported into Gravity Sketch must be of the polygonal mesh type. Most popular CAD packages can export models in one or more of the most common mesh model file formats such as OBJ, or STL. The mesh models created however, are geared towards 3D printing and/or physical simulations such as FEA and CFD, not further 3D modelling. Consequently, these meshes simply recreate the geometry using triangles (figure 3).



Figure 3. Examples of polygonal mesh models generated from the same geometry, using several CAD software packages: Fusion 360 (left), OnShape (middle), SolidWorks (right)

For the purpose of further 3D modelling however, not only the arrangement of these polygons is important, but also the type of polygon. In general, it is better if the mesh is mostly made of quads (four sided polygons) rather than triangles. Therefore, another valuable lesson from this study was the need to re-topologize the models that are going to be imported into Gravity Sketch. In the context of 3D modelling, Topology refers to the arrangement and structure of the vertices, edges, and faces that comprise a 3D model. A good topology ensures efficient and easier manipulation of the model during editing. Depending on the complexity of the model, the mesh generated, and the skill of the student. This is a process that can take up some time.

#### 3.6 Development of Teaching Support Materials

This experience also shed light on the instructional design challenges around VR modelling. In contrast to a traditional classroom setting, where both the student and lecturer can easily point at the same place on a screen, VR modelling lacks this common point of reference. This complicates communication and feedback between the lecturer and student.

In a traditional CAD classroom for example, the lecturer can easily take control of the mouse to demonstrate procedures. In VR however, this is more difficult. Similarly, during a live demo, students in a traditional classroom can readily switch between the projector screen and their own screens. In VR, this is not possible. The only feedback that the lecturer can provide with such fluidity is auditive. These underscores the need for teaching support materials that allow the lecturer to provide visual feedback 'inside the headset.' And while video tutorials could aid in in this scenario, their development requires significant time and effort.

In this case, students were given a series of instructions at the beginning of the first session. These focused first on explaining the students how to add their account to the headsets, and then start screencasting. For this purpose, it would have been good to have screenshots of the headset interface, and even better a video for the students to watch in advance. In this case however that was mostly done using verbal descriptions of what the interface looked like and what the process was. Once screen-casting started, it was easier to tell the students what to do. The other set of instructions students received at the beginning, had to do with an overview of the Gravity Sketch interface and how to performs some of the most basic functions, such as hand motions used to navigate the workspace (panning, zooming and rotating). Students were asked to start by completing a quick 'getting started' interactive tutorial available within Gravity Sketch by default. This worked well as a starting point. As the students continued working on their models however, it was necessary to guide them verbally constantly. This underscored the importance of clear and simple verbal instructions and highlighted the complications of students moving at a different pace through the process, while not being able to easily call everyone's attention to a single screen.

#### 3.7 Curricular Integration

The study has also highlighted time-related issues associated with integrating VR modelling into the curriculum. In this case, the VR modelling sessions in which students took part spanned over a period of just two weeks. However, and even though in this case not all students in the cohort participated, this still resulted in a substantial time investment. While this can be alleviated with additional hardware and efficient logistics, it remains an important consideration. Moreover, in this case the sessions were offered as an extra-curricular activity, however, the formal adoption of VR modelling with its learning objectives and assessments would require changes to the curriculum, which is a time-consuming endeavour. In addition, in many instances, the curriculum is already densely packed with modules and content, leaving little room for additional material without overwhelming both lecturers and students.

#### **4** CONCLUSIONS

By providing an immersive platform for conceptualization, prototyping, and refinement, VR modelling offers an appeal that traditional CAD modelling approaches cannot provide. As VR modelling continues to gain terrain in industry, this is a skill that those universities not already considering incorporating in their curriculums should not ignore.

This paper has presented the findings derived from integrating VR modelling into a design project in a first-year product design degree course. These findings have revealed that it is possible to carry out this integration successfully, however, significant challenges must be overcome. From connectivity and file transfer issues to account management and instructional design constraints, the successful integration of

VR modelling into the curriculum, requires a strategic approach that addresses technical, logistical, and pedagogical considerations. While some of the issues highlighted here may be linked to the specific VR headset used in this case. This insight should prove valuable for any lecturer planning to implement VR modelling in a similar scenario. Moreover, the fact remains that the headset used in this case is the most popular and affordable on the market.

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# ENHANCING STUDENT COMPREHENSION THROUGH APPLIED SCENARIOS: FROM PRACTICE TO THEORY

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#### ABSTRACT

Engineering students frequently encounter difficulties with numerical and analytical techniques, perceiving them as unengaging or overly theoretical and failing to see the relevance to engineering contexts or their future careers. The issue may be exacerbated by the use of traditional didactic teaching methods that often emphasize recall and computational rigor over comprehension and the capacity to adapt and apply the methods learnt to new contexts.

This paper details the approach taken to teaching a third-year module 'Performance Engineering' at Nottingham Trent University. By structuring learning around practical scenarios and introducing technical methods in the context of solving applied problems, students are better able to contextualize their knowledge. Flipped and active learning techniques are used to enhance conceptual comprehension and ensure students are able to apply the methods learnt beyond the contexts presented.

Keywords: Practical application, flipped and active learning, analytical and numerical techniques

### **1 INTRODUCTION & BACKGROUND**

A core skill to be cultivated in engineering students is the ability to apply analytical and numerical methods to solve practical problems. Techniques drawn from mathematics and statistics are ubiquitous across engineering disciplines, requiring students to develop confidence when utilising mathematical language and approaches to describe real-world scenarios, to analyse them and to effectively communicate with others in the profession and beyond [1, 2, 3].

Simultaneously, it is apparent that engineering students frequently struggle with more mathematical topics, perceiving these as overly abstract, disconnected from practical applications and hard to understand [4]. This may lead to a negative perception of mathematics as "a gatekeeper, denying entry to otherwise talented would-be engineers" [5]. The consequent reduction in motivation may contribute to student disengagement leading to poor attendance or drop-out [1, 4, 6].

To counter this, it is critical that students see the purpose of techniques learnt, that these are contextualised, and their meaning and application made explicit. This is particularly true for engineering students for whom maths is a tool for posing, presenting and solving problems not the object of study itself [6]. Instruction in mathematical and related techniques may be better suited to the dispositions of students and to the demands of the discipline where it is structured around their application as opposed to formal introductions in abstract terms. This may be facilitated through effective use of applied engineering scenarios to enable students to see the relevance of methods learnt and to provide a concrete context in which conceptual connections are made explicit and readily apparent [1, 2, 3, 4, 6]. <sup>1</sup> In doing so, theory and practice are integrated, and the student may better appreciate the value of techniques learnt. Furthermore, by asking students to engage in solving applied problems themselves, teaching moves from a 'transmissionist' to a 'connectionist' model focussed on developing understanding of *why* they are using a technique as opposed to merely following a pre-defined procedure [2].

To achieve this may require the collaboration of engineers with mathematicians, when the latter are tasked with teaching engineering students, to enable the generation of appropriate applied examples [1, 2, 10]. When engineers themselves are engaged in teaching mathematical topics, it is commonplace to

<sup>&</sup>lt;sup>1</sup> A thorough elucidation of the importance of making the connections between concepts explicit can be found in the works of the philosopher Robert Brandom [7] as applied to mathematics and science education [8, 9].

provide practical examples elucidating the relevance of techniques learnt to practical engineering scenarios. Anecdotally, these examples may be introduced only in passing or only after instruction in an abstract context, that is, the practice follows from the theory. It is contended in this paper that students may benefit from reversing this progression, instead beginning from an applied problem scenario and introducing techniques in this context. As such, the practical scenario acts as a scaffold for developing students' understanding from which techniques learnt may be subsequently developed and abstracted for future use. Beginning instruction from applied examples may act as an initial source of motivation, clearly setting out the relevance and use-value of techniques while clarifying the meaning of concepts and quantitative features to assist comprehension. Doing so may more effectively orient the student before they have had an opportunity to become lost in abstract details.

This paper considers a 3<sup>rd</sup> year engineering module at Nottingham Trent University (NTU). It illustrates an approach to teaching in which applied examples are used both as a starting point for instruction to be subsequently used as a scaffold for learning techniques, and as a means of extending student comprehension once basic conceptual comprehension is achieved. Feedback from students is considered and conclusions drawn regarding how the approach may be adapted to other contexts.

#### 2 PERFORMANCE ENGINEERING

#### 2.1 Overview of Module

Performance Engineering is a 3<sup>rd</sup> year core module taught to all students in the Department of Engineering at Nottingham Trent University. In the academic year 2023/24, the cohort consisted of approximately 150 students across four engineering disciplines: mechanical engineering, electronic & electrical engineering, biomedical engineering, and sport engineering. Teaching took place across one term and consisted of two lectures and one seminar each week as well as an optional drop-in session. The module aims to develop students' understanding and application of methods for setting, measuring, improving, and monitoring performance of engineering processes. In practice, much of the module is devoted to instruction in statistical, mathematical and other analytical techniques to be applied in an engineering context. Topics leant include discrete and continuous probability distributions, sampling and estimators, the central limit theorem, capability analysis, correlation and regression, hypothesis tests and ANOVA, factorial analysis, statistical process control and reliability engineering. Learning outcomes are assessed through a 2-hour in-person examination and an individual coursework assignment. The exam contains both calculation questions, in which students apply techniques learnt to data provided, and questions requiring students to explain the methods used, their limitations and application. For the coursework assessment, students are given a hypothetical engineering scenario and data relating to this. They choose appropriate methods from the module to analyse the data and draw practical conclusions, delivering their findings through a pre-recorded PowerPoint presentation and supporting Excel calculations.

#### 2.2 Approach to Teaching

Given the technical nature of the module, many students may be intimidated by the mathematical detail required. Furthermore, the range of engineering disciplines represented means that the background knowledge of students may not be equivalent. Teaching time-constraints make it difficult to introduce all required content within taught sessions at a pace all students will be able to follow. To address these issues, the module is taught through a mix of synchronous and asynchronous learning, with a partially flipped approach to instruction [11, 12, 13]. Each week introduces a new topic. Students make use of online resources consisting of a series of short 5-10 minutes videos [12, 14] interleaved with multiple-choice questions for regular formative assessment. At the end of the week, students complete an extended problem set reviewing the week's content. These resources are intended as the primary source of content knowledge. Learning is automatically differentiated as students may work through resources at their own pace.

Week /	Asynchronous Learning	Lecture 1	Lecture 2	Seminar
Topic(s)				
1. Quality,	Quality, performance and	Introduction to	Applied scenario	Excel for data analysis
Performance	statistics. Populations and	module including	(starting a pizza	and problem sets
and Statistics	samples. Displaying &	details of	company):	testing use.
	interpreting data.	assessments.	Previewing topics.	

Table 1.	Module	content ar	nd structure	for Performance	Engineering
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2.	Measures of average &	Case Study 1.1:	Applied scenario (bike	Problem set on
Introductory	spread. Discrete and	Quality	manufacturer):	descriptive statistics,
Statistics	continuous probability	characteristics and	Reviewing prior week,	probability
	distributions. Sampling,	descriptive	introducing probability	distributions, sampling,
	estimators and the Central	statistics.	distributions, sampling	estimators and the
	limit theorem.		and estimators.	central limit theorem.
3. Analysing	Measuring processes.	Case Study 2.1:	Applied scenario	Problem set linking
Processes	Process capability. Cause	Binomial and	(phone case testing):	capability analysis and
	and effect analysis.	normal	Introducing capability	probability
1 Testing	Completion Regression	Case Studies 1.2	Ann Isnikawa diagrams.	Drohlom get on
4. Testing Polationshing	Confidence intervals	case Studies 1.2	(testing biomologulos):	confidence intervals
Relationships	Hypothesis tests	anu 2.2. Probability	Introducing correlation	and hypothesis tests
	Trypomesis tests.	distributions and	regression and	and hypothesis tests.
		capability analysis	hypothesis tests	
5. Further	Multiple and non-linear	Case Studies 1.3	Applied scenario (paint	Problem set on multiple
Testing	regression. Paired t-test. Chi-	and 2.3:	manufacturer):	and non-linear
Relationships	square test.	Hypothesis tests	Hypothesis tests.	regression, paired t-
1	1	51	multiple and non-linear	tests and chi-square
			regression.	tests.
6. Design of	Factorial experiments and	Review of topics	Applied scenario (hot	Problem set on factorial
Experiments	factor effects.	learnt including	chocolate recipe):	experiments, factor and
	Mid-module review	further applied	Introducing factorial	interaction effects.
	questions.	examples.	experiments.	
7. Analysis	Analysis of Variance	Case Studies 1.4	Applied scenario	Problem set on the
of Variance	(ANOVA).	and 2.4: Planning	(drug's manufacturer):	analysis of variance.
		factorial	Hypothesis tests and	
0	<b>T</b> 1 1.0 1	experiments.	ANOVA.	D 11
8.	The need for control.	Case Studies 1.5	Applied scenario	Problem set on
Controlling	Control limits. Establishing	and 2.5:	(Christmas bauble	statistical process
Processes	control limits. Out-ol-control	Application and	Reviewing conchility	control.
	processes. Relation to		and introducing control	
9 Reliability	Reliability vs quality	Mock exam on	Applied scenario (light	Problem set on
J. Renability	Determining failure rates	introductory	hulb manufacturer):	reliability engineering
	'Bathtub' curve Exponential	statistics and	Introducing reliability	remaining engineering.
	and Weibull distributions.	analysing	engineering.	
	Reliability block diagrams.	processes.	<i>88</i> .	
10. Further	Pre-recorded video from	Mock exam on	Quality, sustainability,	Problem set applying
Topics (not	industry speaker on a real-	factorial analysis	environmental	techniques to monitor
examined)	world quality engineering	and ANOVA.	performance, ISO	environmental
	scenario.		standards.	performance.
11. Revision	Practice exams.	Mock exam on	Mock exam on process	Reviewing and
		reliability.	control.	critiquing sample
				answers to an exam.

Synchronous learning consists of two weekly lectures and a seminar. During the first lecture, a casestudy scenario is introduced, and students work in small groups to apply techniques from prior weeks to analyse data and draw conclusions. This serves to revise content and deepen understanding while simultaneously preparing students for their coursework (more details on case-studies will be provided below). During the second lecture, the current topic(s) are introduced through an applied scenario. The lecturer poses a series of questions for discussion first in small groups and then with the whole cohort. New techniques addressing the issues raised are then introduced and students are provided with short questions testing their understanding of these. Towards the end of the week, students attend a seminar. The more challenging parts of the current topic(s) are reviewed, adapting content to the students present and their current level of understanding. Students are then set a series of problems to complete either individually or in small groups. The lecturer assists and answers are reviewed at the end.

Clear instructions are given to the students throughout the module as to the expectations with regards to engaging with both online materials and on-campus taught sessions. The need to complete online materials and activities in advance of seminars is emphasised as is the importance of using these to adequately prepare for assessments. Simultaneously, it is made clear to students that attending lectures and seminars is crucial for understanding how to apply the techniques learnt and pass assessments. The module content and structure are shown in **Table 1** above.

#### 2.3 Selected Examples

Throughout the module, extensive use is made of applied examples to introduce relevant concepts and techniques and to deepen student comprehension and their ability to apply the techniques learnt.

#### 2.3.1 'Cell2U' - Phone Case Analysis

This example was used in a lecture to introduce capability analysis while linking to previous learning on probability distributions. After a brief introduction to the company including an overview of the injection moulding process used for manufacturing phone cases, students discussed how the company should investigate reports of cases falling outside specified dimension tolerances. This initial discussion provided context for the problem scenario and challenged students to apply their knowledge of previously introduced techniques in conjunction with practical reasoning to devise a strategy for investigating the root cause of issues. Subsequently, students were informed that the temperature of a polymer mix may have had an effect. Sample measurements were provided for analysis as well as a specified range of allowable values. While all sample measurements were within specification limits, some students noted that this was no guarantee that temperature would not fluctuate outside these if further measurements were taken. During discussion, students were led to recognise that the temperature could be modelled as a normal distribution with mean and standard deviation derived from the sample. From this it would be possible to estimate the probability of fluctuations outside specification limits. MS Excel was then used to analyse sample values, produce a histogram and estimate this probability. In this context, capability indices were introduced as a means of standardising analysis.

This example illustrates how an applied scenario may be used to scaffold student learning. Students are provided with a concrete situation and a practical problem to solve. In this context, the relevance of previous learning of statistical concepts is made explicit. Use of software helps link the theoretical discussion of the problem to numerical data that can be visualised and interpreted. Finally, the new concepts (capability and capability indices) are introduced. Introducing these through this applied scenario may assist in maintaining engagement, emphasising conceptual links, and making limitations apparent, such as the assumption of a normal distribution.

#### 2.3.2 'SwitchedOn' – Light bulb reliability

In this example, techniques were introduced to assess the reliability of light bulbs. The company was introduced, and students were asked how to assess the proportion of bulbs likely to fail within 1 year from data collected over a shorter timeframe. After discussion, students suggested subjecting bulbs to more stressful conditions than those encountered in normal use to increase the failure rate (accelerated testing). Example data was then presented, an appropriate lifetime distribution used to model data and the model scaled-back to normal operating conditions. From the model derived, the proportion of bulbs expected to fail in 1 year was calculated.

Reliability engineering can be a challenging topic for many engineering students, requiring use of a range of mathematical tools and models that may be perceived as overly abstract and incomprehensible. Starting from an applied scenario aims to make apparent from the start the purpose of the techniques learnt. The mathematical links between concepts such as *failure rates*, *lifetime distributions*, and *reliability* can subsequently be explained within this context after the concepts themselves have been introduced. As with the previous example, the use of software to analyse concrete numerical data may help students link abstract models to physical quantities, potentially illuminating the conceptual structure and illustrating practical application.

#### 2.3.3 'The Cheesy Company' and 'Roped-Up' – Extended case studies

Across multiple lectures, two extended case-studies were used to review and apply techniques learnt and to extend student comprehension building upon prior learning. The first revolved around a cheese manufacturing company and their attempts to optimise the quality of their cheese and improve efficiency. The second centred on a manufacturer of ropes for use in rock climbing and ensuring quality and safety after a change to manufacturing processes. Each week during lectures, students were provided with relevant data for one or both case studies. Working in small groups, they analysed the data using techniques learnt in previous weeks to form conclusions and make practical recommendations.

As well as reviewing prior content, the use of these extended case studies across multiple weeks linked together the methods learnt, elucidating conceptual links between, for example, factor effects, hypothesis testing, probability distributions and capability. In this way, students were provided with an

opportunity to practice techniques and their application with the aim of consolidating knowledge and preparing for assessments.

#### **3 DISCUSSION & EVALUATION**

The module described demonstrates how practical scenarios may be used to scaffold learning. These scenarios aim to assist students in constructing conceptual understanding of numerical and analytical techniques drawn from mathematics and statistics. Simultaneously, students may be better enabled to apply the techniques learnt in real-world contexts. This is consistent with recommendations from the literature to utilise problem-based learning focussing on mathematics applied to real-world problems [1] and upon learning mathematical concepts in the context of engineering applications [6].

A further advantage of this approach is its potential to engage students. To assess this, student feedback was gathered by two means. The first was a survey targeted at evaluating the effectiveness of an extended case study activity used in lectures. Responses were collected pseudo-anonymously from 43 students. These generally indicated a favourable attitude, with most students indicating that they enjoyed the activity (84%), that it helped them to engage (81%) and to understand the topic (86%). Of the remaining respondents the majority were neutral in their responses. Respondents commented that they found "the opportunity to work collaboratively ... [helped them] understand the application of techniques", that it "helped put the topics into practice", and that it cemented their knowledge and reassured them regarding their use of techniques. Others stated that it was a useful preparation for assessments and the opportunity to explain topics to their peers helped them to understand content themselves. The main criticism was that the time provided to complete tasks was limited and that they would have preferred the opportunity to explore the scenarios in more depth. The second method of gathering feedback was through a standard module survey issued to evaluate all modules at Nottingham Trent University. In this, 97% of respondents indicated their overall satisfaction with the module. Students commented that they "understood how these methods can be applied in real life", that they "really like the consistent use of examples", and that the module "gave [them] the chance to actually use this knowledge in real-world-like scenarios". Others suggested that case studies could be made more relevant to manufacturing or engineering processes in their discipline.

This approach does present its own challenges, not least of all the difficulties conceiving suitable applied scenarios that make use of the appropriate methods to be learnt. This may necessitate the use of simplified 'toy-model' examples to enable students to access the problem-scenario and extensive scaffolding. Few real-world engineering scenarios are sufficiently symmetric to yield to a basic analysis at a level suitable for a first introduction to the area. Simplicity is essential to ensure students can access the relevant concepts and are not distracted by irrelevant features or noise in data. As competence and confidence grows, further detail may be added and scenarios evolved toward something more realistic. Equally, the range of students to be taught must be considered to ensure the scenarios themselves do not present difficulties for students from a diverse range of backgrounds. This may require time in taught sessions ensuring the scenario has been clearly conveyed. The use of images to illustrate can assist as can the choice of examples or contexts with which students are familiar.

Finally, mastery may require students to subsequently practice techniques in isolation to ensure they are sufficiently ingrained and procedural knowledge is consolidated. Once basic conceptual comprehension is attained, not all practice need be in the context of a practical scenario as this may slow learning and distract from developing technical competence. However, it is recommended that practical scenarios continue to be frequently used to ensure the link to practice is maintained.

#### **4** CONCLUSIONS

In this paper, an approach to teaching technical content has been illustrated in which instruction begins from practical applied examples. The use of practical scenarios helps students to construct relevant conceptual frameworks, orientating them toward content appropriately from the outset and laying out the context clearly. The background assumptions feeding into concepts are made apparent by providing a concrete starting point and linking abstract concepts to measurable quantities underlying them. The basic comprehension thus developed may subsequently be used as a scaffold to further develop concepts. As students continue to practice the techniques learnt, further use may be made of practical scenarios to build confidence, consolidate conceptual understanding, and appreciate real-world application.

This approach cannot be automatically translated to the teaching of other technical content but will require some effort to generate suitable scenarios which are accessible to students while effectively

capturing the concepts and techniques to be learnt. However, it is hoped that the above analysis demonstrates how an approach centred on practical scenarios as the basis for learning may be achieved and will provide motivation for other educators.

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# TRANSFORMING UNIVERSITY SERVICES: THE EFFICACY OF ENGINEERING LEAN SIX SIGMA TECHNIQUES

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#### ABSTRACT

This paper explores the transformative impact of employing engineering Lean Six Sigma techniques within the context of a university. The study focuses on an examination of several pilot process improvement projects in various service areas of a university located on the southern coast of the UK. Executed over 18 months, allowing both the implementation of improvements and the subsequent analysis of their effects throughout an academic period. This approach yielded a substantial corpus of quantitative data. The utilisation of key engineering tools such as; Value Stream Mapping, Swim Lanes, and Control Charts, played a pivotal role in streamlining processes. Resulting in, significant reductions in processing steps, leading to process enhancements ranging from 12% to 59%, and, in some instances, achieving 100% completion rates. These improvements were further validated by Value for Money measurements, exhibiting gains from 8% to 50%, although the quantification of these gains, was more challenging in certain projects, due to their unique nature. It was often difficult to define the specific data sources and outputs required in these non-traditional engineering environments. Nonetheless, this study underscores the importance of clear comprehension of the Voice of the Customer and Critical to Ouality requirements, with active stakeholder engagement, irrespective of the size or nature of the project. In conclusion, the application of Lean Six Sigma methodologies, beyond traditional engineering realms, proved to be a resounding success. This marks the initial steps in a larger journey, where incremental improvements lay the foundation for growth and a staged shift in organisational culture.

Keywords: Transformation, lean, Six-Sigma, service, improvement

#### **1** INTRODUCTION

Universities, like any other complex organisations, face challenges in delivering efficient and effective services to students, faculty, and staff. In recent years, there has been a growing interest in applying Lean Six Sigma (LSS) methodologies to; optimise processes, improve quality, and enhance overall performance within academic institutions. While traditionally used in manufacturing and engineering sectors, LSS has demonstrated its applicability in various service industries. This paper aims to explore the efficacy of engineering LSS techniques in transforming university services, focusing on pilot process improvement projects, conducted at a university located on the southern coast of the UK.

Thus, seeking to leverage engineering theories as catalysts for regeneration and transformation. Showcasing the versatility of these techniques, and their ability to enrich a broader spectrum of the curriculum, than initially envisioned. Therefore, providing a valuable model, that can be used to expand engineering education within higher education, beyond its traditional technical remit.

### **2 LITERATURE REVIEW**

#### 2.1 What is Lean Six Sigma?

LSS is a combination of two well established techniques; with Lean focusing on reducing waste and Six Sigma focusing on Solving Problems. Li et al [1] state that this combination can be used "to reduce waste, improve flow, reduce variation for improving customer satisfaction." They continue to explain that it is design "maximizes shareholder value" and "can be a very powerful problem-solving methodology in tracking process inefficiency." With Alblooshi et al [2] backing this up, explaining that "combining them will result in a powerful tool that can be used for eliminating variation and waste".

This is then expanded on by Davidson et al [3] in regard to Higher Education, with them focusing on how it is;

"a powerful continuous improvement methodology that HEIs may leverage to improve administrative, academic and development processes."

The main LSS process used to improve a current process for complex and high-risk problems is Define, Measure, Analyse, Improve, and Control (DMAIC). How important this structured problem-solving process is to "provide preventative and corrective action" was further explored by McDermott et al [4]. With O'Reilly et al [5] explaining how the use of DMAIC and a data-driven approach was a key turning point and Li et al [1] consider it a "breakthrough point".

#### 2.2 Use of LSS in Higher Education Institutions (HEIs)

Furtherer et al [6] explains how LSS is gaining traction as an improvement processes HEIs as it allows "collaborate objectively with stakeholders to improve a variety of processes". The importance of this is backed up by Li et al [1] highlighting that;

"Higher education as an industry faces many challenges that have impacted other sectors: increased cost, a reduction of resource support, declining student base, resulting in an overall context for change."

How this is undertaken can be of significances; O'Reilly et al [5] highlighted that;

"Linking projects to not only strategic objectives .... but also, to plans to implement this strategy at lower levels proved fundamental to success in the targeted areas."

There is clear evidence of how LSS projects have benefited HEIs; with Furterer et al [5] highlighting how alternative scenarios were developed and tested, that otherwise, would have been too expensive and taken too long. Also, Wheeler-Webb and Furterer [7] being able to reduce time to invoice by 38% and Davidson et al [3] reaping benefits to quality outcomes. Panayiotou and Stergiou [8] sum it up well explaining.

"The benefits underlined in the cases studied in this paper lead to the inference that LSS can have the positive impact that the theory describes in practice"

Wheeler-Webb and Furterer [7] expanded on this, stating.

"Although LSS has traditionally been successfully applied to manufacturing environments, this project demonstrated the value of applying LSS in higher education."

#### 2.3 Further LSS work in HEIs required

Even though evidence exists on how LSS can be of great benefit, Li et al [1] points out it.

"Has not been widely adopted by many universes and colleges due to the traditionally misconception that it is only meant to for manufacturing companies."

It is also highlighted by Panayiotou and Stergiou [8] how low the proportion of papers on LSS produced in Europe is, and that there is a clear need for more LSS publications. Davidson et al [3] found that the majority of projects with HEIs are student-facing or focus on administrative processes "which provides a limited amount of empirical evidence of its use in the sector". They continue that there is a need "to identify contextualised best practices and generate opportunities for benchmarking in the sector." The urge to use LSS, to realise similar gains and improvements, was mirrored by; Li et al [1], Alblooshi et al [2], Davidson et al [3], Furterer et al [6], Wheeler-Webb and Furterer [7] and Bhat et al [9].

#### **3 METHODOLOGIES**

The study conducted an analysis of several pilot process improvement projects, undertaken at the university over an 18-month period. This was to provide time for both the implementation of improvements, and the subsequent analysis of their effects, throughout a new academic period. These projects encompassed various service areas, including; student support services, academic services, estates, marketing, sustainability, and human resources. The diversity and scope of options, were carefully assessed to provide a comprehensive overview, and grasp of the viability of embarking on an engineering-style improvement project, within the broader university context. Several potential project charters were submitted to a panel and subjected to comparative analysis. Subsequently, a choice was deliberated upon, to optimise the likelihood of success and comprehension, throughout the research pilot phase. Taking into consideration the most cited LSS requirements, as found in research by Alblooshi et al [2], Figure 1.



Figure 1. Categories of the requirements of LSS applications

The implementation of engineering LSS techniques, involved the utilisation of key tools, such as; Value Stream Mapping, Swim Lanes, and Control Charts. Data collection methods included quantitative analysis of process metrics, such as; processing times, error rates, and completion rates. Stakeholder engagement and active involvement, were crucial throughout the project lifecycle, to ensure alignment with the Voice of the Customer and Critical to Quality requirements. Each of these projects investigated and used appropriate data collect and sampling strategies, that were applicable to the size and type of the problem, that they were tasked to improve.

# 4 CASE STUDIES

Of the 12 process improvement projects that were selected for the pilot, due to the page limit constraint, five of the most significant will be used as Case Studies within this paper. That is to provide a clear understanding to the tools used, a rounded picture of achievements, issues and lessons learnt.

#### 4.1 Measuring sustainability in the procurement process

Aligned with the University's strategic plan, which places sustainability as a focal point, this project aimed to integrate sustainability criteria into tenders, for all procurements exceeding £25000. The Voice of the Customer (VoC) methodology was employed to establish a Merit Ranking system for evaluating potential improvements. A before-and-after Swim Lane analysis, depicted in Figure 2, and facilitated by a Gemba Walk for a comprehensive perspective, was utilised to identify areas of waste. The project yielded notable successes, including evident time savings (Figure 2) and a 100% process completion rate (Figure 3). Key insights gleaned from the project, underscored the importance of data clarity in both sourcing and presenting outputs for project success. Additionally, it was recognised that this was just the initial phase, of a broader journey, towards sustainable procurement practices.



Figure 2. Swim Lanes



Figure 3. Completion Control Chart

#### 4.2 Reporting and Tracking of Value for Money (VfM) Initiatives

Since 2022, the university has been mandated to fulfil regulatory objectives concerning VfM, and to demonstrate to the Office for Students (OfS), its delivery of value, to students, taxpayers, and the broader community. Non-compliance with these requirements could potentially lead to the loss of millions in grant income. Given the complex nature of this project, the establishment of a Supplier-Input-Process-Output-Customer (SIPOC) diagram, and a Responsible-Accountable-Consulted-Informed (RACI) Assignment Matrix, was essential to gain a clear understanding of the stakeholders involved. Tools such as; the Fishbone diagram, 5 Whys, VoC, and Swim Lanes were employed to define the problem and devise a solution.

Given the project's focus on VfM, conducting a Value-Added Flow Analysis was paramount in crafting a new reporting process, Figure 4, which resulted in an increase of nearly 8%. Due to the project's

complexity and significance, it was imperative to adopt an incremental approach, and ensure its success to cultivate a new LSS culture within the university.



Figure 4. Value for Money

#### 4.3 Reduction of ineligible student appeals and complaints

The process revealed challenges in stakeholder engagement, particularly during the initial stages, suggesting that an alternative approach, from the project's onset, might have been more effective. However, with the guidance of the Project Sponsor, it became feasible to outline the project's scope following initial setbacks. Stakeholder mapping, as illustrated in Figure 5, was subsequently conducted utilising power-interest ranking and a RACI. Further refinement of stakeholder engagement, ensued through a Gemba Walk and Value Stream Mapping (VSM), to identify Value-Added (VA) and Non-Value-Added (NVA) processes, the outcomes, of which, are shown in Figure 6. This was supplemented by a convenience sampling student survey, to comprehensively capture the VoC; as depicted in Figure 7. Leveraging various LSS tools, a solution was devised resulting in a process improvement of 12.07% and a monetary saving exceeding 50% per prospective appeal.



Figure 5. Stakeholder Mapping

Figure 6. Value Stream Mapping



Figure 7. Voice of the Customer

#### 4.4 Estates Contractor Sign in Project

In the project's initial phases, a comprehensive Stakeholder Analysis, Mapping, and RACI were conducted to precisely delineate the problem. The existing state was assessed through a SIPOC analysis, Gemba Walk, and Swim Lane Diagram, with data gathered from a sign-in sheet and analysed to calculate time taken. This analysis resulted in the initial sign-in times (red plot line) and mean value (grey dash line) on the Control Chart, as depicted in Figure 8.

Subsequent data analysis involved utilising a Cause-and-Effect Mind Map, employing the 5 Whys technique, and constructing a Pareto diagram to identify critical inputs. A Force Field analysis, was then employed to identify potential barriers to change, ensuring a smooth implementation process. Figure 8 demonstrates the project's success, evidenced by a notable reduction in sign-in times (green plot line)

and mean value (gold line). The reduction in mean processing time from 4.4 minutes to 2.62 minutes, a decrease of 59%, resulted in an increase in the process sigma value by nearly one level (0.9).



Figure 8. Comparison Control Chart

#### 4.5 Human Resource Management Information Reporting Improvement Plan

However, not all projects have achieved the desired level of success. Some have necessitated extensions beyond the initial pilot phase. As Li et al [1] asserts, "commitment from top management is always a critical success factor for LSS," highlighting the importance of leadership support in LSS initiatives. Additionally, they note that management may sometimes "jump to solutions and conclusions directly instead of following the DMAIC process." This tendency was evident in this project, leading to delays in identifying the true root cause of the problem at hand. Furthermore, this management approach resulted in inadequate project sponsor support, and confusion regarding the identification of the true customer, exacerbating delays and complicating stakeholder engagement issues that persist.

Nevertheless, despite the challenges and competing demands on time, there exists a clear roadmap forward, which is anticipated to facilitate the completion of this project during the second phase of process improvement initiatives. This underscores the importance of addressing management-related issues and ensuring robust stakeholder engagement for the successful execution of LSS projects.

#### **5 RESULTS**

The implementation of engineering LSS techniques, within the pilot process improvement projects has yielded notable enhancements across various university service domains. As depicted in Table 1, a comprehensive summary of project process improvements, ranging from 12% to 59% showcases significant progress, with a project achieving 100% completion rates. However, calculating precise VfM measurements posed challenges in certain projects. This is due to their unique data sources and outputs, particularly in the non-traditional engineering environment. This complexity is particularly pronounced in customer-facing service organisations, such as HEIs. Nonetheless, Table 1 provides a summary of results, indicating gains ranging from 8% to over 50%, and up to £23,407/annum, despite these measurement challenges.

Project	<b>Process Enhancements</b>	Value for Money
		Measurements
Measuring Sustainability in the Procurement Process	100% process completion	£357/annum
Reporting and Tracking of Value for Money (VfM)	45.5%	7.86%
Initiatives		
Reduction of Ineligible Student Appeals and	12.07%	50% +
Complaints		
Estates Contractor Sign in Project	59%	£3.8k/annum
Human Resource Management Information	Not yet compete	Not yet compete
Reporting Improvement Plan		
Website Creation: Time Reduction	34%	£940.30/website
Automation of Right to Work Checks	56%	£23,407/annum
Exploring the Effectiveness of Current Mental Health	49%	Hard to quantify due to
& Wellbeing Support		nature of project
Improving efficiency in Placements Booking Process	52%	£1400/annum

Table 1: Summary of Project Process Enhancements and Value for Money Measurements

Policy Influence: Volume, Quality and Effectiveness	16% in engagement	Hard to quantify due to
	28% in outputs	nature of project
Timetable Data Gathering	48%	£2,380/annum
Reduce the Time Spent on Completing the Fees	36.6%	£805/annum
Reconciliation		

# 6 DISCUSSIONS AND CONCLUSIONS

The findings of this study underscores the effectiveness of engineering LSS techniques in transforming university services. By streamlining processes and enhancing quality, LSS methodologies have contributed to improving the student experience, reducing operational costs, and fostering a culture of continuous improvement within the university. The importance of stakeholder engagement and clear comprehension of customer requirements cannot be overstated, regardless of the size or nature of the project. It was something that caused issues and delays in nearly all the polit projects, to a greater or lesser extent.

In conclusion, the application of engineering LSS techniques has proven to be a resounding success in transforming university services. This marks the initial steps in a larger journey towards organisational excellence, where incremental improvements lay the foundation for growth and a staged shift in organisational culture. It is often very difficult to prove a change in organisational culture, however, demonstrating that LSS has be successful in these projects, means it could clearly be tested in other contexts. Moving forward, universities must continue to embrace LSS methodologies to drive innovation, efficiency, and excellence in service delivery. Crucially, fostering a culture that encourages open communication and thorough problem definition before solution implementation will be pivotal.

Future endeavours, already agreed upon, include embarking on a second phase of process improvement initiatives. These endeavours are expected to; elevate the visibility of LSS, propagate its success stories, and enhance stakeholder engagement. Additionally, the initial project leaders will assume the role of LSS Champions, facilitating workshops and developing training programs, to deepen understanding and adoption of LSS principles. This approach aligns with the LSS philosophy of starting small and leveraging successes to nurture a culture of continuous improvement, within the university setting. Through these concerted efforts, a robust LSS culture is anticipated to take root and flourish, driving sustained enhancement across university operation efficacy.

This paper gives a clear demonstration of how an engineering process can act as catalyst for regeneration and transformation for strategic and cultural improvements throughout an established HEI.

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# DESIGNING AI-ENHANCED TEACHING PRODUCTS FOR UNIVERSITY OMO CLASSROOMS

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# ABSTRACT

The purpose of this paper is to study the current situation of the OMO (Online-Merge-Offline) teaching model in universities and propose solutions. Although there are numerous studies on the analysis and design of OMO learning environments, few have assessed their effectiveness from the perspective of enhancing design quality. Based on the Social Presence Theory and Quality Function Deployment method, the study identifies the pain points and needs of university students and teachers in the OMO model and conducts functional transformation of user needs in terms of offline terminals and online teaching platforms. The paper presents a set of OMO classroom AI-enhanced teaching interaction products that can improve teaching convenience, presence perception, and student engagement. These products aim to provide a reference for improving OMO teaching interaction quality and applying emerging technology in real-world scenarios.

*Keywords: Online-merge-offline (OMO) classroom, AI-Enhanced interactive classroom products, Quality Function Deployment (QFD), KANO-model, social presence theory* 

# **1** INTRODUCTION

With the rapid development of information technology, the education industry is experiencing unprecedented changes. OMO (Online-Merge-Offline) teaching mode is playing an increasingly important role in the field of engineering and design education and updates the demand for educational interactive products. From the perspective of improving design quality, the purpose of this study is to provide an in-depth analysis of the status of the OMO teaching model and to explore how to optimize the design of instructional products through the integrated application of AIGC (Artificial Intelligence Generated Content) technology. Figure 1 shows the research framework and technical route of this paper.

During the research process, we started with the analysis of our design object, using QFD (Quality function deployment) and KANO-model which can help satisfy the requirements, reduce changes, and decrease the design period to identify the user needs. AIGC was used as a tool to help realize the goals and functional iterations while performing the PDCA(Plan–Do–Check–Act) cycle, and the final design outcome is an educational product that meets the needs of the OMO.

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Figure 1. Research framework and technical approach
## **2 LITERATURE REVIEW**

OMO teaching mode is student-centred, to open up various structures, levels and types of data in online and offline, virtual and real learning scenarios through technological means, to form a scene ecology of online and offline fusion, and to realize a new teaching pattern of personalized teaching and services [1]. Currently, OMO teaching and learning in universities are mainly carried out by online live platforms (such as *Zoom* [2], *Teams* [3], and *Classin* [4]), offline assistive products (such as *Smart Classrooms* [5], *Seewo Whiteboard* [6], and teaching support platforms (such as *Learning Link* [7] and *Google Classroom* [8]). However, OMO teaching paradigms in engineering and design education confront many problems, such as how to keep online and offline teaching content coherent and promote student interest and effectiveness from online learning. In addition, engineering and design education requires the teaching model to develop students' innovative and practical abilities as well as knowledge, which raises OMO model implementation requirements.

Technology advancements and hybrid teaching methods have led to the use of various products to support OMO teaching. Along with established tools like smart classrooms, cloud classrooms, and teaching apps, newer technologies such as virtual reality and digital twins are also being incorporated into hybrid teaching. Gu Yanhua et al. [9] investigated the application of virtual simulation technology in hybrid teaching using college courses as a case study. They developed a virtual simulation practice teaching system and demonstrated that virtual simulation teaching positively impacts teaching effectiveness through practical application. Chai Huifang et al. [10] developed a smart classroom framework with different layers and applied it to university settings to improve smart classrooms in the "post-epidemic era".

Meanwhile, AI technologies provide new ideas to solve the problems in the OMO teaching model. AIGC can generate personalized learning resources based on students' learning data to enhance the interactivity and relevance of online learning. For example, by analysing students' online learning behaviours and performance, AIGC can automatically recommend learning materials suitable for students' levels or generate targeted practice questions.

## **3 THEORETICAL FOUNDATIONS AND RESEARCH METHODS**

## 3.1 Social Presence Theory

The social presence theory has its roots in the Community of Inquiry (CoI) model proposed by Garrison in 1999 [11]. The CoI model proposes a theoretical model for sustaining the teaching and learning experience in higher education as it moves into a computer-mediated environment and states that the teaching and learning experience is comprised of three essential elements: cognitive presence, social presence, and teaching presence.

#### 3.2 Quality function deployment (QFD)

QFD is mainly composed of two major parts: Quality Deployment and Function Deployment. Within the framework of QFD, KANO-model was introduced to determine the impact of the presence or absence of different product features on the ultimate satisfaction of users. The Kano model is designed to understand the relationship between the performance of product features and the subjective perception of the user through a questionnaire. Through better-worse coefficient calculation, the quality characteristics of the product are classified into Must-be Quality, One-dimensional Quality, Attractive Quality, and Indifferent Quality. It is to differentiate the positioning of different features in the product and to be able to optimize the product iteration and upgrading based on this feature [12].

## 3.3 Quality Management PDCA Cycle

The PDCA cycle, also known as the Deming Cycle, is a management method for continuous improvement, which consists of four consecutive phases: Plan, Do, Check and Act. In this study, the PDCA cycle is mainly used to combine the development of modern technology to Cyclic the part of user satisfaction, to realize the iterative upgrading of functions.

#### **4 NEEDS ANALYSIS**

#### 4.1 Interviews to Obtain User Requirements

In OMO education, teachers, online students, and offline students are the main users of teaching products and have different needs. This study conducts demand interviews with four teachers (3 females

and one male, who have rich experience in teaching foreign languages in universities) and students (2 females and two males, who have experience in OMO learning) with different backgrounds. By analysing the content of the interviews, we initially obtained the users basic needs of the OMO teaching process.

## 4.2 Categorizing User Requirements Using the KANO-Model

A user satisfaction questionnaire based on user requirements elements was created and distributed to the target users. Based on the valid questionnaires (n=33), combined with expert interviews, users were asked about their satisfaction with the function from both positive and negative aspects. The Better-Worse coefficients of each function were obtained after calculating the data (see Figure 2 for the calculation method). A coordinate system is drawn with the absolute value of Worse as the horizontal axis and Better as the vertical axis. The coordinate system is partitioned with the intersection of the mean of the absolute value of Worse and the mean of Better (0.220, 0.445) to obtain the Better-Worse matrix [13] for the classification of the demand attributes, as shown in Figure 2. In the design of the subsequent products, the priority order Is ①Must-be Quality, ②One-dimensional Quality, ③Attractive Quality, ④Indifferent Quality.



Figure 2. User needs distributed on KANO-Model

## 4.3 Functional characterization using QFD methods

After analysing the user requirements by KANO-Model, we got the categorization of the demand attributes and the satisfaction grading of the teachers and students in the OMO experience. According to the theory of social presence it decomposes and transforms the needs and gets the functional characteristics. Further, using the QFD method, we constructed a quality house. Through the quality house analysis, the functional matrix of the relationship between functional characteristics and user requirements is obtained (as shown in Figure 3). For example, one of the user's needs, the real-time image of an online classmate, has a strong correlation with a target score of 5 for the function-OMO holographic hardware.



Figure 3. OMO Quality House Modelling

The results of this study provide a reference for the main functions of teaching product design in the subsequent OMO teaching model. Platform-wide message alert, Multi-view playback, Turning on audio/video with one click offline, OMO holographic hardware, Curriculum data analysis, Multi-view switch, and Strong reminders for online interactions, which are strongly related to user needs will be

focused on in the subsequent design. At the same time, the other functions will not be innovated based on simple design.

## 5 INTELLIGENT DESIGNING OF AI-ENHANCED PRODUCTS

## 5.1 Constructing Product Design Objectives

We first sorted out the general OMO class process and drew a flowchart from the perspectives of three participants: online students, offline students, and teachers; from the three aspects of time: before, during, and after class (un-highlighted part of Figure 4).



Figure 4. OMO Teaching Model Complete Objective Process

Then, the research team designed a specific kit for OMO class, named OMO! Pro-Sense Superman OMOPSS). It consists of an offline companion terminal and an accompanying online integration platform. The design objectives of this kit for different subjects in the OMO classroom are mainly shown in Table 1. These objectives were then implemented into specific aspects of the OMO classroom (shown in the highlighted part of Figure 4).

Target Group	Goal	Solution		
		Real-time holography, presenting images of		
		online classmates		
Tanchar	Balance the difference in their focus	Distance design, individual control		
Teacher	on online/offline classmates	terminals		
		Strong reminders for online student		
		questions		
Online student	Make it an immersive classroom	Self-adjusting omnidirectional camera		
Onnie student	experience	Personalize the perspective of your lessons.		
	Deduce the difficulty of their	Real-time holography to facilitate group		
Offline student	interactions with their online	discussions		
		Monolithic matching to move the		
	classifiates	corresponding terminal on demand		

Table 1. Summary of functional design objectives

## 5.2 PDCA Cycle for Function Iteration

After arriving at a preliminary list of features, the research team re-examined the reasonableness of each feature and iteratively upgraded it by using the PDCA cycle method to combine AI technology with some of the features (See Figure 4 for details of the Integrated application of AIGC).

## 5.3 Proximity-based offline terminal design

From Garrison et al. (2000) who proposed the online community of inquiry model [11], it is known that the main methods to enhance the sense of presence in the OMO classroom are: course design and organization, facilitation of discussion, and direct instruction, etc. These methods are dependent on the

individual teacher's pedagogical skills. But in terms of generalizability, enhancing the presence of online students from the perspectives of sight, sound, and touch, so that the distance between the classroom's member units is perceived, thus increasing the possibility of interaction.

The OMOPSS offline terminal (Figure 5) is controlled by online students, and it tries to use technological means to stereoscopically the images of online students in the offline space. Its underlying use logic is that each terminal can be paired with an online classmate in the offline teacher's classroom space. It should be emphasized that, because the current holographic projection technology is not yet able to fully achieve media-free stereoscopic imaging, it is possible to add the required media projection screen based on this program when considering landing.



Figure 5. OMOPSS Design

In offline spaces equipped with OMOPSS terminals, teachers can place offline terminal in the front row of the classroom and wait for online matching. After successful pairing, online students can control the camera of the OMOPSS to follow and adjust the viewpoint (as shown in Figure 6). This will greatly enhance the presence of online students in the offline space and increase the possibility of interaction between online and offline students.



Figure 6. How to use the OMOPSS

## 5.4 Online Integrated Platform Design

Based on the functional settings of offline terminals, the research team accompanies the design of the online integration platform (Figure 7). The most important function of the platform is to help online students control the offline terminal devices and to assist the classroom in better online and offline interactions. To continuously maintain the learning status and enthusiasm of online students, the students' overall classroom performance will be evaluated by AI tools, and appropriate suggestions will be given. This approach helps students improve their learning methods and continues to promote the progress of the course and the student's personal progress.



Figure 7. Student homepage of the OMO! Online platform

## **6** CONCLUSIONS

Based on the online presence and improving design quality, this paper finds the user demand points through the KANO-model and derive them into the QFD user demand satisfaction indexes and determine the product characteristics that need to be focused on the design.

The research results can help teachers improve their focus on the online learner groups under the OMO teaching mode, strengthen the connection between offline and online learners, and promote the equality of offline and online learner groups participating in teaching activities in OMO teaching. At the same time, the research results explore new AIGC application scenarios by adding AI technology and upgrading functions, which are still insufficient but focused, so that the research results are basically in line with the research objectives. The results are a useful attempt to innovate software and hardware products under the OMO teaching mode.

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# THE ROLE FOR AI IN A COIL PROJECT INVOLVING FAST FASHION, PERSONAL FLOATATION DEVICES, AND A LMIC COMMUNITY

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#### ABSTRACT

This paper explores the use of artificial intelligence (AI) in collaborative educational design projects across three continents, interfacing fast fashion with design standards to produce affordable and functional life-saving interventions for artisanal fishing communities. The paper details the methodology of three educators from Germany, Canada, and the UK in co-designing a project brief using AI-generated prompts. Each author explored the use of AI with an agreed initial prompt and how much effort they had to expend to correct the generated brief with further prompts. An evaluation matrix was used to determine the effectiveness using key criteria such as technical accuracy, logistics, alignment to learning outcomes and feasibility. The discussion and conclusion propose a need for a model and framework for use in the application of AI in the development of content for educational projects and investigation into the efficiency of the process. Next steps refer to the authors' intention to run the proposed COIL project in 2025 to test the outputs generated to ascertain if they meet, not only the needs of educators and students but most importantly the beneficiaries of the interventions produced.

*Keywords: Personal protective equipment (PPE), extreme textiles and co-teaching, COIL learning formats, AI, design methods, LMIC and integrative design* 

#### **1** INTRODUCTION

Balancing collaborative design learning formats is extremely relevant to emerging EU regulations and new 'EU Standards' by the European Parliament (Green Deal and the Green Claim Directives). Extreme textiles and new bio-based material-design, represent only one case of businesses in design that focus on the provision of functionality. These are countered with fast fashion-based textiles and their prevalence in society and problematic performance and abundance. Within this frame, our aim is: scoping a transcontinental collaborative design project for student groups to support experimenting and learning across three continents – using AI in textile design engineering - for creating with different methods across different competency levels. This submission provides the background, process, and scope for a Collaborative Online International Learning (COIL) design project involving intercultural design skills, that seeks insights to: What is the role for AI in integrative design? What difference does it make in this context?

Defining the project across three continents is a challenge that requires navigation of learning and designing formats, alongside rapidly emerging technologies (AI). The role of AI in design project development and project management will be researched, by experimenting and comparing different generative design methods. Within the post-digitalisation phase, we could have taken benefit from interlinked learning landscapes [1], providing the technical frame for working intercontinentally across and within students design groups, but the reality of undertaking this project will be the proof. And we realise the need to extend collaboration to AI since the speed of development of AI-based creation tools is faster than the training of scholars, students and teachers in the modified media landscapes within the universities. [2]

#### **2 BACKGROUNDS**

Artisanal fishing communities in Lake Victoria Tanzania experience very high drowning rates. Research on Lake Victoria carried out in 2018 showed very high levels of drowning amongst communities living around the Tanzanian shores of the lake. Here the average drowning rate across all villagers is found to be 231/1,000,000, and if the population is narrowed down to fishers, it reaches a rate of 1,505/100,000[3]. The results of research undertaken to date and discussions with key stakeholders including those most affected by drowning, reveal the highly risk-based behaviour response to fishing as a livelihood amongst marginalised and small-scale (artisan) fishers.

Affordable and sustainable quality lifejackets, which are widely evidenced globally as a risk reduction intervention are not available to the fishers and The Royal National Lifeboat Institution (RNLI) is working with partners in Tanzania to design and develop solutions that address the high burden of drowning amongst artisanal fishing communities.

The RNLI is leading the creation of a bespoke design process to create interventions to reduce the risk of drowning. Combining both traditional research methodology with human centred design tools, a process has emerged which brings together all those with an interest in a problem and allows them to work collaboratively to create sustainable solutions. One of the authors professional practice roles (at the RNLI) is leading a project to address this need for affordable buoyancy and with contacts made at E&PDE is scoping a multi-institution student collaboration 'COIL' project with the remaining 2 authors institutions. It is hoped that this COIL project will not only inform the issue but also allow students from 3 different countries to work with community stakeholders, drowning prevention practitioners and fashion and textile experts.

Community and government stakeholders have agreed that, as well as addressing the need for a lifejacket that is designed and manufactured to international standards, at-risk communities should have access to resources that enable them to produce personal and group buoyancy devices locally.- Communities have welcomed the idea of using several water bottles incorporated into a fabric shell to provide this solution and it is with this in mind that the idea to link fast fashion with technical buoyancy came to the authors. Fast Fashion and protective apparel are an unlikely coupling, and ethically incompatible in the long term, but in the context of this paper, the authors consider the supply chain of fast fashion textiles. The reduction of fast fashion consumption and responsible spending behaviours among consumers has both microlevel and macrolevel implications [4]. While the fast fashion industry continues to feed a mass audience, only a few consumers possess a comprehensive understanding of the harmful effects of fast fashion on the environment [5]. Research shows that young adults aged 20 to 26, are motivated to express uniqueness through fashion, while being cost-conscious, which leads to compulsive buying habits [4]. The starting point for this design project in protective apparel is primarily to address an incountry need to reduce the risk of drowning in Tanzanian fishers, while secondarily raising awareness of the impact of these buying behaviours in a global context.

Today, within the fields of 'design engineering – in special textile design engineering' discipline, creating with AI only in CAD-systems as 'conventional trained' at this moment. Questions about the power of AI co-pilots, and who would feed faster and more data for textile engineering, that prompts could be used soon, are in our time. Everybody could use Chat GPT, but how to use this in a resilient, beneficial manner? And if we, as three teachers, with different expertise and background are collaborating with AI, who will evaluate to what kind of technical accuracy, contextual validity and presentation? All this didactically, pedagogically and strategic perspectives have to be analysed and reflected for the academic purpose and at the same time for project management perspectives for creating extreme textile design solutions - within complex conditions [6].

Why COIL? For this collaboration, the authors embraced this initiative for its approach that brings students and professors together across cultures to learn, discuss, and collaborate as part of their class. COIL enables students to foster their global competencies through an intercultural learning environment that links classes in different countries. Using various communication technologies, students from different countries complete shared projects, with faculty members from each country co-teaching. With COIL, Educators work together to define the learning goals, the length of the interaction, the comparative and collaborative activities, methodologies and tools, and how student learning will be monitored [7]. This scoping paper in 2024, will make some experiences with Chat GPT for AI generated briefings and reflecting these to be continued with COIL project in 2025: In 2025, for all three student groups - from three different countries - we will give briefings and intro based on this pre-generated design project, brief generated with Chat GPT 2024.\*

#### **3 EDUCATOR METHODOLOGY - CO-DESIGNING**

Many studies have indicated an increase in the workload of academics. Jordan & Layzell [8] suggested that academic staff in Arizona work on average 50-60 hours per week, which includes 30 hours of teaching. This suggests that any way of reducing the amount of time spent on non-teaching activities as well as ensuring high quality curricular outputs, would be welcome. Educators spend a lot of administrative time and effort designing design briefs, yet they also express their teaching style and pedagogical approach. Thus, raising the questions; how much confidence do educators have in AI to generate design briefs, including technical accuracy, contextual validity, ethics, logistics and presentation. The 3 authors set out to design a project brief via AI that addressed the following needs:

- Benefit a real-world problem given by a 'live brief' (sustainable and effective buoyancy)
- Utilise the expertise of the authors and students from each academic institution
- Remove ambiguity and satisfy the learning outcomes for each unit at each academic institution A hypothesis based on the Authors' research, experience and assumptions, could read: providing AI

A hypothesis based on the Authors' research, experience and assumptions, could read: providing AI with more information through prompts generates a higher fidelity brief. In this context - technological fidelity is relevant - addressing the degree of correspondence between the input and the output and the time and energy required to achieve a 'prototype' brief. For the purpose of this paper, the authors sought to address the fidelity of the brief by evaluating for accuracy, feasibility, ethical and cultural relevance, structure and logistics. A 10-point framework using a rating of 0 (strongly disagree) to 10 (strongly agree) was developed and applied to each statement, by each author. Cumulatively, a higher score overall would translate into less time needed to 'revise' the brief prior to use.

Basic prompt:	Additional prompts:
Prepare a design brief for a group of 20 design students in each of 3 different countries to address the problem of buoyancy for Tanzanian fishers using fast fashion materials.	<ul> <li>The equipment designed should be able to be manufactured in Tanzania.</li> <li>The project should be designed to be completed in 7 weeks and suitable methods identified and assessment criteria produced.</li> <li>Fishers from Lake Victoria Tanzania will be available to answer student questions throughout the 7 weeks.</li> </ul>

The following section outlines the characteristics of each educator, their student group, and how they applied the prompts. The results of their evaluation are presented in the section following, in addition to the insights generated.

Author 1 Profile: The expertise and competencies of German teacher reflects the perspective of ongoing handling in this topic and gives reason for the academic ongoing: The background expertise as industrial designer and master tailor for textiles since 30 years, consultancy of sustainable material design since 20 years and as teacher since more than 15 years, argues for interdisciplinary designing in all design disciplines, and arguing for hands on designing in balancing with digital helping media [9]. Author 1 is an academic researcher, professor about design theory, with focus on sustainability in design /-education and with focus on textile applications in all design disciplines. The interdisciplinary interlinking design methods are of interest in the European design field. [10]

**Method:** Author 1 used evaluated design methods and adjusted them by looking at human embodied experiences and cultural background. Designing experiences' by Rossman and Duerden [11] supports that we as *human designer* (Wachs) have to shape the AI instruments, before they will shape us [12]. By designing experiences with experiments and comparisons, design thinking combined with hands-on designing: this interdisciplinary complex process is the reason that the German group of design stakeholders sought to compare the ONE prompt generated for all three groups in advance) for the AI-generated brief for the design task with analogue design management processes. In addition, it is pedagogically significant, when the students gain knowledge by didactically evaluation, to reflect on comparing the analogue generated brief with the Chat GPT AI-generated brief. Author 1 used <u>https://chatgptx.de/</u> because it is free and does not require registration.

Author 2 Profile: Author 2 is an academic in soft and hard product design and engineering at a Canadian university. The author's professional practice and research area is in the technical field of design for extreme environments and human resilience in the face of the changing climate. Projects to date include cold water extrication, passive thermal rewarming and various protective equipment for high-risk environments. The students are undergraduates completing a 4-year degree program with industry

involvement and a focus on hands-on prototyping, material and usability testing, sustainability and manufacturability (technical packs).

**Method:** The author 2 first carried out an early 'scan' of the topic; AI-generated 'background' content, using the relevant keywords framed into questions an Educator asks students in the early stage of scoping a project; such as: Q1: 'how do fast fashion and buoyancy relate'; Q2: 'what materials are used in personal protective equipment for fishers'; Q3: 'what textiles are available in Tanzania'; and, Q4: 'what are the materials of fast fashion?' The author then used the group-agreed prompt guidelines. Content was generated via AI sources (<u>https://chat.openai.com/</u>).

Author 3 Profile: Author 3 is an academic in design and engineering at a UK university. The authors professional practice and research area is in the technical field of international drowning prevention where they currently lead projects including the reduction in risk for Tanzanian artisanal fishers and preventing drowning of newly mobile under 2-year-olds in Bangladesh.

**Method:** The author 3 used the group agreed prompt guidelines and first searched for literature that provided best practice in this area. Eager, B., & Brunton, R [13] provide some guidance in their paper on prompt methodology and the author adapted the prompt.

#### 4 CO-EVALUATING AI: RESULTS AND KEY INSIGHTS ARISING

In Table 1 we provide the framework and results for evaluating and exploring the possibilities of Chat GPT for textile design/ing multi-country project briefs solutions in the future; *How much effort does the educator need to expend to correct the AI generated brief and is it worth it?* How is it responsive to the problems identified (fast fashion, life-saving buoyancy devices for Tanzanian fishers) while speculative of new applications? Other parameters include the Sustainable Development Goals (SDG's).

Author 1 Insights: On the one hand, we are looking forward to evaluating the 'correct' data, resulting in design solutions, created by AI. On the other hand, AI is an effective helping hand for designing complex solutions - not only for buildings in architecture [14]. It seems to be time efficient -with restriction by trial and error, it seems to be a democratic tool, when everybody gets access to open AI, it is bridging the geographical gaps and supporting diversity and togetherness [6]. But we have seen as well, that by integrating ONE defined prompt in one same software tool (open AI) we got different solutions, different structures of the design brief. And the question raises: what about the evaluation, who will decide that ethical [15] and technical correct data could be extracted by the result? This has to be discussed further for a practice-based project, and specifically for the project scoped in this paper, across three institutions, countries and two continents with different policies and procedures.

"The Design Brief"	Author 1	Author 2	Author 3
is technically accurate.	6	7	7
aligns to SDGs	9	5	5
addresses contact hours and course logistics.	8	8	7
is clearly scoped.	8	7	6
is implementable.	5	8	8
is feasible.	8	7	7
addresses cultural aspects relevant to the project.	9	8	7
mediates know ledge about extreme textiles.	9	8	8
meets ethical requirements.	3	5	5
provides structure and the presentation is clear and explicit.	8	9	8
TOTAL evaluation score /100	73	72	68

 Table 1. Evaluation framework for the AI-generated briefs using 0-10 point scale (0: strongly disagree to 10: strongly agree)

Author 2 Insights: The cultural context of the brief wasn't addressed by the basic prompt and required further details to incorporate full relevance of designing for/with Tanzanian fishers. The timeline in the AI generated brief was set at 15 weeks with the basic prompt and only reset to 7 weeks with the added prompts, which raises questions about the scoping of projects and their feasibility within the collaborating institutions against the meta-content from which AI draws. Deliverables shifted substantially, but not necessarily more relevant, despite the expanded prompts. With a single basic prompt statement, issues of scalability were included through a sustainability report, which was not included once expanded prompts were added, thus educators would need to review these carefully.

Author 3 Insights: The first agreed iteration of the AI prompt used was surprisingly good with suggested itinerary, outputs and assessment criteria close to what the BU author would of suggested, however the AI missed or assumed that the students would have knowledge of the technical buoyancy requirements of artisanal fishers and the technical understanding of buoyancy as a force. Further prompts were used to refine the brief, including; "Design a schedule for the above allowing the students to spend 8 hours per week on the project." Either the AI didn't understand the further prompt or the author didn't write the prompt in the correct format. It was found that changing the prompt was more effective than adding additional prompts after the fact. The author also noted that more emphasis should be placed on the structural and buoyancy properties of the product and the iterative testing for this.

Returning to the core questions: What is the role for AI in integrative, intercultural design? What difference does it make in this context? Does It extend beyond logistical challenges to address EN/ISO standards vis a vis affordability/sustainability? Sharing methodologies on the development and application of AI prompts, and then discussion of the emergent brief, generated high levels of reflectivity on issues of educator confidence, fidelity, intellectual property, quality and ultimately did the AI help with collaborations and refereeing between the educators? Is there a need for a proposed model and framework for use in the use of AI in the development of content for; a LMIC community needing buoyancy solutions for fishers (SDG 3+14)? How Does it reflect intercultural design skills (SDG 5+17).

#### 5 DISCUSSION AND NEXT STEPS

The design didactic purposes of this COIL-scoped project are to be applied to master and bachelor students, in cohorts of 10 to 25 participants, who will design together, using co-creation methods [16] in multidimensional working locales to support new design competences. Students will be invited to experiment with prompts and reflect on the outputs alongside hands-on textile repurposing for protective equipment, alongside new extreme textiles of buoyancy, will provoke the students to lean into the humanity of extreme environmental conditions. Design through multidimensional working stations (hands on designing, prototyping, scoping with Rhino, and Chat GPT) the students will: analyse Tanzania's fishers working conditions and safety needs for buoyancy alongside the availability of textiles resulting from fast fashion dilemma (from landfills, filled by European fast fashion transfer, to collecting institutions).

In the next step, the co-authors will develop an AI generated collaborative project in REFLECTION on the decisions that should be made for sustainable material performances - for extreme textiles - with ethical new standards [6]. By collectively adopting collaborative design formats (as supported by COIL) for inner-student groups, and for across cultural institutions, countries and continents - we aim to further develop 'cross cultural learning landscapes' [17] because 'working in interdisciplinarity within a new research field today generates a new discipline of tomorrow' [1]. This approach to integrative design [18], involving reflective insights into how to bridge the challenges in different understandings, different perception of material and cultural behaviours, is also a first step in addressing perceptions of different ethical values, while also providing an opportunity to investigate the role of AI in creating new ethical standards in designing transcontinental solutions for humanity [19] projects across cultures.

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# A SYSTEMATIC REVIEW OF THE ROLE OF AI ARTIFICIAL INTELLIGENCE IN DESIGN EDUCATION

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## ABSTRACT

With the advent of GPT-3 in 2020 and the development of artificial intelligence (AI), scepticism persists among educators regarding its role in design education. This study uses a systematic literature review to locate and summarize the core papers from 2020 to 2023, categorizing the role of AI in design education. Following the PRISMA method, 38 papers were selected for review. The research reveals the potential impacts of AI on developing students' design skills, perceptions of AI applications among students and teachers, and challenges in implementing AI technologies. Drawing from these findings, the study proposes implications of AI on both the practice and theory of design education. By shedding light on the current state of AI integration in design education, this research aims to inform educators, policymakers, and stakeholders about the opportunities and challenges presented by AI technologies. Based on the research results, this study proposes the impact of artificial intelligence on design education.

Keywords: Design education, systematic literature review, Artificial intelligence (AI)

## **1** INTRODUCTION

Don Norman highlighted the increasing complexity of modern design, which traditional education does not cover. What we need is not "teaching outdated methods and skills" [], but rather education that addresses the inherent instability of the current environment. To ensure design makes a constructive contribution, design education must continuously evolve []. Since the advent of GPT-3 in 2020 [], AI-based methods have the potential to reduce the complexity and subjectivity of tasks in design education. AI is an emerging interdisciplinary field [], transforming teaching design and student learning in modern design education []. From a technical point of view, AI focuses on specific applications that support learning, teaching, or management []. From the user's perspective, AI assists teachers in facilitating student learning []. Educators believe that using AI can enhance the effectiveness of learning structures and academic systems []. The application of AI in design education can provide technical support and data information for teaching [7]. Currently, the potential of AI in teaching design education is just beginning to be explored []. There is limited understanding of AI's complex role in teaching and learning processes []. Therefore, this paper focuses on outlining the current applications and potential shortcomings of AI in design education. It specifically addresses the following research questions.

Sub-Question 1: What AI tools and techniques have already been used in the learning and teaching of the design discipline?

Sub-Question 2: What new changes have been brought to the learning and teaching of the design discipline through the introduction of AI tools and techniques?

Sub-Question 3: What difficulties and challenges do educators and students face when using AI tools and techniques in design classrooms?

## 2 METHOD

Systematic literature reviews, compared to traditional literature reviews, involve a more rigorous process of literature retrieval and selection. They are aimed at identifying, collecting, analysing, and synthesizing all available publications relevant to a specific research topic or question through unbiased search strategies []. Therefore, this study adopts this method to (1) summarize the existing evidence of the impact of AI on design education, (2) address the sub-questions posed earlier.

## 2.1 Search strategy

In the first stage, we queried the core journals in the Web of Science and Scopus databases using the refined search strings shown in Table 1. We recorded and collected the initial search results from the databases using Excel sheets, eliminating duplicate versions. Following the criteria in Table 2, we evaluated the relevance of abstracts and conclusions; if they were irrelevant, we reviewed the introduction section. For cases that remained uncertain, a thorough examination of the full text was conducted to ensure the selected studies were highly relevant.

Database	Queries					
resource						
WoS	Topic = ("AI" OR "AIGC" OR "Generative AI" OR "Artificial intelligence") AND					
	Topic = ("design education" or "design course" or "design courses" or "design					
	student" or "design learner" or "future designer" or "design students" or "design					
	learners" or "future designers" or "design teaching" or "teach design" or "teaching					
	design" or "design learning" or "learn design" or "learning design")					
Scopus	Keywords, title, Abstract: "AI" OR "AIGC" OR "Generative A" OR "Artificial					
	intelligence" AND keywords, title, abstract: "design education" OR "teach design"					

Table	1.	WoS a	and .	Scopus	search	aueries
i ubic		,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,		ocopus.	0000/01/	queneo

In the second stage, a manual screening of references from candidate literature, known as snowballing [], was conducted. The purpose of this manual search was to enhance the representativeness of the literature and ensure that all important studies were noticed. Google Scholar was used for this stage, and the full texts were evaluated based on the criteria in Table 2. Eventually, 38 articles were selected to be included in this study.



Figure 1. PRISMA flow chart

## 2.2 Literature screening criteria

The final 38 articles retrieved were subjected to full-text reading, data extraction, and mutual comparison, followed by the calculation of reliability among the raters. The purpose of data extraction was to analyse and extract useful information from each study, while data synthesis involved organizing and synthesizing the extracted data to provide an overview of the results [].

Includes the following publications	Excluded publications			
These studies should be relevant to AI-enabled	It is not closely related to our research			
design education.	background and questions.			
Provide the full text in the target database	No full text			
English writing	Duplicate version, other languages			
Published in the last four years (2020, 2021,	Published in 2019 and before			
2022, 2023)				

Table 2. Description of inclusion and exclusion criteria

WoS core literature	Non-WoS core literature
These studies should be published publicly.	Unfinished and unpublished research.

We utilized the PRISMA method table to ensure comprehensive and transparent reporting of this review []. The SPIDER qualitative evidence synthesis tool was employed to guide the development of a systematic search strategy suitable for addressing non-quantitative research questions. The MMAT method was used to assess the quality of each accepted paper, and scores were categorized as high, moderate, or low quality based on the matrix [].

## **3 DATA ANALYSIS AND FINDINGS**

After carefully reviewing the full text of the original research, data extraction is conducted to analyse and extract useful information from each study. Data synthesis involves organizing and synthesizing the extracted data to provide an overview of the results [14]. During the data synthesis process, studies with similar research topics are grouped, such as related concepts or impacts. Previous studies have identified three basic modes of AI in knowledge processing: knowledge representation, knowledge acquisition, and knowledge deduction []. Building upon this foundation, the study categorizes the searched papers into three dimensions: (a) Design Representation: using AI to enhance the presentation of design outcomes; (b) Design Deduction: using AI to assist in design education; (c) Design Acquisition: using AI to support the design process. By further organizing and synthesizing the extracted data, statistical results for the years 2020 to 2023 are summarized as follows: In terms of the target audience, there are 30 papers targeting university student design education and 6 targeting professional designers. Among the papers, 11 are theoretical research, and 27 are empirical studies, with 11 being quantitative research and 27 being qualitative research. Detailed analysis results will be provided in the next section.



Figure 2. Search document classification schematic

Design education is an emerging interdisciplinary field, and the intervention of AI has complex and diverse impacts on it. AI has the potential to fundamentally transform educational practices by altering the roles of teachers and students and enhancing assessments [9]. AI's influence on teaching in the design discipline will manifest in three aspects: providing new perspectives on sensory experiences, introducing new concepts for products and services, and shaping new discourses on lifestyles. With the deepening application of AI technology, the field of design is poised to undergo significant changes in artistic presentation []. While AI can liberate designers from many traditionally logic-based tasks, the core decisions still rely on human designers. AI significantly enhances the originality, practicality, manufacturability [], and novelty of design outcomes, and it may also lead to the next paradigm shift in design aesthetics [27].

#### 3.1 Artificial intelligence tools and technologies involved in design education

The literature search reveals that AI-Generated Content (AIGC) is the primary AI technology used in design education. Students utilize tools such as ChatGPT [], Stable Diffusion [19][20][21][22], Midjourney [19] [][][], DALL [20][21][22], and Kinectt [10] for classroom assistance, coursework, and self-study. AIGC is the most common application of AI in design education, with its content generation technologies encompassing text, images, audio, video, code, games, 3D, and multimodal content. AIGC is integrated into various design teaching scenarios. It is becoming a more efficient and convenient content creation method, following Professional Generated Content (PGC) and User Generated Content (UGC).

## 3.2 Changes brought about by artificial intelligence technology

AI provides students in design classes with unique visual stimuli and design concepts, aiding in the development of sustainable and innovative designs and enhancing creativity. Fiebrink et al. found that machine learning-based courses and tools can offer students new creative outputs, means of self-expression, and better economic benefits []. AI-ADT studied the optimization of art and design curricula in higher education institutions within an AI context, finding that AI-enhanced design education methods exhibit characteristics such as intelligence (98.1%), flexibility (96.5%), performance (93.6%), engagement (94.9%), and interactivity (95.1%) [].

AI has transformed art and design education, providing new ways to create, explore, and learn in nontraditional design classrooms [20]. The target audience for design education includes students, professional designers, and design enthusiasts. Amateur designers can access a wealth of information through the internet and social networks, enabling informal, non-institutionalized learning practices []. In design projects, designers' roles are increasingly diverse, focusing on core interactive tasks and datacentric responsibilities [].

Additionally, AI tools can detect plagiarism in art and design projects, promoting academic integrity [20]. The application of AI in art and design education will evolve in several directions: facilitating creative collaboration through intelligent tools and platforms, supporting real-time cooperation, providing creative inspiration, and enhancing teamwork [10].

#### 3.3 Stakeholders face difficulties and challenges in the use of AI

Many design students worry about their careers being replaced by AI, as AI can generate designs directly. This raises questions about the role of teachers in design courses. When students rely too heavily on AI, how can teachers ensure they maintain independent thinking and creativity? The emergence of AI demands higher capabilities from students and teams, prompting changes in teaching methods and curriculum content.

AI's integration into design education has caused professional anxiety among stakeholders, with growing public discourse on mitigating AI's negative impacts [26]. There is a mismatch between industry needs and AI-generated products [19], leading to anxiety among design students about AI-driven job loss. Some studies predict that 20% to 50% of future jobs could be "lost" to AI [25].

The teaching paradigm for AI in design education is still undeveloped. There is no consensus on what AI knowledge design students should learn or how to integrate this knowledge with creative and aesthetic design skills []. While progress has been made in providing accessible resources for beginners, there is a lack of specialized materials or courses to guide designers, and many are unsure how to envision AI's future in diverse ways [24]. A significant issue in design education is that "traditional design" skills and computer-aided design (CAD) skills are often taught as separate paradigms that do not overlap with traditional teaching systems [25].

With the rapid development of AI technology, design students and collaborative teams face higher demands. Communication barriers and differences in AI tool usage are becoming more prominent [26]. Students encounter challenges in AI-assisted design, and some teams avoid engaging with AI altogether []. To address these trends, design students need not only design expertise but also interdisciplinary integration, lifelong learning abilities, and foundational knowledge in AI and big data. Senior designers, in particular, should master AI programming and data modeling algorithms to guide machine design [].

## 4 **DISCUSSION**

This literature review summarizes three new ways AI has been integrated into design education over the past four years: design representation, design deduction, and design derivation. It systematically outlines the impact of AI on design education. The influence of AI in this field is evident in practical outcomes, the roles of teachers and students, and issues of social reputation. In design representation, design students can use AI to develop innovative solutions, improve user experiences, and optimize design outcomes. In design derivation, AI serves as a supplementary tool to enhance learners' creative toolkits []. In design deduction, AI can transform design education practices by altering the roles of teachers and students and refining assessments. Additionally, AI involvement positively impacts educational equity, public aesthetic improvement, and the democratization of design education.

Most studies in this review focus on analysing and identifying patterns in existing models to summarize trends and make predictions. At this stage, there is almost no evidence directly linking AI-driven design teaching to improved teaching and learning quality. An important function of this systematic review is

to describe the current situation and explain the impact. It encourages researchers to explore more empirical studies on the development and implementation of AI in design education, aiming to broaden our understanding of the reasons and mechanisms behind this dynamic evolution.

## 5 CONCLUSIONS

AI and related machine learning concepts and technologies have expanded design education [27]. AIGC, an emerging mode of multimodal content generation, has been fully integrated into design education. This integration demands higher standards, including interdisciplinary integration, lifelong learning, and collaborative human-computer interaction skills. Consequently, designers must not only master design expertise to solve problems using AI tools in team collaborations but also adapt to the challenges brought by technological innovations. Future research could explore the impact of AI on stakeholders in design education, using quantitative and empirical studies to measure the extent of this influence.

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# BACK TO BASICS? TECHNICAL DRAWING, SKETCHING AND VISUAL COMMUNICATION IN THE AI ERA

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#### ABSTRACT

This paper focusses on the teaching of technical drawing practice across multiple engineering disciplines, in particular first year teaching where there is a common approach to the delivery of core subjects, such as design. The paper critiques current drawing practice and questions its suitability in providing modern, equitable and inclusive learning for a diverse range of students. The paper also investigates the development of Artificial Intelligence drawing tools which threaten the application of fundamental drawing skills. The conclusion of the paper recommends a more pragmatic approach to teaching fundamental drawing skills to assess students core understanding.

*Keywords: Sketching, drawing, inclusivity, equality, Artificial Intelligence, machine learning, automation* 

#### **1** INTRODUCTION

Technical drawing and communication is a key aspect to engineering education. Many generations of Mechanical Engineering students in the UK have referred to various editions of Engineering Drawing Manuals [1] to support their learning of engineering drawing, such to a point that 'BS8888' and the 3<sup>rd</sup> angle projection symbol has been ingrained into their psyche. As part of a dedicated module, it is as common as Maths and Mechanics. Students at Imperial College London learn how to "Produce industry standard engineering drawings on CAD" as part of Design & Manufacture 1 and a core part of the module syllabus is 'Design Representation' through drawing and sketching. At Oxford, drawing and design forms part of a first-year engineering science student's practical work. Across the Atlantic Ocean, Junior Mechanical Engineering students at Stanford learn sketching and orthographic projection as part of ME 102: Foundations of Product Realization. For 1st year students studying engineering in the UK, swapping a calculator for a pencil and asking them to draw can be a challenge. Most engineering courses in the UK ask for A-levels in Math's and Physics for entry requirements. In most cases, an A-level in Design & Technology: Product Design is a 'good to have' for most Mechanical, Aerospace and Civil Engineering courses. Unless students have an A-level in Art & Design, or an extracurricular interest in sketching, its unlikely many students would be entering their first year of engineering as confident drawers (unless they make a special effort on graphs or free body diagrams to look nice). Thankfully, technical communication is not an 'art class', nor is it to be associated with the level of representation and sketching ability required for product or industrial design. For an engineering student, a low fidelity level of sketching is sufficient, if it is clear and represents an idea or the design features of the product well. Where more nuanced skill is required is the interpretation & representation of engineering drawings in orthographic projection with the inclusion of key features and dimensions. Such skill is important for producing drawings in both freehand sketches and CAD, providing information to workshop technicians for prototyping, as well as manufacturing drawing. Civil Engineers and Architects also use this visual language, where the elevation, side-elevation and plans of buildings, bridges and other infrastructure can be clearly communicated to clients and stakeholders. Electrical engineers also use 2D drawings to show diagrams and schematics, with standard conventions, rules and symbols. As engineering disciplines become more integrated (for example, there are combined Mechanical and Electrical Engineering courses) such fundamental skills are becoming common across disciplines. For Mechanical Engineering students at Imperial College, much of what they learn is based on what other students in similar courses would learn in an introductory Design and Manufacturing module, for example, the design of shafts and machine components, parts and assemblies, and technical drawing practice that aligns closely to manufacturing (including variation and tolerancing). At institutions such as Oxford, one may expect a broader approach, given the nature of some courses allows students to specialize in engineering disciplines later in study. Drawing a detailed transmission shaft and learning about geometric and dimensional tolerancing on a lathe may not be the best introduction to technical communication for a Civil Engineering student (some Mechanical Engineering courses can be somewhat obsessed with shafts). As with any general engineering curriculum, there needs to be a balance of nuanced disciplinary practice, and aspects that are broader across all engineering disciplines. Students from across all engineering disciplines benefit from understanding fundamental principles of Engineering Math's, Engineering Science, Experimental and Lab work, as well as the core design and professional practice. This is where a refreshed approach to engineering drawing and technical communication can be utilized.

#### 2 A DIFFERENT APPROACH TO TECHNICAL DRAWING

How can a design educator ensure basic competency is met, while providing an engaging series of drawing exercises that will keep beginners and experienced students engaged and challenged? Imagine if students were given a very simple shape or object to communicate using 2D and 3D drawing; what are the basic components that are required? What would the reader of a drawing be looking for? Looking at the type of manuals commonly used for drawing teaching [1], there is a significant amount of information on drawing management, manufacturing, IP and standards (this is before there is any drawing content). Typically, the principles of first and third angle orthographic projection are what needs to be understood first, otherwise anything beyond that is redundant. It is a foundational principle that engineering students need to understand, and one that is quite difficult to explain. Understanding orthographic projection requires good spatial visualization skills and mental rotation. Differentiating between first and third angle projection is also important for a 21st century engineer, as overseas supplier or archived part drawings may be presented in an alternative format. It's important to note that there is no 'correct' way between first vs third angle, much in the way that other nations across the world drive on different sides of the road. It's also important to note that some CAD packages may be installed as either first or third angle projection as default. In the design module, students were introduced to both, and in some exercises were given the opportunity to choose between first or third angle projection, as long as it was clearly indicated in the drawing. Exercises using augmented reality were useful here, to show the rotation of a simple object on paper and limited the reliance of physical artefacts in a large class (although technical hitches and reliance on smartphones/apps limited the inclusivity of this tool.). Tools such as Augment & Vuforia can be used to help students to see how 3D objects are oriented and rotated in orthogonal views, but the accessibility of such software is questionable (Augment is only accessible via a subscription). Understanding the orientation of an object on the page and how views are aligned is a pivotal first step in the technical drawing process. Dimensioning principles are also fundamental, students may have drawn a shape correctly, but there is no information on how big/small the object is. Equally, when specifying a manufacturing or construction drawing, incorrect or missing dimensions would cause confusion and costly mistakes. Using correct notation is also important, to distinguish between diameters and radii, as well as centrelines and centre-marks. If certain features of the object are obscured, for example, a screw hole which can only be seen from a plan view, hidden detail or section views need to be considered. Hidden detail has its merits, but for immediate clarity a section view is superior. Being able to slice through an object and see what is going on inside helps provide immediate clarity for the reader of the drawing. In the world of 3-dimensions, isometric views are very common in engineering (they are the default projection method for most CAD packages) and benefit from being easy to understand when converting from 2D orthographic drawing to 3D and back again. However, there are other projection methods with their own merits. Oblique is another projection method which, apart from isometric, is described in BS and ISO standard manuals [1] but introducing dimetric and trimetric projection provides the context that isometric projection sometimes needs. While isometric projection is useful, for some applications it often provides a skewed perspective which can trick the reader's eyes (anyone who is familiar with the Penrose stairs or stared at a complicated exploded assembly for too long will understand). Dimetric provides a good example of foreshortening to provide proportion and a sense of realism to an object. As such, when students in the module had become familiar with the basics of 2D drawing, the core axonometric views were introduced and explored. From such technical manuals, and bearing in mind the scope and timescales, what is not necessary? This is where

any mechanical engineers reading the paper may become upset, but it was deemed that tolerancing, limits and fits and surface finishing would not be covered in the module for two reasons i) it was conceivable that a student who does not understand orthographic projection may be able to understand tolerancing, and ii) none of the students had learned anything about manufacturing yet. Therefore, there had to be a line drawn between visual communication using 2D and 3D projection methods, and additional drawing details for manufacturing drawing. The same can be said for nuts, bolts, screws and washers, as well as keys and keyways (shafts again). To support this argument, there are other, broader manuals to technical drawing, which focus more on Civil Engineering practice [2]. Here, there are references to 'elevations' and 'side elevations' terms that students would use in construction drawing. As such, when describing orthographic projection, these terms were used interchangeably. Such technical manuals also refer to projection methods (but not specifically 1<sup>st</sup> vs 3<sup>rd</sup> angle projection) as well as section views (used heavily in construction drawings to show detail and different materials). There is also a broader description of axonometric 3D projection methods. To challenge more experienced students, the module provided a topic on perspective and freehand drawing. This helped students understand the principles behind foreshortening and further develop their 3D sketching skills. Overall, it was to help students naturally draw a freehand sketch without the need for tools.

#### **3 THE FUNDAMENTALS OF TECHNICAL COMMUNICATION**

Based on the requirements of a basic approach and the commonality between drawing manuals used in both Mechanical and Civil Engineering practice, one may define the universal fundamental principles of technical drawing as follows:

- Orthographic projection in 1<sup>st</sup> and 3<sup>rd</sup> angles.
- Technical annotation and dimensioning (inc section views)
- 3D representation (using isometric and other axonometric views)

From this, a simple assessment rubric can be developed, based on the students understanding of each core topic. Particular focus and weighting should be given on orthographic projection and technical annotation and dimensioning. A core part of any assessment was that there would be an expectation that students would meet all these criteria, using a checkbox rather than grade boundaries. Either the student has understood these principles, or they have not. As such, a series of exercises that are constructively aligned to be at this minimum level of understanding is necessary. As such, gateway assessments such as PASS/FAIL modules are appropriate, as it is irrelevant to provide an exercise where students drawing ability be graded from 'good' to 'exceptional'.

#### 4 21<sup>st</sup> CENTURY APPROACHES IN DRAWING TEACHING

One of the first issues that an educator needs to consider is the redundancy of the drawing boards. A2 drawing boards are cumbersome and take a significantly long time to collect, set up and put away in a class. Drawing boards are also not the most portable of devices, which raises the issue of students wishing to continue drawing work outside of class, or practice at home.

A3 college boards, which were lightweight and transportable, can be considered. However, they can be costly compared to the other drawing equipment (pencils, rules, set squares) students are provided with, and deemed unnecessary for the short time students could be using them. Instead, students can be provided with an A3 booklet, which contains all the necessary drawing exercises and information students needed, as well as grid and iso paper for 2D and 3D drawing respectively. Students can also protect their exercises and keep them safe, rather than use loose sheets of A3 paper. (See Fig 1.)



Figure 1. Example of drawing exercise from booklet

The first week of a drawing class needs to focus on fun and help students appreciate drawing again, this should mainly focus online work and circles, encouraging students to draw big shapes on paper and with confidence, before moving onto orthographic projection. Students should be given preparatory exercises to help them understand each topic. Educators may consider using a 'verbally described' object as a method of exercise that allows students to 'graphically ideate' the object in their minds before putting it to paper, as its simple to copy across 2D information to 3D and vice-versa. The verbally described object provides an opportunity for discussion and comment. Another exercise that students can engage with is a peer assessment exercise, where students can submit a 2D drawing of a simple shape or object they have created themselves anonymously to a peer, with the peer then having to interpret the object and draw it in 3D. This form of exercise helps reinforce the true meaning of technical drawing, communication. To draw and interpret/read a drawing are part and parcel of this visual engineering language-and one can never understand the effectiveness of clear communication without someone to speak to. Students can be assessed on fundamental principles using a very simple shape (e.g. a cube with a cylinder and some key features). The complexity of the shape should be kept to a minimum to focus on key drawing elements. An important factor of the shape is that it should never be visually shown to the students, it is verbally communicated throughout class to encourage students to imagine the shape (graphic ideation) & draw out a basic sketch, while providing more details and fidelity to allow the students to progress. See Fig 2.



Figure 2. left-orthographic view of shape right-isometric view of shape with half-section

#### 5 FREEHAND DRAWING VS CAD-THE ADVENT OF AI

A debate that goes as far back as 20 years ago [3] is the merit of computer aided drawing against freehand drawing. With CAD packages, students can create accurate technical drawings from their laptops without the need for using drawing boards, printing booklets as well as drawing equipment. However, while students may gain a better appreciation of an object in 3D, technical drawings produced from CAD are 'automated', in that users don't really need to think about the orientation or placement of views as the CAD package achieves this for them. Equally, many CAD packages allow users to import dimensions straight from their 3D model to the 2D drawing. However, there is still some thought and skill required to complete a CAD drawing. One can argue that drawing in CAD does not produce the same level of 'cognitive modelling' that hand drawing achieves. It's also important to develop and improve core 3D visualization skills, which have been identified as fundamental to engineering education since the beginning of the 21st century [4]. Once students achieve sufficient skills in 'spatial visualization', they need to work on their 'mental rotation' and mental transformation' skills which are essential for technical drawing and putting ideas onto paper. As such students were given fun & engaging tests such as PSVT: R (Purdue Spatial Visualisation Test-Rotation) to develop their 3D manipulation/mental rotation skills. Encouraging students to draw a verbally described object allowed students to imagine the object in their heads (rather than copying a 2D or 3D form) which in combination with seeing visual objects & the act of drawings allows all visual imagery to be complete [5].



Figure 3. Cognitive modelling of 2D to 3D & back to 2D [3] & McKim's model of visual thinking [5]

One observation that can be found with CAD drawings is the same fundamental mistakes with hand drawing can be made on a CAD drawing, for example, not aligning principal views or using the incorrect project methods (although students arrive at these mistakes much quicker), especially if students are not familiar with the more advanced drawing tools provided with the software. When students gain more competency in CAD, producing engineering drawings from CAD parts and assemblies can seem like an afterthought, an extra set of tasks on top of all the work put into modelling. When one considers a complicated assembly with many subsequent sub-assy and part drawings, it can represent a significant amount of time and work. The advent of AI-generated drawing tools seeks to reduce this semi-automated process. AI is not relatively new in the field of CAD, for example, Autodesk has been using AI tools for generative design, as well as automated markup and similar tools for AutoCAD. There has also been the recent development of AI tools and assistants for technical drawing, such as information retrieval and searches of large databases [6] or in some cases information extraction using machine-based learning approaches [7]. So far, the interpretation of technical drawing could be performed by a machine, but as of Feb 2024, Autodesk announced drawing automation in Fusion 360. Designers can now create assembly and part drawings at the push of a button, and with the placement of 'seed' dimensions, will then populate a drawing with associated dimensions. The designer still can select if dimensions are base dimensions as well as the origin, but fundamentally the AI tool places the views and attaches dimensions itself. While this process is relatively new in the field of mechanical engineering and manufacturing drawings, such tools have been used within Building Information Management (BIM) within the Civil

Engineering and construction sector, such as BricsCAD. The link between architectural drawing and reasoning, with early graphical output produced by AI techniques, can be traced as far back as 1996 [8]. The advent of cloud based computing and industrial demand for faster products to market has accelerated the need for AI tools and assistants with CAD and CAE.

#### 6 **RESULTS AND CONCLUSIONS**

A more pragmatic approach is required to assess the drawing ability of students. When implementing the techniques described in this paper within a first-year engineering curriculum, a PASS rate of 81% was achieved, and a minority of students failed the assessment despite all solutions being provided in class. A more rigorous approach was adopted the following year, with solutions for preparatory exercises provided but not for those that were assessed. A PASS rate of 75% was achieved, with some concerning observations. Many students did not provide dimensions on drawings despite being explicitly instructed to do so. There were also fundamental misunderstandings of orthographic projection that prevented students gaining a PASS mark. If the ability of technical communication was assessed on CAD alone, students may have passed the module without dealing with these fundamental errors. Feedback from students indicated that some found the drawing elements of the module enjoyable, while others struggled, stating they required more 'examples. There needs to be a focus on helping students understand these core principles from the outset, before they perform more complicated activities (for example, CAD drawings or advanced techniques). In conclusion, the revised approach to technical drawing has provided a unique insight into the way students understand technical drawing. Perhaps other approaches are too complicated, and students may fumble through a Design and Manufacturing module by doing well on other elements. It may be argued that some students 'go through the motions' without really understanding the fundamentals. Nonetheless, educators may find benefit in the findings of this paper by taking a step back and questioning what is important. Such exercises and approaches could be used for introductory or foundational drawing classes to help students understand the core principles of technical drawing. Such an approach is analogous to aspects of mechanics and thermos-fluids. Students are expected to understand the fundamental and core principles, beginning with analytical hand-calcs and free-body diagrams, but one would not argue that using computational methods such as FEA or CFD is 'cheating'. We are at such a paradigm with AI-drawing tools, which present challenges within engineering and design education within this area. Perhaps it is ample time to go back to basics.

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# USE OF ARTIFICIAL INTELLIGENCE IN THE PRODUCT DESIGN PROCESS. IMPACT ON THE DETAILS DESIGN STAGE

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#### ABSTRACT

Product design involves a set of stages; many methods may be used to resolve the different stages of the process, which are conditioned by the nature of the project or its magnitude. However, introducing artificial intelligence (AI) tools has significantly simplified this process. This research aims to identify the impact of one such tool, the Gencraft® artificial intelligence tool, applied in the details design stage and its implications in the teaching-learning process of students pursuing the Bachelor of Design degree. To achieve the research purpose, a sample of 22 students (two groups) in the sixth and eighth semesters of the Bachelor of Design program at Tecnologico de Monterrey, Mexico, was assembled to use the Gencraft® tool in the details design stage of their projects. After the exercise, the students responded to a survey-type instrument to assess the tool's impact and potential in the design process. The analysis of the responses identified that most students in both groups agreed that the tool could have much value in the conceptualization or ideation stage because the generated images look like product renders. This research affirmed that the artificial intelligence tool used was perceived positively by the students in their learning process as valuable and facilitatory in product design.

Keywords: Design process, Artificial Intelligence, CMFs, educational innovation, higher education

#### **1** INTRODUCTION

Due to the advances in Artificial Intelligence (AI) technology, generating images for different uses has been successfully simplified by giving textual instructions ("prompts") [1], [2]. This ability has led to the development of innumerable applications, ranging from art to education at different levels. Many of these tools allow going from text to image, offering excellent quality and making the interpretation of the prompts easier by writing with natural language [3]. In the case of education, generative artificial intelligence (GenAI) such as ChatGPT (Chat Generative Pre-trained Transformer) [4] and others have revolutionized how activities are carried out inside and outside the classroom, raising essential questions about what and how a subject is taught, why, by whom, and who does the work, in a constant search for efficiency; thus, over the years, many technological tools have shaped the answers to these questions and conditioned the primary purpose of education [5], [6].

These questions did not arise only with the emergence of Artificial Intelligence in Education (AIED) [7]. The slide rule, the calculator, the computer, and computer-aided design (CAD) [8] are other technological developments that have impacted education. Their use was initially prevented until they became necessary and mandatory within the teaching-learning process. The concern was not whether or not to use the tool, but how well a teacher knew to use it or how capable they were of leveraging it, that is, being as efficient as possible.

Like any technological proposal, AI still presents challenges, barriers, and opportunities to address from many perspectives [4]. In this sense, design (product, graphic, visual, industrial, engineering, etc.) is a professional discipline significantly impacted by this technology; it seeks to achieve the expected efficiency. With this premise, Huang et al. [8] suggest that AI can impact design through three "horizons": (i) in the approach of new sensory experiences, (ii) in the generation of new products or services that are conceptually different and (iii) in the reinterpretation of how people live and relate to the environment.

The product design process involves stages that generally start from detecting a problematic situation, a user's need, a client's requirement, etc. [9], [10]. However, many methods can be used to resolve the

different stages of the process, which are conditioned by the project's nature or its magnitude [11], [12]. Hanington y Martín [13] propose dividing design methods into five phases: (1) planning, scope, and definition; (2) exploration, synthesis, and design implications; (3) concept generation and first iterations; (4) evaluation, refinement, and production, and, finally, (5) a launch and monitoring phase. Moreover, besides the phases of the design process, in all cases, the time will come when the colour, materials, finishes (CMFs), or final product appearance must be defined [15]; therefore, there is a tendency to make iterations of the possible combinations of these elements with the idea that the product achieves the function as expected, that the user can interpret and perceive it in the way desired by the designer [14], and that it also meets the specifications or technical-productive requirements previously raised [9]. Likewise, in many universities, Product Design students usually receive a brief document that presents critical elements that must be met in the project [15], to which is generally added the link with a real user, a client, or a project applicant (also real), with imperative conditions that the final product must meet. At this point, specific artificial intelligence (AI) tools can impact by simplifying the process. In particular, this research aims to identify the impact of applying the Generaft® Artificial Intelligence tool for image generation in the detailed design stage (CMFs) and its implications for the teaching-learning process of students studying for the Bachelor of Design [8].

#### **2 METHODOLOGIES**

To begin this work, a literature review was conducted on using artificial intelligence in the teachinglearning process and the methods associated with the product design process [16], from which the main research question emerged. Once the purpose of the research was identified, a search was carried out for AI programs that could support the design process at some stage. From this search, the possibility of using Gencraft® for the Detail Design stage arose, considering that it is a tool that (i) offers excellent graphic or visual results and (ii) allows generating ten images daily for free. By this point, the students already had a clear conception of their proposed product. They had developed it without using AI in any previous stage of the process, so using the tool would not determine the product's general configuration but its appearance.

To achieve the research purpose, a sample of 22 students (two groups) in the sixth and eighth semesters of the Bachelor of Design program at Tecnologico de Monterrey, Mexico, was assembled to use the Generaft® tool in the details design stage of their projects, defining their CMFs. The students had developed their project as a team, but for this exercise, they were instructed to generate the images individually and each to decide the prompts they would give to the tool. They were asked to query the tool to create an image of their product, starting with only three prompts. Then they generated a new image, but this time with four prompts, and so on, to generate images from a total of 12 prompts, thus completing the maximum daily amount that the tool allows for free (10 images) with the idea that the generated images would look increasing more like the product they had designed. Thus, the prompts were refined so that the result continuously improved; the students paid particular attention to the colours, materials, and finishes (CMFs) [15] the tool produced in the images. After generating these, the students selected the CMFs they considered most appropriate for the product based on the design requirements they had established from the brief. Once the exercise was completed, a survey-type instrument was applied to the students [11], having four main themes: experience with the technology, ease of use, perception of image quality, and perception of the tool's value; the purpose was to assess students' perceptions of the impact of using the tool and the potential it could have in the design process based on their experience.

#### **3 RESULTS**

#### 3.1 About the application of the Al tool

As previously explained, the students individually generated ten images. Sometimes, these images increasingly resembled the initially designed product; however, in some cases, they exhibited no logical evolution but instead reflected something completely different as the prompts were added, possibly due to the students' lack of knowledge about the technology and lack of experience in using it, that is, not knowing the correct prompts to obtain the best result [1]. Below are three examples of image groups generated for each project and a brief explanation of each:

Table 1 shows the first example: the prototype made by the students, followed by some of the images created with AI, where comparisons help define the tool's contribution. This project consisted of a foot therapy product for older people.



Table 2 shows another sequence of images generated by AI. In this case, the project was a set of activities and products for occupational therapy representing objects of daily use in traditional Mexican cuisine. In the example, only the images generated for a single piece of the set are shown.

Table 2. The sequence of images generated by AI: Example 2



Table 3. The sequence of images generated by AI. Example 3



Table 4. The sequence of images generated by AI. Example 4



Table 3 presents another example of images generated for a playful and educational occupational therapy project for older adults. The final image shows the user interacting with the product, highlighting the intention of reflecting how the older person should use the product.

Table 4 presents the case of a product aimed at people of any age: a three-dimensional puzzle contained within a transparent sphere. The person must move so that a ball inside moves and reaches the goal. In this example, the images generated by AI largely maintain the CMFs' similarity in most cases. Still, despite the number of prompts, a logical coherence of all the elements is not indicated.

As seen in the four examples, the diversity of images generated does not necessarily correspond in principle (three prompts) with the base product. However, the exercise's idea was to use the tool to define the CMFs and not perform the product configuration in general. It can also be noted that the number of prompts increasingly impacts the similarity of the images to the initial proposed prototype.

#### 3.2 About the survey applied to the students

As mentioned above, an online survey was administered to the students at the end of the exercise. The survey contained dichotomous, Likert-scale, multiple-choice questions [19], and the students responded to questions about different aspects of using the AI tool. The 22 students answering the survey consisted of seven men and 15 women.

When asked about previously using AI tools, 92% said they had used some tools, and 8% said they had no experience. When asked if they had used any tool within a design process, 54% said they had used it previously in another project.

The students were asked when they considered it best to use this tool. 75% said it seemed best in the concept generation stage (stage 3). When asked (using a Likert scale where one represents "not at all" and five means "a lot") how much they considered that this was the best time within the design process to use the tool (stage 4 of evaluation, refinement, and production) and how much they could contribute at that stage, the result was precisely the same for both questions (see Figure 1). The highest number of students (30%) scored it as three, 24% as four, and 23% as five.



Figure 1. Comparison between moment and contribution

The students rated finding value in the tool to define the CMFs highly (according to the Likert scale where zero is nothing and five is a lot) in the three main elements (colours, materials, and finishes), appreciating the colour, where more than 60% rated it three or four, and the finishes, where more than 50% scored it between four and five; however, the materials also had a favourable rating although not as high as the other two elements, (see Figure 2).

Figure 3 shows the student's assessment of the tool's value to generate new ideas and more innovative proposals; in both cases, the evaluation is quite positive (according to the Likert scale where zero is nothing and five is a lot). This corresponds to those expressed previously when 75% said they thought it was better for conceptualizing. Among other things, students were asked if they would use the tool again, to which 54% answered yes. Finally, they were asked to rate the coherence of the images generated with the proposals they already had using a Likert scale (where one represents no coherence and five indicates a lot). Forty-six percent rated it two, and 38 % rated it three; this is considered a negative assessment of the tool regarding image coherence.



Figure 2. Comparison of value that students give to the tool to define CMFs



Figure 3. Comparison of the value students assigned to the tool's ability to generate ideas and increase novelty

#### 4 DISCUSSION AND CONCLUSIONS

With the analysis of the information, it can be concluded that most students agree that the tool used can be valuable in the conceptualization or ideation stage because the images generated look like product renders produced from different ways of interpreting textual prompts. Concerning the CMFs, the majority agreed that the main contribution was the colour part, and they scored the material part slightly less. The students also stated that despite the number of prompts they provided to the tool, there was very little coincidence with the design they had already defined for the final configuration; however, despite the negative evaluation, it does not mean that the tool did not fulfil the purpose in the exercise because the objective was the CMFs, without ruling out that a learning curve could be noticed in text-to-image communication [3] to the extent that students achieve a better combination of words (prompts ) so that the tool generates what they expect, that is, an image of their product. Part of this can be considered one of the challenges that AI technology still faces, as suggested by Michelle-Villarreal et al. [4]. On the other hand, in the design process, it is evident that AI tools will impact not only the generation of ideas or CMFs, as demonstrated in this research, but that they will be linked to all the stages that arise (Hanington and Martin) [13], even to define the process itself, ceasing to be just another tool or method.

Finally, with this research, it was possible to identify that the artificial intelligence tool used is considered positively by students within their learning process and as a helpful element within product design. Likewise, it is expected that the experience with this AI tool will allow students to deepen their knowledge about the technology and leverage its potential to execute the design process more efficiently, aligning with what was stated by Huang et al. [9] about the change in design teaching based

on the three "horizons." On the other hand, this research continues with different groups of students. It is expected to assess an increase in knowledge of AI as the technology deepens its penetration.

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# PHOTO-BASED RESEARCH: ANALYSING ATTRIBUTES OF UNINTENDED INTERACTION TOWARDS MAINSTREAM PRODUCT

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## ABSTRACT

This paper intends to critically assess the attributes of unintended interaction patterns that influence human behaviour towards mainstream products. Several such studies focus on investigating the influence of human experience on users' and designers ' differing concepts of existing products. Furthermore, some problems are found in current practice regarding whether photo-based research can be used to support scientific design research. This paper introduces the study's methodological approach, which employs photo-based analysis to uncover designers' interpretations of people's perceptions of unintended use of products by evaluating the attributes. The four main dimensions that describe sources or aspects of human experience and interaction with products were evaluated by 30 designers based on photo representation as well as to assess the reliability of photo analysis. Photos were used as research subjects for a series of assessment criteria and thoroughly examined according to Pauwels' theoretical framework of visual analysis. Comparisons were made based on an agreement measure. The findings of the study revealed significant descriptive patterns across several dimensions, resulting in the identification of aspects of understanding, experiences, and perception between users and designers. This study suggests that the approach used is applicable to assist in the design of product usability and in the design thinking process by informing the association between the specific dimension of human experience that is valuable for conceptual product design and innovation.

*Keywords: Design thinking, mainstream product, unintended human behaviour, user interaction, photo-based analysis* 

## **1** INTRODUCTION

Product design and behavioural research are topics of significant relevance for user interaction studies, as these are the main elements that connect people, products, and designers, providing intuitive, enjoyable, and satisfying design of user-products [1]. Research that promotes designers' involvement with users' experiences as a crucial part of the design process emerged in response to improving the design of user-product interactions. Previous studies reviewed the problem that intended use designs do not always translate into actual use and users' needs [2][3]. They conclude that designers directly translate user perceptions or needs based on their understanding. Indirectly, the situation causes the use of products beyond the designer's expectations. Designers' interpretations of the issues may differ due to knowledge and individual experience in understanding users' experiences and the reality of people's lives [1]. In dealing with the issue of using products out of context, understanding the factors that influence human experiences is crucial. In psychology studies, such a phenomenon is defined as "unintended human behaviour" (UHBe) when people unintentionally use a product in a way that deviates from the designer's intent [4][5][6]. The phenomenon of using a product in a novel way encompasses the interaction between the cognitive process and behaviour patterns that influence human perceptions and actions. According to Hassan et al. [6] UHBe exhibits inconsistency in action as a goal or objective without intentional intent and/or planning. In the context of user research, UHBe interactions occur regularly as users connect with diverse objects, resulting in unanticipated object use. Both conditions can happen if the object allows it, and the user believes in its efficiency. The statement aligns with the concept of "affordance," which holds that objects and human interactions inherently offer perceptual and ability-based opportunities for action. Norman [2] coined the concept of "design affordance" in "Psychology of Everyday Things," which pertains to the way users perceive the capabilities of an object. As claimed by Gibson's theory of perception, human beings acquire information about objects through direct perception, which is intricately linked to the potential behaviour manifested by the environment. Several scholars on the notion of UHBe concur that unintentional occurrences often reveal insights into people's needs that designers can use to create design opportunities [5][7][8][9][10]. Referring to Sleeswijk et al., [11], diverse design methods and approaches have been developed to overcome this problem. These methods and approaches show an increasing interest in understanding user behaviour and interpretation [5][12], context-of-use issues [11], design concept [3], and everyday design [8][13]. Although these design approaches have aided designers in collecting information about user needs, they have not facilitated a deeper comprehension of how human perception aligns with the product's interaction experience. To address this shortfall, this paper introduces a study that investigates how designers interpret and assess the attributes of UHBe based on user perception, which followed the preceding study [14]. Further, a comparison between user-designer interpretations would be discussed based on an agreement measure. The approach provides an early-step evaluation of human perception that can benefit the early design process.

## 2 BACKGROUND STUDY

## 2.1 The Attributes of Unintended Interaction

Human behaviour reflects the interaction between humans and their environment, showcasing their mental, physical, and social capacities in response to internal and external factors across their lifespan, intentionally or unintentionally, consciously or unconsciously. Conforming to Freud [15], behaviours that demonstrate the achievement of an unconscious intention appear to be clumsy and interfere with unintentional acts. There is limited discussion on UHBe interaction in design studies to interpret the phenomena in the context of design thinking. For that reason, a comprehensive study has been conducted to investigates the value and prospect of UHBe for enhancing user-product design. The term unintended use of a product in user research refers to the innovative use of a product by individuals and have new sensory experiences. Ridgway and Price [16] concluded that UHBe as "unplanned behaviour" involves the introduction of new ideas, innovation, and solutions to issues. Hirschman [4] concurs with Ridgway and Price's statement and then creates a model of use innovativeness (UI) that includes two forms of behaviour when users creatively use existing products: inherent use innovativeness (IUI) and actualized use innovativeness (AUI). Later, they provided a theoretical framework by highlighting five dimensions in the Model of Use Innovativeness to evaluate such "unplanned behaviour": risk-taking, voluntary simplicity, creativity/curiosity, multiple use, and creative use. Menold et al. [17] condensed the dimensions into four categories for assessing creative attributes, actions, and cognition: creativity/curiosity, voluntary simplicity, risk-taking, and multiple uses/creativeness. In identifying a dominant characteristic that underlines UHBe interaction, 32 attributes were analysed through Visual Inventory Analysis (VIA) from a user perspective. The attributes were derived from research on unexpected behaviours, designing appropriation, unorthodox use, non-intentional design, design by use, and unselfconscious interaction [6]. Figure 1 reveal the attribution of UHBe extracted by the UI model for each dimension. The characteristic of the dimensions as portray in Figure 2.



Figure 1. The attributes of UHBe adapted by UI model

Through VIA, the participants analysed the attributes via a visual that represent UHBe in everyday interaction with mainstream products. The results of the analysis found four dominant attributes that represented four dimensions of UI, as depict in Table 1. Based on the preceding study, 88.6% of respondents concurred that 'quick solution' (risk-taking dimension) was a dominant attribute that triggers UHBe interaction with existing products. They corroborate a statement that users unintendedly interact with a product to perform and streamline everyday tasks due to a lack of access to specific

products in urgent or emergency conditions that occur unexpectedly. For instance, some people cover their heads with a plastic bag instead of using an umbrella on a rainy day. They seek an alternative object (an existing product) that can effectively fulfil the intended objective, even if it involves some risk. As Norman [2] stated, user product design is affected by differences between designers' and users' concepts of product. The question arises: how different are their interpretations? Will the difference provide a point of meaningful insight in the early design process and create value for conceptual product design? Thus, this paper suggests an approach using photo-based analysis (P-BA) to assess designer interpretation and associate the differences to inform the value of UHBe interaction.



Figure 2. The characteristic of UHBe attribute [14] Table 1. The result of user's perception towards UHBe

		Dominant Attributes Analysis						
Visual	Scale Analysis	Curiosity & Creativity: Trial & Error / Creativeness	Voluntary Simplicity: Social	Risk-Taking: Quick Solution	Multiple Use: Object Ability			
Inventory Analysis	Strongly Disagree / Disagree [%]	1.4	0.0	0.0	1.4			
rindigoto	Moderately Agree [%]	17.1	12.9	11.4	14.3			
	Strongly Agree / Agree [%]	81.5	87.2	88.6	84.3			

## 2.2 Photo-Based Research

Visual media is having an increasingly significant impact on our society and culture as they depict human experiences, behaviours, and emotions in daily life. In recent decades, researchers in the social sciences have begun to pay serious attention to the use of images to enhance their understanding of the human condition [18] and use photos for the analysis and interpretation of images, focusing on the underlying meaning behind the images [19]. Recently, P-BA research has gained popularity as an important form of "social.". In a study by Copes and Davis [19], scholars enhance current approaches by introducing a new perspective, collecting detailed multi-dimensional information, and providing valuable understandings about participants' daily lives. Photo images are "active", performing the visual equivalent of speech acts; the audiences of an image participate in interpreting its meaning and responding to its particular "action." Burri [20] proposed the concept of "visual rationality," where images become vital parts of knowledge reasoning processes to be more visual based rather than just linguistic or textual, and how the visual leads to phenomena like "seeing with images," where insights come directly from engaging with visuals. In mainstream research, P-BA is considered a supplementary resource to text-based research. Thus, this paper employs an integrated framework for a visual research study [21] to provide a comprehensive understanding and critical analysis of the phenomenon.

## **3 METHODS**

This study employs P-BA to assess the attributes of the UHBe interaction. The photo has been extracted through three different approaches: (i) natural observation (researchers' sources), (ii) voluntary images (participation sharing), and (iii) social media (public posts). There were four sections in this study that the respondents examined. The first section was the visual reference section (focus frame). The other three sections were Visual Data Resource (source and subject), Visual Research Focus and Design (analytical focus, content analysis, and visual dimension attributes), and Overall Analysis (adapted from Pauwel's integrated framework of visual research) [21]. According to Pauwel's framework, the visual analysis process continues by carefully presenting plates of photos illustrating the theoretical point. The survey provided a text description to support respondent perceptions in the photo analysis process. The

first section was the backbone for the three other sections to determine the response of the respondent in evaluating the attributes of UHBe. The photo was derived from social media and was classified as a "found image" (the highest scored image selected by respondents in the preceding paper) and was the most common interaction and context of use that has been seen, experienced, and practiced by society in unintended ways [14]. The image presented the context of "parents bathing their babies using a wash basin." This study used the Likert scale (1: "strongly disagree" to 5: "strongly agree"). Four different levels of product designers involved in the survey responded with a critical understanding of the phenomenon and confirmed that the photo analysis was accurate. 30 designers were involved, consisting of 10 junior, 8 novice, 7 senior, and 5 expert product designers. The designers were selected using a snowball approach from a clearly defined group, as well as to clarify the reliability of the photo analysis.

## 4 FINDINGS

This section presents the results of the P-BA on 30 respondents to the research survey. Some photo analysis segments are reported in detail through explanation and discussion by relating the significant findings to the literature gathered in the research area. P-BA was designed based on Pauwel's framework [21] using the highest score image that was selected by the user as representing the significant UHBe interaction, which was extracted from the preceding paper. Due to ethical issues, the image was only revealed to the participants involved in the survey and was blurred for publishing purposes. Figure 3 illustrates a set of evaluation schemes for P-BA designed in the study.



Figure 3. Sample of Photo-based research Analysis

## 4.1 Photo Analysis finding

The respondent was requested to analyse and interpret four sections of the survey scheme, which depended on the photo in Section 1 accordingly. Section 1: Visual research reference (focus frame) indicated that the images were identified as "people bathing a baby using a wash basin." Section 2: Analysis of visual data resources required the respondent to give their opinion on whether the photo can be found on social media such as Facebook, a blog, or on other media platforms. They were also requested to make a validation on the photo's subject, consisting of (i) the first user (the parents); (ii) the second user (the child); and (iii) the product being interacted with (the washbasin). Section 3: For the analysis of visual research focus and design, the respondent interpreted the photo through (i) analytical focus; (ii) content analysis; and (iii) visual dimension. Analytical focus refers to the context of use often practiced by users. They assess the significance of the scenario and whether a wash basin is often used for bathing a baby instead of a baby bathtub due to the unavailability of the product in a daily context. Content analysis indicates that people achieve the goal (bathing a baby) by exploiting the physical properties of the object (wash basin: form, surface, height, water source). The analytical focus and content analysis were the analytical lenses through which the research subjects examined the visual stimuli, revealing any possible biases or focal orientations that might have influenced the interpretation of the data. Visual dimension analysis is the heart of this study. It reveals four main attributes that represent four dimensions of UHBe according to user perception, namely, creativity and curiosity, voluntary simplicity, risk-taking, and multiple use. Finally, the overall analysis represented a holistic overview of the predominant sources of analysis, shedding light on the primary reservoirs of insights leveraged throughout the study. The result of the analysis will be discussed in the next section.

## 4.2 Respondent Evaluation of the Photo-based Analysis

The table (Table 2) encapsulates the findings of a research endeavour aimed at elucidating the factors triggering UHBe in mainstream products, focusing particularly on the four dimensions: curiosity/creativity, voluntary simplicity, risk-taking, and multiple use. The study engaged four distinct

levels of product designers (junior, novice, senior, and expert) as respondents to provide a critical understanding of the phenomenon as well as confirm the reliability of the photo analysis. The table is structured into four main sections, delineating critical aspects of the research process and outcomes. Based on the result, the evaluation of the photo analysis gained a positive response from respondents, where all nine items are mostly rated as "good." The analysis went through section by section, except for Visual Reference. In the Visual Data Resource section, the source of the photo evaluation score is 73.3%. However, in the subject column, the score is good and rated at 80%. The respondents agreed that the photo reference was clearly representative of the first and second users using subject research. In the section on Visual Research Focus and Design, there are three components of evaluation: (1) "Analytical Focus" scored 70%, and (2) "Content Analysis" scored the highest at 90%. This means that the respondents strongly agreed with the description that the image portrayed the situation of the user's goal by exploiting the physical properties of the object unintendedly. As the focus of the study, (3) "Visual Dimension Attribution" has mutual agreement among the respondents. The multiple use dimension has the highest score as 93.3%, and respondents strongly agreed that the object ability (Oa) influences human cognition while interacting with the product. The second highest rate that portrays UHBe is the risk-taking dimension, with a score of 87.6% through the factor of quick solutions (Qs). However, trial and error (Tt) and the social sharing (Ss) attribute have a lower score than Oa and Qs, with 80% agreement. Meanwhile, there were respondents who strongly disagreed (3.3%) that trial and error and social sharing attributes may influence UHBe. Nevertheless, the overall analysis was rated according to different perceptions of evaluation, with scores of only 76.7% strongly agree or agree, 16.7% moderately agree, and 6.6% strongly disagree or disagree.

Visual Research Reference	Scale Analysis	Visual Data Resource		Visual Rersearch Focus & Design						
			Subject	Analytical Focus	Content Analysis	Visual Dimension: Attribution				Overall
		Source				Curiosity & Creativity: Trial & Error / Creativeness	Voluntary Simplicity: Social	Risk-Taking: Quick Solution	Multiple Use: Object Ability	Analysis
	Strongly Disagree / Disagree [%]	6.7	3.3	6.7	3.3	3.3	0.0	3.3	0.0	6.6
	Moderately Agree [%]	20.0	16.7	23.3	6.7	16.7	20.0	10.0	6.7	16.7
	Strongly Agree / Agree [%]	73.3	80.0	70.0	90.0	80.0	80.0	86.7	93.3	76.7

Table 2. The result of respondent evaluation on photo analysis

#### 4.3 Associating the Differences

The contradiction between the designers' interpretation and the users' perception reveals a slight discrepancy in Oa and Qs attributes. Numerous designers agree that UHBe is influenced by Oa. They make a judgement based on their understanding, knowledge, and experience about design affordance, as emphasised by Norman [2]. Later, the designers agree that Os attribution is the second-highest attribute that influences UHBe interaction. They perceive that the actions are linked to the context of the use of everyday objects. Contrary to the users' perception, they conclude that Qs and Ss are the most important attributes that trigger UHBe interaction among users. The users believe that such behaviour is influenced by social context and life experiences such as open access to social media, internet of thing, or cultural factors, nowadays. However, the difference in the level of knowledge about the value and objective of the product causes the users to slightly disagree on the Oa of the product, which triggers UHBe compared to the designers' perception. Thus, the design team should consider these differences in early product design activity because users are the buyers of the products. Throughout the literature on UHBe research, scholars have posited that user actions and interactions give an important 'signal' to design team [1][2][5][6][8][15][22]. They believe users would maximise the use of the product function, whether intended or unintended. However, both user-designer interpretations of UHBe have an almost parallel view of the "quick solution" attribution based on the percentage of agreement obtained. In summary, each attribute proposed and discussed in this study has a value that could be considered appropriately in different contexts.

## 5 CONCLUSIONS AND FUTURE WORK

Principally, designers should be more sensitive to factors that can inspire and innovate ideas, such as sharing on social media and the life context of users. The user's insistence on the nature of instant solutions reflects the real situation of human life today, which is faced with time constraints, emergencies, and economic status. These differences should be celebrated to find a unification that can benefit all parties. Although UHBe faces certain risks, designers should look at the meaningful side by understanding human behaviour more realistically. The implications of this study allow designers to

expand their design thinking parameters based on the potential of UHBe interactions and create motivation for new product design concepts. We believe that P-BA approach used in this study can be used as a guideline to improve the parameters of design thinking for designers in conceptual design and does not depend on the interpretation of the designers' experience alone. We can conclude that the objective of this study has been fulfilled: to observe creative ways in which people unintendedly interact with the product, as well as to assess the factors and attributes of interaction and obtain validation of reliability. Despite the limited number of respondents, the study consistently found a cohesive pattern of perceptions. To enhance in-depth understanding of the phenomenon, verbal protocol analysis will be conducted to investigate designer interpretations and reflections through the design activity.

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# PRACTICAL TRAINING NEEDS OF TEACHERS FOR ENABLING HIGH SCHOOL STUDENTS TO IDENTIFY AN APPROPRIATE PROBLEM IN DESIGN-BASED INQUIRY LEARNING

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#### ABSTRACT

Following the publication of the new curriculum guidelines in 2018, a "Period for Inquiry-Based Cross-Disciplinary Study" is now offered in high schools in Japan. Because of the nature of multidisciplinary inquiry-based learning and the need to tailor lessons to the specific circumstances of schools and the regions where they are located, there are no textbooks for this subject. One of the few resources available is a booklet of worksheets developed by the Sustainable Development Goals (SDGs) Design School, Faculty of Design, Kyushu University, in collaboration with public high school teachers. This study looks at an implementation of the Period for Inquiry-Based Cross-Disciplinary Study at a high school in Japan from April to October 2023. Nineteen 100-minute lessons attended by a total of 314 third-year students were observed. During these lessons, a revised version of the SDGs Challenge Project handbook was used to try to give the students guidance on the problem-finding stage of inquiry-based learning. Both the students (n = 248) and teachers (n = 19) participated in a follow-up survey to understand the challenges they experienced. The most common process identified as difficult by the students was ideation, whereas problem finding was the process with which the teachers had the most difficulty. Based on a thematic analysis of the responses to the open-ended questions in the survey, the study finds that more training in facilitation would help enable teachers to lead students to find problems of an appropriate scope and link them to social issues.

Keywords: Design education, design process, problem identification, ideation, Japan, high school

#### **1** INTRODUCTION

In Japan, design is not taught as a subject in the general high school curriculum [1][2]. However, under the new curriculum guidelines published in 2018 and implemented nationwide in 2022, a new "Period for Inquiry-Based Cross-Disciplinary Study" was established in high schools in Japan [3]. The process of introducing multidisciplinary inquiry-based learning in high schools is currently underway, although adequate instructional training and teaching materials are not yet available to teachers. Japanese public high school teachers collaborated with the Sustainable Development Goals (SDGs) Design School, Faculty of Design, Kyushu University, to co-design inquiry-based learning materials for high school students. These materials, which began to be implemented on a pilot basis in 2019, take the form of a booklet of worksheets in which students can describe their discussions as well as their ideas and research findings. They are intended to guide students' self-learning, help them think about the social issues around them, and seek solutions to those issues [4][5].

This study examines the introduction of these materials during the Period for Inquiry-Based Cross-Disciplinary Study at a general high school in the context of the SDGs Challenge Project. The study covered 19 lessons, the curriculum time for each of which was 100 minutes. The study was conducted from April to October 2023, and all 314 third-year students in the school participated. It was intended as part of a broader investigation into how to implement design-based skills for multidisciplinary inquiry-based learning in Japanese high schools.

#### 2 LITERATURE REVIEW

The Period for Inquiry-Based Cross-Disciplinary Study requires each school to set its own goals and content, as each school is expected to develop learning activities according to its students' actual
situations and the characteristics of the school. There are, of course, no textbooks, as it is not possible to generalise about this type of study. In 2023, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) published a handbook on curriculum management based on the revised Courses of Study for High Schools, which explains the basic concepts, provides examples of lesson plans for Periods for Inquiry-Based Cross-Disciplinary Study, offers learning guidance and organisational systems for developing such plans, and introduces examples of excellence in practice [6]. MEXT noted the significance of addressing the goals and content of the Period for Inquiry-Based Cross-Disciplinary Study in school-wide training [7]. However, a detailed description of what this involves is unavailable. These materials alone are not sufficient for teachers. As mentioned above, each high school has its own specific objectives, and each region has its unique characteristics, meaning that no materials can perfectly match the content to be worked on in a school. Teachers must improvise or devise new plans and methods according to the situation. In other words, Japanese inquiry-based cross-disciplinary study is still in its early stages, and there is a lack of accumulation of pedagogical content knowledge by teachers [8]. As high schools need to set their own learning content individually, they are not provided with enough specific or generalised training relevant to this subject compared with others such as mathematics and languages. There is a need for training to support the development of lessons tailored to individual schools, based on analysis and discussion of precedents [9].

## 3 METHOD

To clarify what knowledge is necessary for teachers to teach the Period for Inquiry-Based Cross-Disciplinary Study, the following key research question is posed: "How might teachers guide students to be able to identify an appropriate problem in design-based learning?" The current study adopts a qualitative approach to build a case study around the SDGs Challenge Project in a Japanese high school. Although the SDGs Challenge Project is a comprehensive programme encompassing the entire process, from identifying a problem to proposing a solution, the current study focuses on the process of finding problems. This is because previous research has shown that teachers participating in this programme find teaching the problem-finding process to be the most difficult part. In previous SDGs Challenge Project case studies, students selected a theme of interest relevant to the SDGs during the problemfinding process, used mind maps to identify more issues related to their chosen theme, and then focused their exploration on issues. As a result, many students in these cases focused on issues of poverty in distant countries that they associated with the SDGs. However, it was difficult for teachers to teach the process because of the students' lack of real-life experience and empathy [2][10][11].

Therefore, the current study modified the worksheet used by students in the SDGs Challenge Project as follows to address the difficulties of the problem-finding process. In Step 1 of the problem-finding process, students identify 30 problems in their daily lives along the timeline of a day and describe the ideal situations wherein each of the problems could be solved. In Step 2, students write down their areas of interest and why they are interested in them, describe 10 problems, difficulties or challenges in these areas, and describe the ideal situation in which each of these challenges could be solved. They then use mind maps to expand on relevant stakeholders and concepts and to examine the issue's historical and social context. The original worksheet was changed into a scaffolding worksheet with these detailed steps and clear goals to accomplish and tasks to complete in each step.

A post-project questionnaire consisting of open-ended questions was administered to investigate the impact of this change on students and teachers. A questionnaire survey of the 314 participating students and 23 teachers was conducted. The students were asked to identify the most difficult process used in the programme. The teachers who conducted the classes were asked which processes were most difficult to teach, why they were difficult to teach, and how they thought these difficulties could be overcome. Following immersion in the data, the responses to the open-ended questions were analysed, categorised and interpreted to look for a lineage of concepts. Based on the results, the current study discusses how to enable teachers to meet students' needs in the problem-finding process.

#### **4 FINDINGS & DISCUSSION**

Of the 314 students, 248 responded to the survey. The question they were asked was, "Which of the processes used in the programme worksheet was the most difficult?" As it was mandatory to select one response to this question, all 248 students selected one process. The most common response was ideation, which was selected by 79 respondents, or 32% of the total (Figure 1). The next most popular response was idea improvement, which was selected by 10% of respondents. No other process was

selected by more than 10% of the respondents. In the current study, many student groups explored the issue of sleepiness among high school students, possibly as a result of the changes to the problemidentification process in the worksheet, which encouraged students to look to their everyday lives for problems. This modification of the worksheet reduced the difficulty of the problem-finding process for students.



Figure 1. Students' feedback on the programme

The same questionnaire was administered to the teachers. Out of the 23 teachers, 19 responded to the survey. Finding problems in everyday life was the most common response, with 10 respondents (Figure 2). The teachers' opinions as to why this process was particularly difficult were elicited through an openended question (see Table 1), and the responses were sorted into six categories. The figures in brackets indicate the number of teachers who mentioned each category of reasons.

In previous studies, Japanese high school students tended to pick problems related to poverty in distant countries that they were unable to empathise with because of the distance from their real-life experiences [12]. We therefore moved the scope of the problem-finding process closer to students' familiar everyday problems and divided what they needed to do into smaller steps. We modified the problem-finding process based on the hypothesis that teachers' difficulties would be reduced if the students were able to proceed with self-learning. Although the students were less likely to identify the problem-finding process as the most difficult process in the worksheet (with the percentage of students selecting this option falling from 10% before the changes to 8% afterward), the teachers indicated that the problemfinding process was still difficult. This indicated that what is needed for teachers is not just the right scoping between students and problems. The open-ended responses indicated that the teachers ideally wanted the students to identify problems that were within the appropriate scope, not too familiar or personal, but also not too unfamiliar or distant, as in the case of a foreign country that is completely unknown to the students and therefore difficult for them to empathise with, and that still had a social impact (Figure 3). However, exploring practical problems does not help teachers in achieving their ideal goals. What teachers need is not to be able to get their students to give ideal answers, but to receive training in facilitation so that they can bring their students to the expected level. They need to be able to show their students a broader perspective if their problem scope is shortsighted and to bring them closer to the problem at hand if it is too far away.



Figure 2. Teachers' feedback on the programme

Table 1. Reasons for teachers	s' difficulty with the	problem-finding process
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Categories of Reasons	Indicative Answers
Because teachers are unable to link	It was difficult because I could not link the topics in
everyday problems to wider issues,	which the students were interested with their daily
e.g. SDGs (4)	problems. The group interested in the economy explored
	topics such as truancy and disaster prevention in terms of
	everyday issues. It would have been nice if I could have
	connected them to the economy from there, but I didn't
	have enough teaching skills, and we didn't get that far. I
	but I falt it was necessary to link them to tonics of interest
Because everyday problems are too	If the initial work is limited to familiar problems, the rest
narrow in scope to be expanded (3)	of the work will not be extensive
Because more groups choose similar	Considering everyday life and familiar matters many
problems when they explore problems	problems and issues to be solved can be identified but
taken from everyday life (2)	many groups tend to select similar problems.
Because students do not have real	It is difficult to find problems to solve when working only
experience (1)	in the classroom without fieldwork
Because the problem is not suitable for	Many problems were not suitable for exploration or
exploration or presentation (1)	nresentation
Because the time for exploring the	I think there are many troubling situations in their own
problem is too short (1)	lives but when I asked students to write them down it
	seemed difficult for them to come up with them. I thought
	it would be a good idea to make it a homework
	assignment for a week or two, asking them to write down
	any 'troubling' situations they encounter.



Figure 3. Conceptual diagram of problems identified by students and teacher expectations

Gaining knowledge of facilitation is important for teachers, who may have little experience guiding such discussions. Teachers need to guide students to widen the scopes of their problems if they are too narrow, and to focus them if they are too broad. In the former case, the goal is to broaden the perspective to other problems that could be caused by the problem and to link it to social issues. To take the example of sleep deprivation, this is not just a problem for high school students, so looking at for whom the problem is being solved can expand the discussion of the problem to have a social impact. Sleep deprivation among mothers raising children may be linked to their work environment and to gender inequality, or excessive workloads because of a surge in online shopping may ultimately be responsible for a sleep-deprived long-haul truck driver causing a road accident. Another approach is to collect sufficiently deep data on high school students' sleep problems so that the underlying causes can be discovered in depth. The inability to sleep may be due to too much time being spent using smartphones at night or a school curriculum that requires students to study for long hours. If students are questioned to change their perspective in this way, the same issue – sleep deprivation – can be linked to multiple different social issues, even if the starting point was the same.

Conversely, drawing on previous studies, if the scope of the problem is too remote from students' real experiences or too broad, it is essential to try to increase students' empathy for the problem, thus giving them a more concrete understanding of who the problem affects and how it affects them [13]. Empathy can be divided into two functional components: cognitive empathy, which involves deducing and understanding the other person's state of mind, and emotional empathy, which involves sharing the other person's state of mind emotionally [14]. Kikusawa showed the usefulness of anchoring experience [15], subject embodiment by persona, and mind mapping as methods for fostering these [12]. Even when the scope of the problem that students initially set is too narrow or too broad, teachers can guide them in this way, leading to a deeper understanding and a broader perspective.

# **5 CONCLUSIONS**

This study aims to identify how teachers can guide students in identifying an appropriate problem in design-based learning through a Japanese high school programme. To answer this question, a longitudinal study was conducted on a programme implemented in a Japanese high school. As previous research showed the problem-finding process to be difficult for both students and teachers, the scope of the process was moved closer to students' familiar everyday problems and broken down into smaller steps. This reduced the difficulty of the problem-finding process for the students, although the teachers indicated that they still found it difficult. The teachers' open-ended responses indicated that they ideally want their students to set problems that are appropriately scoped – not too familiar and not too unfamiliar – and that have a social impact.

However, teachers need training in facilitation to prepare them to lead students to the expected level, because if the students explore realistic issues of a practical and complex nature, they may go beyond the scope assumed by the teacher. If the scope of the problem is too narrow, teachers can question the students to change their perspective and link it to a social issue, allowing the students to widen the scope of the problem. In cases where the scope of the problem is too broad, it is essential to increase students' empathy with the problem to allow them to understand more concretely what the impact of the issue is and who it affects. The limitation of this study is that it has not presented methods to improve teachers'

facilitation capacity in a form that can be practically used in classrooms, and it has not validated these methods. Subsequent research should aim to address the implementation of methods for enhancing facilitation skills among teachers and obtaining feedback from both teachers and students.

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# HOW CAN AI SUPPORT THE CREATION OF NOVEL IDEAS IN PRODUCT DESIGN

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#### ABSTRACT

The rise of Artificial Intelligence (AI) provides an exciting opportunity in many fields and aspects of life. In the field of design, one area to be explored, is how AI could be used to support a designer to develop more novel ideas at the idea generation stage of the product development journey. In this paper, we explore how AI can be utilised to support a traditional 6-3-5 creative design methods workshop, and whether it increases the novelty of the concepts. In our workshop, students were tasked with using the 6-3-5 method to generate ideas for a product which could make life easier for an arthritis sufferer when undertaking tasks in the kitchen. Some of the students were advised they could use ChatGPT to support idea creation; some of the students were advised they could use Google to support idea creation; and the remaining students were advised they would not be able to use any additional support for idea generation. This group was considered as the control group. A feedback survey was distributed among the participants to gather their thoughts on whether the use of AI/Google had assisted them in the application of the design method to generate more novel and creative concepts. Further analysis was then conducted, with a focus on novelty, on the outputs of the 6-3-5 to assess whether the novelty of the concepts in the AI/Google groups was greater than that of the control group. The results of the workshop indicated that the ideas generated with AI support were more novel than those without, and that students utilising AI became more relaxed in their approach to idea generation, relying on AI before fully exhausting their own ideas. Interestingly, the perceived helpfulness of AI was also not fully appreciated by the more novice designers in comparison to those more experienced designers. In this paper we discuss how AI could be used by educators to support teaching and application of more creative design methods such as 6-3-5.

Keywords: P-I-T method, 6-3-5 method, 6-3-5 brainwriting, creative design methods

# **1 INTRODUCTION & LITERATURE REVIEW**

Design methods are used to guide and support the design process. They are used by design practitioners to justify decisions made in a systematic way. Educators teach design methods to students so that they understand how to develop concepts in a systematic way and to allow them to overcome barriers in the design process, such as, when they run out of ideas.

6-3-5 is a concept generation method that is commonly taught in Product Design education [1]. The method involved 6 people, 3 ideas and a 5-minute timeframe. It is sometimes referred to as Method 635 or Brainwriting, and is a common lesson in textbooks including the Delft Design Guide [2] The benefits of 6-3-5 are the wide range of ideas generated in a short time frame and reduced impact of dominant team members on the creative ideas of students less likely to share their ideas in other brainstorming activities from a team working perspective [3].

The use of traditional design methods could be under threat by novel technologies that can replace the designer in the design process. Artificial Intelligence has been used to support creative thinking and the development of conceptual ideas [4]. Generative text-to-image AI and natural language processing AI have several applications in product design [5] including the generation of images which may be used to represent conceptual ideas, or text descriptions on conceptual ideas using these AI technologies (such as ChatGPT and DALL $\cdot$ E).

There is evidence within the research that methods including 6-3-5 can encourage students with less experience of concept generation to produce a greater number of creative concepts [6] and therefore

these are important tools and methods in developing basic design competencies in early design education. However, given the rise of AI, we must consider how AI could be utilised to support designers without compromising on foundation knowledge and skills' building. It is important to test these AI supported approaches in a structured educational environment before adopting as best practice [7]. This leads us to explore the possibilities of the use AI within an educational setting with the following

questions:
Can AI be used to support the creative design process of students when they have exhausted their

- Can AI be used to support the creative design process of students when they have exhausted their own ideas to create novel ideas?
- Can AI be successfully used within an educational environment to support the applied learning of the 6-3-5 method?
- Can AI replace the use of creative design methods such as the 6-3-5 method within the design process?

The research detailed within this paper aims to investigate these questions and discussion is made of the appropriateness of the technology in its current developmental state.

# **2 METHODOLOGIES**

In this section, the methodology for the design, delivery and evaluation of an experiment to assess whether AI increases novelty in the 6-3-5 method is presented.

## 2.1 Design & Delivery of the experiment

Twenty-eight Postgraduate students from the University of Strathclyde, studying a ten-credit module on Design Methods were asked to participate in a 6-3-5 creative method.

The class was of mixed experience with regards to design education, with some having studied Undergraduate design-based courses, and some being completely new to the field of design. To assess the base level of creativity in the room, the students were asked to score themselves on two questions. Q1. On a scale of 1-10, how creative would you say you are? (10 being highly creative). Q2. On a scale of 1-10, how would you rate your ability to think outside the box? (10 being highly capable). As can be seen in figure 1, we had a range of experience and average 'creativity' scored 6.8/10, and average 'ability to think outside the box' scored 6.72/10.



Figure 1. Student perceived 'Creativity' & 'Ability to think outside the box rating'

The 6-3-5 process was first explained to the students. The class was then divided into five groups. Due to class numbers, we had three groups of six students and two groups of five students. The groups of six would undertake a 6-3-5, and the groups of five would undertake a 5-3-5.

The scenario was set that the students were a team of product design consultants, who were tasked with developing a new product to make life easier for an arthritis sufferer when working in the kitchen. Students were asked to think and list all the challenges an arthritis sufferer may face in the kitchen to ensure they understood the problems to be addressed. Their thoughts were recorded and discussed before moving in to the 6-3-5 activity.

The students were informed they would conduct the activity in one of three approaches – either using ChatGPT for support, Google for support or no support (i.e. the control group). For the Google and ChatGPT groups, they were advised that they should only use ChatGPT or Google once they reached the point that they felt they had ran out of their own ideas. Two groups of six would be permitted to use 'ChatGPT' support (12 responses received), one group of six would be permitted to use 'Google' support

(5 responses received), two groups of five would not be permitted to use either ChatGPT or Google and were tasked with undertaking a traditional 5-3-5 (9 responses received).

# 2.2 Evaluation of the experiment

The experiment was evaluated using a survey, to determine at which stage ideas were exhausted, and to establish the students' perspectives on the usefulness of AI or web searching, to support the generation of novel ideas.

To investigate if the use of AI or Google web searching supported the novelty of the ideas created, a coding method and intercoder methodology was implemented. Coding would be based on a predetermined set of criteria as defined by Oman et al [8]: Usual/Unusual, Commonplace/Astonishing, Customary/Surprising, Overused/Fresh, Commonplace/Original, Common/Astonishing, Predictable/Novel and Average/Revolutionary. Each coder would determine which of these pairs of words best described the concept. The intercoder method was used to systematically conduct the coding and reduce the amount of coding required overall. Our evaluation utilised three coders. Each coder reviewed two thirds of the data overlaping with the other reviewers. All concepts were reviewed by two of the coders. Where the two coders disagreed, the third coder would decide on the coding applied. A spreadsheet was used to code the data and reveale the results. The average of each team was calculated to indicate if AI, web search, or utilising their own ideas only, resulted in novel concepts.

Novelty was selected as the measure focus on in this paper. Criteria measurments for concepts such as creativity went beyond the scope of this research, concerning aspects of the concepts such as variety, quality, quantity, appropriatness, technicality, harmony and others [8].

# **3 RESULTS & DISCUSSION**

The results of the survey and 6-3-5 analysis are now discussed.

# 3.1 Survey Feedback

A feedback survey was distributed among the participants. One participant in the traditional 6-3-5 group did not respond, and one participant in the Google group and one participant in the ChatGPT group, who did respond, are thought to have misunderstood the questions, therefore their results were removed from the analysis. Based on this, we had twenty-five responses for our analysis.

Participants were asked to inform us at what point in the 6-3-5 they felt they had ran out of ideas. As shown in Table 1, in the ChatGPT and Google groups, a higher % reported they ran out of ideas earlier in the process than those undetaking a traditional approach, perhaps due to the subconsious knowledge that when they reached this point, they could rely on external sources of AI to continue the process.

One participant in the Google group, and three participants in the ChatGPT group, reported never running out of ideas, therefore didn't use ChatGPT or Google. Their results were removed in the further analysis. This left twelve respondents from the Google and ChatGPT groups to evaluate the impact of AI.

Of the twelve participants who did utilise ChatGPT or Google, 75% reported the use of Google/ChatGPT was helpful.

	Traditional	Cumulative	Google	Cumulative	ChatGPT	Cumulative
I had no ideas at all	-	0	-	0	-	0
(from the start)						
After round 1	-	0	1	1 (20%)	1	1 (9%)
After round 2	1	1 (11%)	1	2 (40%)	1	2 (18%)
After round 3	-	1 (22%)	-	2 (40%)	3	5 (45%)
After round 4	3	4 (44%)	1	3 (60%)	2	7 (64%)
After round 5	2	6 (66%)	1	4 (80%)	1	8 (73%)
<u>I never ran out of</u>		<u>3 (33%)</u>		<u>1 (20%)</u>		<u>3 (27%)</u>
<u>ideas</u>						

Table 1. Point at which participants ran out of ideas

They were then asked to score how helpful Google/ChatGPT was in assiting them to come up with new creative ideas.Of the twelve responses, two scored 10/10. These two participants belonged to the ChatGPT group and reported running out of ideas after round 1 and round 2. Interestingly, these two participants both reported they were experienced designers, having studied four or five years of undergraduate design studies, with prior experience of the 6-3-5 method. The average' helpfulness' score overall was 3.5/10 for Google and 5.5/10 for ChatGPT.



Figure 2. Perceived helpfulness of AI

An interesting observation was that those less experienced designers scored overall 'helpfulness' much lower than the experienced designers. This is an area requiring further exploration and investigation, and consideration should be given to things such as ontological, experiential or self-esteem issues of the participants, which are not considered in this study. It is hypothesised, that a reason for this could be that without the experience of having applied the method without AI, they do not see the benefits that AI can bring. This is in comparison to our more experienced designers who have been taught the method previously, without using AI, and therefore have their prior experience for comparison.

# 3.2 Intercoder Analysis

The results of the intercoder analysis are now shown. The results demonstrate that those in the ChatGPT and Google groups came up with more novel ideas than those undertaking the traditional approach (scores closer to 0 indicate higher novelty).

Therefore, we can say that, in the study, the use of AI in the 6-3-5 method does increase the novelty of concepts being generated by the students. Therefore, the use of AI can be implemented with digital 6-3-5 design tools [8].

To answer our research questions:

• Can AI be used to support the creative design process of students when they have exhausted their own ideas to create novel ideas?

	1	2	3	4	5
	ChatGPT	ChatGPT	Google	Control	Control
Group Average	-2.33	-3.89	-2.89	-5.06	-4.33

Table 2. Results of Intercoder Analysis

To answer our research questions:

Can AI be used to support the creative design process of students when they have exhausted their own ideas to create novel ideas?

Yes, these technologies can be appropriately used as per this context. However, we must consider that there is evidence, as shown in Table 1, that students may use the technology so that they do not have to put in as much effort as they otherwise might in creating their own novel ideas. This supports the idea that AI can be used as inspiration within the design process but perhaps should not be used to generate initial concepts [9] with more novice designers.

• Can AI be successfully used within an educational environment to support the applied learning of the 6-3-5 method?

Yes, AI can support the applied learning of the 6-3-5. From our results it is suggested that AI integration to support the 6-3-5 is most successfully implemented with more experienced designers and should be taught after students have some experienced of applying these methods without AI.

• Can AI replace the use of creative design methods such as the 6-3-5 method within the design process?

Yes and no. Our research suggests that ideas generated with the support of AI were more novel than those without, and this therefore suggests that educators can implement AI for idea generation. However, the perceived helpfulness of AI was not fully appreciated by novice designers (as shown in figure 2) therefore there could be a greater challenge to overcome for novice designers if they do not learn to apply the method themselves in the first instance.

# 3.3 Limitations and Future Work

The limitations of this study are in the sample size. Backgrounds of the participants is also not explored in detail, other than number of years design experience. Consideration could be given to ontological, experiential and self-esteem of the participants to further understand why more notice designers viewed AI as less helpful than those more experienced designers. The intercoder methodology has been proven as reliable for this research investigation and should be followed for any repetition of the findings. Research, across similar classes and other institutions can test these findings across further similar classes and institutions. This research may expand to determine if aspects beyond novelty can be coded and conclusions made.

# 4 CONCLUSIONS

The results of the study indicated that when using AI to support idea generation, students are more likely to rely on the technology before fully exhausting their own ideas. The generated concepts were more novel when AI (ChatGPT or Google) was used, however an interesting observation was that the perceived helpfulness of the AI approach was lower with the more novice designers.

In summary, AI can be successfully used to support the applied learning of the 6-3-5 method, and it can be used to support the creative design process of students when they have exhausted their own novel ideas. However, we need to keep in mind that students may not put in as much effort as they otherwise might in creating their own novel ideas when AI is available. On the question of, can "AI replace the use of creative design methods such as 6-3-5 within the design process?" Our early research indicates that AI does have perceived benefits to more experienced designers and does achieve more novel concepts, however in our novice designers, there still needs to be a foundation appreciation of a method without the use of AI to see its benefits.

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# PARTNERING WITH THE INTELLIGENCE COMMUNITY TO ENHANCE AI INTERFACE DESIGN EDUCATION

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### ABSTRACT

Artificial intelligence (AI) is increasingly expanding its capabilities and presence in fields because today's industry demands working with big data (BD) to extract meaningful user insights to align its goal with success. The government sector, specifically the intelligence community (IC), is no exception to this need. The study partnered with the IC sponsors and set up a conceptual enterprise dashboard project to explore novel AI features to search, triage, and contextualize BD and to address the educational challenges in preparing students to work in the changing technological industry when designing a new product. The study focused on improving the students' academic experience in navigating the ambiguity built into the explorative aspects of AI projects. During each phase of the Design Thinking (DT) process, eleven students, in groups of three, discussed the difficulties of finding design solutions because of the user data gaps in the brief due to the confidentiality required in the IC and the challenge of the innovation in building novel interactive features. The study utilized the DT and Design Inquiry of Learning (DIL) framework to identify the design process's understanding, defining, ideating, and validating phase to benefit from including role-playing and storytelling activities for students experiencing frustrations due to the ambiguity built into the project.

Keywords: UX design education, generative AI, ambiguity in design, role-playing, storytelling

#### **1** INTRODUCTION

The disruptive nature of Artificial Intelligence (AI) technology is "Reshaping the global ecosystem," which also "Significantly impacts the financial market" [2]. Researchers in other fields, like medical biology, are also trying to utilize AI to analyse data [9]. Reviewing an accurate depiction of quantitative data or attaining qualitative insights offers better choices for organizations when making important decisions. The public sector also needs to process big data (BD) to "Recognize decision-making process opportunities" and implement AI to aid human agents in the workflow [4]. To improve the quality of undergraduate senior students' User Experience (UX) design learning opportunities, the study partnered with the Laboratory for Analytic Sciences (LAS) and the National Security Agency (NSA) of the United States to collaborate on an AI-driven conceptual Enterprise Cognitive Computing (ECC) tool while addressing the industry needs to find more designers capable of discovering novel interactions between a human agent analysing BD using AI. Because AI technology can maximize its impact on increasing the value of enterprise businesses by implementing ECC in data [8], the project scope involved student designers reimagining the ECC tool as a data dashboard. Utilizing the Design Inquiry of Learning (DIL) framework, the study plans to evaluate educational challenges and identify pedagogical approaches for the studio project in a higher learning environment [6]. In addition to DIL, the sponsored project utilizes the Design Thinking (DT) process, which shares similar methods like "Need-finding, brainstorming, and prototyping within multidisciplinary teams" [1, 7]. The challenge of the project involves students learning to design an ECC product by finding the relevancy among data, analysing tasks with built-in AI features, and identifying the areas to improve in the conventional process for three personas provided by the sponsors. While DT offers a structured framework for an educator to facilitate a speculative ECC product design process for UX and UI senior undergraduate design students in a studio setting, the need for creative flexibility becomes a crucial component of the learning experience when faced with navigating through an ambiguous territory in innovation that can result in frustration. The sentiment echoed in DT practitioners who see the "Step-by-step process" hinders "Fluency in thinking and

flexibility in approach, which is essential in Design-driven innovation" [1]. Therefore, the study utilizes the DIL to highlight areas of the educational challenge in the DT design cycle for students speculating a novel design solution for the IC. Observation, discussion, and documentation of the student's work progress in each of the DT design cycles establish valuable insight to answer the research question: How can a role-playing mindset and storytelling ability help address ambiguity in a speculative AI project for undergraduate students to improve the learning experience when designing a dashboard for data analysts from the intelligence community?

# 2 METHOD

Partnering with Intelligence Communities (IC) like LAS and NSA added the educational benefit of increasing ambiguity associated with innovation so that students could learn how to derive and develop an AI dashboard solution with data analytic features by utilizing the DT as a framework (Table 1).

	Understand Users	Define Problems	Ideas/ Prototype	Feedback	Implement/ Delivery
Timeline	1 weeks	2 weeks	3 weeks	1 weeks	2 weeks
Number of Senior Undergraduate Students	11	11	11	11	11
	Requirements	User Persona	Flow Charts	Internal Testing	High-Fi Wireframe
UX Design	Value proposition	User Story	Low-Fi Wireframe	Usability Testing Link	Figma Files
Memods	Market Research	Journey Map	UI Components		UX Documentation
	Questionnaires		Prototype		
Tools	Google Workspace/ FigJam/Figma/ Interactive Game	FigJam	Pen/Paper/ Whiteboard/ Post-it note/Figma	Google Workspace/ Figma/ Zoom	Figma
Facilitators	A faculty member, graduate assistant, and technical program manager from the sponsor.	A faculty and graduate Assistant	One faculty, graduate assistant, and guest workshop facilitator	A faculty and graduate Assistant	A faculty and graduate Assistant
Sponsors	LAS & NSA	LAS & NSA	LAS & NSA	LAS & NSA	LAS & NSA

Table 1. Project Scope

Because the sponsoring IC is part of the public sector that needs analysing BD to extract meaningful insights, incorporating AI technology encouraged students to explore novel approaches in improving the dashboard's graphical user interface (GUI) concerning search, triage, and contextualization of data. The unique challenge of collaborating with the IC community on the given topic was for the students to reimagine the interface without fully understanding the sponsors' current technology, data, and user information due to the confidentiality tied to the industry. The proxy data from the sponsor represented a BD for the dashboard and user data. DT offered a design framework for the students, and DIL enabled

the study to discuss the educational challenges of the specific phase within the DT design cycle. Using the structured steps in the DIL and DT as a framework for conducting the UX design methods helped to locate areas of improvement in learning (Figure 1).



Figure 1. Design Thinking (DT) and Design Inquiry of Learning (DIL)

The study collected research data through semi-structured questions, participant observations, and documentation of the entire design process; the limited access to the contextual user data regarding the working environment, the current tools, and the workflow was the culprit that caused the students to experience uncertainty and anxiety about committing and validating a design direction. (Table 2). The semi-structured questions were chosen because of their flexibility and strength in exploring the topic versus the structured format, which provides more validity but hinders in-depth discussions.

	Group Discussions	Participant Observation	Documentation of the Design Output
Number of Student Participants	11	11	11
Duration of Each Session	30 Minutes	4 Hours	4 Hours
Number of Sessions	3	18	18
Settings & Location	In-person lab	In-person lab	In-person lab
Data Type	Text	Text	Digital File
Data Storage	Figma	Figma	Figma, FigJam, and Google Drive

Table 2. Data Collection Methods

Learning about students' roadblocks in the understanding, defining, ideating, and feedback phases from the DT process as areas causing the most frustration, the facilitator implemented role-playing and storytelling as a pedagogical approach to mitigate the students' pain points in conceptualizing the speculative AI dashboard. Because of the effectiveness of learning the subject materials through acting out assumptions and improvisations in role-playing, the educational method became the tool for understanding users with limited access to their behavioural information [5]. Storytelling was another method that enhanced the empathetic outlook of the user and context, resulting in design discoveries [3]. The two educational methods are designed to improve the learning and design outcomes for the students in the following areas of the project.

- Role-playing mindset to understand users: Provided a proxy background story and game concerning user data for better empathizing with a user group.
- Storytelling to fill the data gap: Involved the cohort using storytelling ability to synthesize user scenarios from proxy data and attained confirmation through the questionnaire results.
- Role-playing mindset and storytelling to innovate: Conducted a supplementary flowchart

workshop and internal usability testing session to help ideate and refine the design direction.

## 2.1 Role-playing Mindset to Understand Users

Since the sponsors were not allowed to share data that might breach a security measure guided by the agency, the project began with brief representative information about the problem space and users with an interactive game to help explain types of daily tasks. The brief included artificial objectives, labels, and backgrounds regarding the place and people. The crime investigative game shared by the sponsors provided a flow of analytical tasks without displaying the technology utilized by the people at the agency, which assisted three groups of three to four students with a role-playing mindset to develop an understanding of the types of analysis. The three separate student group settings allowed the project to address the target audience's different experience levels and daily tasks in finding contextual insights by searching through potential relevancy among random raw data sets. Proxy maps and the artificial names of the organizations with personas helped the group with a mental model of the roles of users within a context regarding their environments and objectives.

#### 2.2 Storytelling to Fill the Data Gap

The proxy dataset provided by the sponsors included a map of an artificial country and regions. The challenge for the students involved creating relevancy among the data types such as date, time, data permission, mobile number, device data, battery charge level, battery drain level, connection type, name, user ID, regional area code, cellular location area code (LAC), cellular tower ID, signal power level, Wi-Fi network service set identifier (SSID), Wi-Fi speed, review submission time, rating, text, picture URL, responses from business and App business ID. Each group with an assigned persona had to find relevancy between data types to address the persona's objective; as mentioned in the following research questions, the facilitator converted from the sponsor project brief to guide the students.

- Persona 1 Team Leader "Christian" How can a digitally assisted search feature help collect and prioritize global information for the IC data analyst team leader to create a contextualized report to inform a domestic policymaker?
- Persona 2 The Devotee "Maria" How can a search result widget leverage optical UI components for the IC data analytic consultant to identify and present new relevant sources of information?
- Persona 3 The Beginner "Evan" How can a digital assistant and human-aided filter components help eliminate the learning curve for the beginner-level IC data analyst in becoming an expert at sorting through auto-generated irrelevant data in a relatively short time?

For example, the facilitator guided each group of students to build a situational story from the given proxy data to help explain the objective and action needed for each persona because the cohort struggled to find relevancy between different data types. The facilitator directed a group to devise a story that involved a given proxy map surrounded by the ocean. By incorporating the situational context, like hurricane season, the group was able to construct a scenario for locating a vulnerability in the region's telecom network to help address the objective of the persona, creating a report for a policy change. The inclusion of the story aided in creating a mental map for the student group to develop a user flow of an AI-driven dashboard that can generate contextualized reports for the persona, "Christian," who informs the domestic policymakers (Figure 2).

# 2.3 Role-playing Mindset to Innovate

# 2.3.1 Workshop

Flowchart within the ideate phase from DT required the students to imagine an optimal workflow for the personas. To enhance the learning outcome, a guest facilitator from the E-commerce industry conducted a virtual workshop concerning a novel solution for designing a flowchart for personas in the medical field.

DT	N THINKING (DT) Understand same + Ritie playing Define problem + Benytalling Undersyna Prestayne Prestaware + Ritie-playing Angeweent	DIL	DESIGN INQUIRY OF LEARNING (DLL)  1. Educational challenge 2. Lidentify pedagogical approach 3. Imighte Free past Innexations 4. Index 5. Protoches 5. Protoches 6. Areas of Improvement 7. Reflection
Collect + Review Data	Educational Challenge	Challenge The tack of situati students resulted user story within i	ional information given to the in ambiguity when constructing a DT.
	Add a Synthetic Situation	<ul> <li>Situational Scenar</li> </ul>	io Contextualized Story

Figure 2. Storytelling in the DT's Define Phase

The prompt from the workshop facilitator reflected the complexity often presented in e-commerce and health sectors' ideating workflows that require data-driven products like the sponsored project from the IC. In collaboration with the guest workshop facilitator, the study deliberately created ambiguity in the workshop activity to foster innovation and to engage the cohort in developing their ability to recognize opportunities for new approaches through a role-playing mindset. The students communicated the benefit of participating in the workshop, which involved the cohort acting as an artificial design team to solve problems for employees and customers using an enterprise digital product. The session lessened the frustrations expressed by the students, especially when they realized the parallel between the workshop and the funded project that required the role-playing mindset to be comfortable with the presence of ambiguity in the design process.

# 2.3.2 Internal Usability Testing of the Dashboard Solution

The study conducted external and internal usability testing after completing a prototype draft in Figma with preview links that can be accessed through any web browser. The prototype link with a few questions was sent to the sponsors for the data analysts' virtual feedback due to the security and logistical restrictions of being unable to conduct the session in person. While waiting on the user feedback, the study asked each student group to access the other team's workflow, acting out as their assigned persona. Each team member had not seen the progress of different groups' dashboard solutions since the rough wireframe stage to mitigate bias. The student testers entered the lap one at a time to prohibit each student from sharing the results of individual walkthroughs. They were screen-recorded using a facilitator's laptop to locate areas of improvement. Compared to the feature-driven sponsor comments, the role-playing students provided insightful navigational feedback, allowing each group to revisit their design solution with a clear direction. (Figure 3).



Figure 3. Role-Playing in the DT's Feedback Phase

# **3 CONCLUSIONS**

During the nine-week studio sessions, the study recognizes designing a novel AI feature in a data dashboard for IC requires a UX UI design practitioner to navigate through ambiguity, especially in the

understanding, defining, ideating, and validating phases of the DT. The undergraduate students struggled when constructing user stories and flow charts from the proxy data the sponsor provided without much detail on a user's environmental, technological, or behavioural context in utilizing the current dashboard. This allowed the study to identify pedagogical opportunities to incorporate storytelling and role-playing activities to reduce learning challenges. The storytelling mindset encouraged the students to construct a situational scenario to find relevance among proxy data and establish the design direction. Role-playing as a user group when conducting internal usability testing improved learning about the method while receiving valuable feedback from peers. The students expressed that the internal usability testing was more useful than the written feedback from the sponsors because they could see their peers' behavioural responses when struggling to navigate a specific part of the prototype. The sponsor user group could not attend the usability testing in person due to the restriction in revealing their identity to the public. Activities like interactive gaming and flowchart workshops also mitigated the students' frustrations of not knowing the current state of user needs concerning the technology in place and their workflow, especially in the early stage of the project cycle. With a few student participants, this qualitative study gained much of its in-depth insights to answer educational challenges within a specific DT cycle and deliver a speculative AI dashboard design outcome to the IC sponsor during the final presentation.

Therefore, the study advocates a learning environment that includes role-playing and storytelling activities in the DT process for developing new technological digital product features when partnering with sponsors to work with sensitive data. Furthermore, exploring different role-playing and storytelling pedagogical methods to increase contextualized understanding about the user without jeopardizing the exposure of restricted information will advance the learning experience for undergraduate UX design students, taking on the challenge of solving ambiguous problems in designing a new AI product features for any industry sectors working with protected data.

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# PRODUCT DESIGN METHODS WITH RECYCLED MATERIALS BASED ON BIOMIMICRY

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# ABSTRACT

The damage that human activities have caused to our planet is undeniable, especially since the Industrial Revolution. We are in the era of the Anthropocene: characterized by the excessive consumption of natural resources and the generation of greenhouse gases, which have had a significant impact on the climate and biodiversity. Fortunately, in recent years related initiatives have emerged to reverse the above. Some of them are zero waste, recycling, downcycling and upcycling design, related to the reduction and maximum use of waste, as well as the extension of the useful life of products and/or the use of their materials. The circular economy, a production and consumption model that allows the useful life of products to be extended, has also brought benefits to the environment, the economy, and people. In congruence with the above, in the Product Design course, last year elective open course of the Industrial Design program, two design methods have been proposed based on the Biomimicry design spirals, for the development of products based on the use of recycled materials, especially derived from wood and plastics. The general objective of this work is to disseminate the new design methods and share the first results of their implementation. This paper shows the new methods and the results of their implementation in three courses, taught to students from different disciplines, this in the academic periods Summer 2022, February-June 2023 semester, and August-December 2023 semester.

*Keywords: Recycling design, biomimicry spirals, higher education, professional education, educational innovation* 

# **1** INTRODUCTION

The overexploitation of natural resources has caused great damage to our planet, within an insatiable capitalist and consumerist system. An example of the above is the abuse in the manufacturing-consumption of products with plastic materials: There is evidence of the presence of microplastics (small plastic particles) in all the seas and oceans of the world, which represents a great danger to ecosystems. marine and for the human being himself. One of the professions that has contributed to this degradation of the planet is, unfortunately, industrial design. Discipline that emerged from the Industrial Revolution and whose initial mission was the configuration of objects for mass production. Although industrial design tries to improve people's quality of life, it has also been (most of the time) just another cog in the complex machinery of capitalism-consumerism.

In response to the above, and for some decades now, there have been efforts to rethink the profession, as is the case of the German designer Dieter Rams and his 10 principles of Good Design [1]. These principles state that a well-designed product should contribute to the conservation of the environment, through the better use of natural resources and the reduction of pollution throughout its entire life cycle. These principles are reflected in design methodologies, focused on solving human problems and needs through the development of products and services. Among these methodologies we can highlight the biomimicry spirals, which allow the development of products with the lowest possible impact and with nature as a reference [2].

Biomimicry, for its part and since the end of the last century, offers an empathetic and interconnected understanding of how life works; It is a practice that learns and imitates the strategies that living species use today. The goal is to create products, processes and systems, new ways of life, that solve our greatest design challenges sustainably and in solidarity with all life on earth. Biomimicry is about valuing nature for what we can learn, not for what we can extract, harvest, or domesticate. In the process, we learn about ourselves, our purpose, and our connection to each other and our home on earth [3].

Another initiative from industrial design is recycling design, which can be defined as the design of products based on waste materials/products, where the original form/function is lost, and the important thing is the raw material. A clear example of recycled design are products made with recycled plastics such as PS (Polystyrene), PP (Polypropylene) and PE (Polyethylene). A great advantage of this type of products is that eventually, at the end of their useful life, they can be raw material for new products. The possibility of cutting, roughing and/or grinding makes it easy to reuse these materials for a long time, without the need to use virgin material.

# **2 METHODOLOGIES**

The innovation presented can be defined as the development and application of a new product design methodologies based on recycling and the biomimicry design methodologies (spirals) "From biology to design" and "Challenge to biology" [2]. It is important to mention that, although the reference methodologies are used for the development of products with low environmental impact and taking nature as an example, they are not designed for the creation of products based on waste materials. Strategies and means for recycling materials exist [4][5], but there is little evidence of exclusive design methods for the development of products based on recycled materials. Figure 1 describes the Biomimicry design spirals "From biology to design" and "Challenge to biology".



Figure 1. Biomimicry design spirals

The first new product design methodology is described below, based on the biomimicry design spiral "From biology to design":

- **Discover.** Identify available waste materials.
- Abstract. Identify the properties of the available materials: hardness, colour, thickness, opacity, etc. and its manufacturing possibilities: cutting, roughing, bending, thermoforming, joining, etc.
- **Brainstorming.** Explore the possibilities of transformation, product typology, use/function.
- **Emulate.** Choose the final product proposal using an evaluation matrix. Make models for validation.
- **Evaluate.** Evaluate under the criteria of Life Principles.

On the other hand, the second new product design methodology is described below, for a design based on waste materials, and based on the biomimicry design spiral "Challenge to biology":

- Identify. Identify a need or define a type of product.
- **Interpret.** Identifies requirements and restrictions of the materials required for the product.
- Discover. Identifies available waste materials and defines the ideal materials for your product.
- Abstract. Identify the properties of the available materials: hardness, colour, thickness, opacity, etc. and its manufacturing possibilities: cutting, roughing, bending, thermoforming, temporary/permanent joining, etc.
- Emulate. Choose the final product proposal using an evaluation matrix. Make models for validation.
- **Evaluate.** Evaluate under the criteria of Life Principles.

It is important to mention that it was considered to maintain the essence of Biomimicry [6], the practice of imitating life and nature, but applying it to the creation of products with the lowest possible ecological impact and taking nature as an example to follow. The new methodologies aim to be inspired by nature

engineering to solve the world's pressing challenges and guarantee a sustainable future for all life on earth, through the maximum use of waste materials.

Regarding the application of these new methodologies, the information on the implementations is presented in Table 1.

Implementation of methodologies							
Information of imp	olementations	Implementation 1 Implementat Summer 2022 February-June		on 2 2023	n 2 Implementation 3 1023 August-December 2023		
	Number of students	11 27			24		
Product Design group information	Academic programs	Architecture (3) Communication (3) Industrial design (3) Animation and digital art (1) Entrepreneurship (1)	Architecture (1) Architecture (1), Cor Communication (1) Animation and digit Industrial design (13) Digital Systems Engin Animation and digital art (11) Engineering (2), Biotec Mechanical Engineering (1) (1), Business Admit Engineering		mmunication (1), Industrial design (1), tal art (7), Mechanical Engineering (3) eering and Robotics (1), Food Industry hnology (1), Mechatronics (3), Marketing nistration (1), Industrial and Systems, (1), International Relations (1)		
	Methodology	From biology to design					
Project 1 information	Individual/Team	Individual		Teams of 3		Teams of 3-4	
	Training partner	No		No		No	
Project 2 information	Methodology			Challenge to biology			
	Individual/Team	Teams of 2-3	3	Teams of 3		Teams of 3-4	
	Training partner	Yes		Yes		Yes	

Table 1. Implementation of methodologies

As can be seen in Table 1, the two methodologies developed specifically for the development of products based on recycled materials were implemented for the first time in an optional Product Design course. In this first implementation, carried out in Summer 2022, the methodologies were tested with academic projects and considering a Training Partner for advice and technical support. The training partner was Eng. Rubén Barrera from Precious Plastic León [7].

Similarly, the following two implementations conducted in February-June 2023 and August-December 2023 were applied in elective courses on Product Design. These periods were longer than the first implementation and involved a larger number of students and a greater diversity of disciplines. In both semesters of 2023, we had the participation of the Training Partner Kids Club Campus Querétaro, who requested our assistance in developing educational materials and products for the children attending the program.

# 3 RESULTS

Some of the results of the implementation of new design methodology based on recycling and based on biomimicry spiral "From biology to design", can be seen in Fig. 2.



Figure 2. Examples of products with methodology based on biomimicry spiral "From biology to design"

To carry out these product proposals, scrap materials were used such as wood, foamboard, acrylic, clothes hanger, thread, among others. The intention was to develop products that contemplate simple transformations and that fulfil simple functions, such as structuring, supporting, containing, among others. No mechanisms were considered.

In this same summer period, a second project was carried out based on the methodology created based on the biomimicry spiral "Challenge to biology" and consisted of the development of products based on a specific need or defined product but considering recycled plastic as the main raw material. It is important to mention that for this project we have the advice and technical support of Rubén Barrera, from Precious Plastic León. The above was possible because in our facilities we have equipment for recycling plastics, such as a crusher, injector, extruder, laminator and moulds. In Figure 3 we can see results of products made with plastic recycling and with the injection process.



Figure 3. Examples of products with methodology based on biomimicry spiral "Challenge to biology"

In this second project of the first execution, recycled plastic materials were used, specifically polyethylene, polystyrene, and polypropylene. The idea, in this second project, was to make simple products based on processes such as lamination and injection.

In the February-June 2023 iteration, Project 1 entailed the design of products utilizing waste materials. These materials encompassed acrylic, foam PVC, wood and its derivatives, foam board, screws, fabric, among others. The methodology employed for this project was "From Biology to Design," which facilitated the unfettered development of products ranging from small-scale pieces to furniture. Drawing upon research and information gathered from the CES-Edupack software [8], the physical properties and transformation capabilities of the waste materials were considered. Most students hailed from creative disciplines closely tied to design. Below (Figure 4) are examples of the products developed:



Figure 4. Examples of products with methodology based on biomimicry spiral "From biology to design" February-June 2023

The second project in this same period was developed using the "Challenge to Biology" methodology, inspired by the biomimicry spiral, and focused on creating products to meet the needs of the Training Partner Kids Club Campus Querétaro. The material requirement was to use a minimum of 60% recycled plastic in their product, mostly polyethylene and polypropylene. Additionally, they received guidance and technical support from Rubén Barrera of Precious Plastic León. They used plastic recycling equipment such as a shredder, injector, extruder, laminator, moulds, and dies available in our facilities. It is worth mentioning that, for the use of both methodologies, it was required to follow the Principles of Life: form follows function, optimal use of material, benign manufacturing, self-assembly and resilience. These principles governed its design and decision making for the use of material and the shape of its product. Examples of the products created are shown in Figure 5.



Figure 5. Examples of products with methodology based on biomimicry spiral "Challenge to biology" February-June 2023

In the August-December 2023 version, the requirements remained the same as the previous semester, although there was greater diversity in disciplines, most of them unrelated to design. Additionally, some students had never used machinery before. In this iteration, glass was included as an alternative material for Project 1. For Project 2, some students designed their own moulds and experimented with other processes to transform plastics. Images of the results are depicted in Figures 6 and 7.



Figure 6. Examples of products with methodology based on biomimicry spiral "From biology to design" August-December 2023



Figure 7. Examples of products with methodology based on biomimicry spiral "Challenge to biology" August-December 2023

As part of the Evaluate stage, students evaluated their project with the criteria of Life Principles and the Eco-Design Wheel and proposed a business model. In their conclusions they showed a genuine interest in the process and the importance of the meaning of the project. Quoting a group of students from this latest iteration "...the project demonstrates that sustainability can coexist with functionality to generate a product with human meaning; and the difficulties encountered offer valuable lessons for future similar projects."

# 4 CONCLUSIONS

As first experiences applying the developed methodologies, it is considered that they were a success in general terms. Beyond the results obtained, the most important thing was the fact of sowing the seeds of ecological awareness among the participating students. A genuine interest, commitment and awareness with the preservation of the environment could be observed. The possibility of new design solutions with less environmental impact is a lesson learned, but they even discovered new business ideas around the development of products based on recycling.

There are many design methods, but developing a unique approach for designing with recycled materials is crucial in an increasingly environmentally conscious world. It is fundamental to recognize and educate about the negative impact of excessive waste production on the environment. Designs using recycled materials can help reduce the amount of waste ending up in landfills, thereby decreasing pollution and environmental degradation [9]. Nature serves as a perfect model of efficiency and sustainability. By

observing how ecosystems function in nature, designers can draw inspiration to create products and systems that mimic these principles [10]. It is necessary to create methodologies and design tools that focus on recycled materials, including techniques for selecting, treating, and transforming them into design products. Additionally, guidelines are established for designing products that facilitate their disassembly and recycling at the end of their life cycle. Designing with recycled materials requires close collaboration among designers, engineers, materials scientists, and sustainability experts. It is important to educate both designers and the public about the importance and possibilities of designing with recycled materials.

Regarding the students' feelings in these first experiences, we can affirm that they were well received in general terms. The students maintained great interest and a good attitude in the development of the projects. This was reflected in the ECOA (Student Opinion Survey), with a very high numerical rating and very positive comments such as the following: "...I loved the content we saw, both projects were a great challenge". "I love that being such a diverse group, you were able to adapt so that everyone could bring out their greatest potential". "The project demonstrates that sustainability can coexist with functionality to generate a product with human significance; and the difficulties encountered provide valuable lessons for future similar projects."

In summary, developing a unique approach to designing with recycled materials involves not only creating innovative products but also a shift in the mindset and culture of design towards sustainability and respect for the environment.

# **5 FUTURE WORK**

Due to changes in the academic plan, this exercise cannot be reapplied to this course. However, it is planned to implement it in the last third of this first semester in another Learning Unit (Creative Thinking Methodologies) with first-year students from different disciplines in the School of Architecture, Art, and Design, and the School of Humanities. This will allow us to instil sustainable awareness and introduce methodologies from early stages of their careers so they can practice them throughout their studies for a longer period. The available time for its implementation in this course will be 5 weeks, equivalent to 20 hours, shorter than previous exercises.

Additionally, it is planned to implement this educational innovation with university students in short workshops at Design Conferences to disseminate the methodology in other spaces.

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# EMPATHETIC INNOVATION: HARNESSING DESIGN THINKING FOR SUSTAINABLE AND INCLUSIVE BRAILLE PACKAGING SOLUTIONS AND IMPACT ON SUSTAINABLE DEVELOPMENT GOALS (SDG)

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# ABSTRACT

This paper presents an approach to packaging innovation through the integration of Design Thinking with a specific focus on Braille packaging. The problem regarding visually impaired individuals face challenges in accessing important information, particularly on product packaging. Traditional packaging often lacks inclusivity, as it doesn't accommodate the needs of the visually impaired. This presents a barrier to independence and can lead to exclusion from essential goods and services. The objective of this study is to explore the application of design thinking principles to develop sustainable and inclusive Braille packaging solutions. By leveraging empathy and creativity, the aim is to create packaging that not only meets the functional needs of the visually impaired but also aligns with sustainable development goals (SDGs). Through this approach, the study seeks to promote accessibility, independence, and social inclusion for visually impaired individuals while advancing environmental sustainability. Applying Design Thinking's empathetic and user-centric methodologies, by creating packaging solutions that are not only ecologically sound but also accessible to visually impaired consumers. The methodology includes iterative process of prototyping and feedback inherent in Design Thinking allows for the exploration of tactile elements in packaging, with Braille as a central feature. The study resulted in the development of innovative Braille packaging solutions that are not only accessible and user-friendly for visually impaired individuals but also environmentally sustainable. Through the application of design thinking principles, the packaging designs incorporate features such as easy-to-read Braille labels, tactile cues, and eco-friendly materials. Moreover, the adoption of these solutions contributes to several SDGs, including Goal 8 (Decent Work and Economic Growth), Goal 10 (Reduced Inequalities) and Goal 17(Partnerships for the Goals). The findings highlight the potential of empathetic innovation to drive positive social impact and support sustainable development initiatives.

*Keywords: Braille accessibility, consumer-centric innovation, design thinking, inclusive design, sustainable packaging* 

# **1** INTRODUCTION

The majority of working-age blind people are unemployed (74 percent) and depend on support such as disability income benefits [1]. It is estimated that the lost productivity due to blindness and eye diseases is \$8.0 billion per year in the United States. Of the 26 percent of blind people who are employed, the majority of them are braille readers. The correlation is clear braille is an extremely important tool for blind people to become literate, and it is a critical component that supports educational advancement and increases employment prospects. We celebrate World Braille Day every year on January 4th because it's Louis Braille's birthday. He's the inventor of braille. Louis was born in 1809 in France and became blind after a childhood accident. But he quickly mastered his new way of living. According to National Braille Press, research shows that braille literacy directly correlates with academic achievement and employment. Donuts make an ideal choice for Braille packaging to raise awareness about Braille culture because they're a universally loved treat. By integrating Braille into donut packaging, it reaches a broad audience, fostering understanding and inclusivity. It's a simple yet effective way to promote the

significance of Braille in our diverse society. The concept of Braille packaging for donuts involves inclusivity. By incorporating Braille on flavour choices, it allows blind or visually impaired individuals to independently select their preferred donut flavour. This inclusive design promotes accessibility and empowers all customers to make informed choices, enhancing their dining experience. People with the ability to see should be aware of Braille because it is a tactile writing system that enables those who are blind or visually impaired to read and communicate. Understanding Braille promotes inclusivity and accessibility, allowing sighted individuals to assist and interact with the visually impaired community. Knowledge of Braille can lead to more diverse employment opportunities, fostering a more inclusive society.

# **2 TRIANGULATION STRATEGY**



Figure 1. A Visual Diagram of the Mixed-Methods Concurrent Triangulation Strategy

To investigate the integration of Design Thinking into Braille packaging innovation, our methodology was structured in a multi-phase approach. Initially, we conducted a comprehensive literature review to establish a theoretical foundation in the domains of Design Thinking, sustainable packaging, and accessibility standards. Subsequent phases involved qualitative methods, primarily in-depth interviews and focus groups with stakeholders, including design professionals, sustainability experts, and members of the visually impaired community, to gather insights and validate the empathetic design principles [2]. We employed a participatory design framework, inviting visually impaired users to engage in cocreation workshops. These sessions facilitated iterative prototyping, allowing for real-time feedback and refinement of Braille packaging models. Quantitative methods were also utilized, with experiments conducted to measure the usability and environmental impact of the prototypes, comparing them against conventional packaging benchmarks.

Data triangulation ensured validity, with findings cross-verified through multiple data sources. The iterative cycles of prototyping and testing were guided by Design Thinking processes, with a focus on human-centred design, empathy mapping, and rapid prototyping. They begin to realize that the emotional factor in product design is very important in attracting customers to buy and use the product [3]. The research culminated in the development of a scalable model for Braille packaging innovation that emphasizes inclusivity and sustainability, substantiated by empirical evidence and user-centred evaluation.



# **3 INTEGRATING DESIGN THINKING INTO PACKAGING INNOVATION**

Figure 2. Design thinking methods by Nanda Nini Anggalih (2021)

Integrating design thinking into packaging innovation begins with empathizing to gain deep insights into consumer needs, Understand the consumer's needs, experiences, and motivations. Design involves, among other things, people, products, tools, and organizations [4]. For packaging, this might involve researching how users interact with similar products and what issues they face, such as difficulty opening the package or disposing of it. Followed by defining the specific packaging problems that need addressing. Clearly articulate the problem you are trying to solve. In terms of packaging, this could mean defining specific goals like reducing material use, increasing functionality, or enhancing user experience.

The ideation process then allows for the generation of creative solutions. Generate a wide array of ideas and potential solutions. Brainstorming sessions with diverse teams can lead to creative packaging concepts that are both functional and aesthetically pleasing.

After which prototypes are developed to bring these ideas into the tangible realm. Create scaled-down versions of the product packaging to explore the potential solutions. Prototypes can be used to test the functionality, durability, and user interaction with the packaging. Testing these prototypes with users is crucial to gather feedback and refine the design, leading up to the final implementation where the packaging is prepared for production and distribution. As stated by Nanda Nini Anggalih Packaging design prototypes were developed based on the observation results, including primary and secondary packaging, which can be applied according to the availability of local resources. Share your prototypes with a wider audience to gain feedback [5].

Testing packaging designs with actual users can reveal practical issues and areas for improvement that may not have been initially apparent. Take the final design and prepare it for production. This involves finalizing the design details, selecting materials, and considering the manufacturing process. This approach ensures that the packaging not only meets functional requirements but also resonates with consumers on a practical and emotional level. Therefore, active packaging is the component that takes some action, while intelligent packaging is the component that senses and shares the information. Intelligent and active packaging can, almost inevitably, work in synergy to create what is called a "smart" packaging.



Figure 3. Technical Drawing(left) and Layout Design(right) for Donut packaging with Braille



# 4 BRAILLE-ENHANCED PACKAGING FOR INCLUSIVITY IN FOOD PRODUCTS

Figure 4. Donut packaging with Braille on flavours

Mastery of braille letters is the basis for incoming knowledge as input from the reading process experienced by children with visual impairments, this process of mastering braille greatly affects the quality of literacy that is owned, not only the quantity that children can read, but also concepts ranging from mastery of letters to awareness of differences. arrangement of words in words and sentences [6], for Arabic, it greatly affects word mastery or phonological as well as the use of numbers and braille codes.

Imagine a donut box, elegantly designed with both visual and tactile elements [7]. Where one sees the words "White Chocolate" or "Tiramisu," another feels the distinct dots spelling out the flavours in braille. This simple yet profound integration of braille into food packaging design can create a ripple effect, encouraging other brands to follow suit and prioritize accessibility [8]. In order to make the product explicit, at the concrete level, we also discovered that the designer continued with the use of hand posture activity in order to get a feeling for the tactility (responsiveness to stimulation of the sense

of touch) [9,10]. The process begins with empathizing with the visually impaired community, understanding their experiences and the barriers they face.

This initiative does not stop at braille; it is about rethinking how we can make everyday experiences more accessible to everyone. By choosing food packaging that incorporates braille, we can use design thinking to create a more inclusive world. It's about offering a touch of insight, one donut box at a time, and ensuring that pleasure in the little things like choosing a donut is an experience shared by all.

# **5 UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS**

By addressing these goals through braille food packaging innovation, stakeholders can contribute to a more inclusive economy that benefits everyone, particularly those with disabilities, while also fostering a culture of sustainable and equitable development. An in-depth sustainability analysis (e.g., environmental or social live circle assessment) could not be performed with the SDG-Check. For an effective sustainability analysis (e.g., with the hotspot analysis) this would be sensible: the selection of the goal and targets does not necessarily have to be the most significant sustainability potential of the innovation. The selection is based on a self-assessment, which can be used as a basis for the further dialogue and should be evaluated by other experts [11]. Goals to be reached, **Goal 8: Decent Work and Economic Growth, Goal 10: Reduced Inequalities and Goal 17: Partnerships for the Goals.** 

# **6 CONCLUDING REMARKS**

**6.1 The Role of Design Education in Promoting Inclusive and Sustainable Innovations** Braille packaging solutions. Product emotion study is based upon the form's origin, which is also the influence of user emotion and product characteristics. It is important to understand the relationship between basic form and the products character so that the designer can achieve the goals of design and target their user by the product emotion. Design education is intrinsically linked to the approach described in the abstract through its emphasis on Design Thinking and practical applications for realworld problems. Design Thinking's core principles empathy, creativity, and an iterative process are central to design education. Students learn to empathize deeply with users' needs, mirroring the abstract's focus on understanding the challenges faced by visually impaired individuals. The creative problemsolving and ideation skills developed in design education led to innovative solutions, such as the Braille packaging highlighted in the study. Moreover, the iterative process of prototyping and feedback, a fundamental aspect of Design Thinking, is a key part of design education curricula.

In addition to fostering innovation, design education emphasizes inclusivity and accessibility, teaching students to create products that cater to diverse populations.

Practical skills such as prototyping, feedback incorporation, and sustainable material selection are also central to design education. Students are taught to iteratively develop and refine their prototypes, as described in the abstract, ensuring that the final products meet user needs effectively.

and responsibly. The emphasis on using eco-friendly materials in packaging design mirrors the lessons in sustainability that design students learn. Through these practices, students are equipped to balance functionality with environmental impact, creating sustainable and responsible designs.

Moreover, design education instils the value of empathetic innovation, encouraging students to create solutions that have a positive social impact. The study focuses on promoting accessibility, independence, and social inclusion for visually impaired individuals through design aligns with these educational goals. Ethical considerations and the societal implications of design are integral to the curriculum, ensuring that students understand their responsibility to create inclusive and beneficial solutions. Collaborative efforts, emphasized in the abstract through partnerships for achieving SDGs, are also fostered in design education through group projects and interdisciplinary collaborations.

The empathy-driven design process, coupled with a focus on sustainability, not only addresses the immediate needs of a specific user group but also contributes to the broader global agenda of sustainable development. This innovative approach demonstrates the potential for design thinking to be a force for positive change, pushing the boundaries of conventional packaging norms to embrace a more inclusive and environmentally conscious future. the outcome from the analysis of image's scenario will help designers to expand their design thinking and reasoning parameters by reflecting the subtle interaction existed between the users and the products, which identified the user's need and be inspired to create an innovative product design concept. As we move forward, the lessons learned from this exploration can serve as inspiration for future endeavours that seek to harmonize innovation, empathy, and sustainability for the betterment of society and the achievement of the SDGs.

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# PERCEPTIONS OF LECTURERS OF ARTIFICIAL INTELLIGENCE ON INDUSTRIAL DESIGN STUDENTS

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# ABSTRACT

The industrial design process consisting of activities discovering, defining and solving problems represents the designer's thinking cognition and innovation ability. However, with the emergence of artificial intelligence (AI) technology, there is a potential for designers to incorporate unintended problems into their design solution. For example, a false information, or bias error and ethical imbalance can infinitely amplified through computer coding incorrect design solutions. If the teachers have poor understanding of the AI limitations this may have devastating impact on the development of future industrial designers. This paper surveyed Industrial Design teachers in China. The survey aimed to explore the Industrial Design teachers' understanding of AI role in the design process. The following questions guided this study: How do teachers envisage the use of AI by their students? Do they think that the AI may affect students' creative behaviour? First, we reviewed literature to understand the AI potential to inform industrial design activities. Then we examined the feasibility of AI intervention in the design innovation process. The results indicate that teachers believe that AI, as a design tool, can facilitate industrial design students to generate design solutions faster. Nevertheless, the data also indicate that AI does not provided students with learning opportunities and development related to creativity skills.

Key words: Creative behaviour, AI, curriculum, design process, design education

# **1** INTRODUCTION

Wang points out that the emergence of generative AI is challenging the systematic knowledge of teaching in higher education [1] and according to Edwards and Cheok [2] the emergence of AI may directly change the development of the education industry as it is expected that AI will play the role of teachers and support students to answer questions at any given time. However, Kaudi et al. mentioned that there is still a big gap between AI educational technologies and how they are actually implemented [3]. Assuming that AI can participate in or replace a certain role in the design process, may also indirectly affect how teachers engage in cultivation of students' creativity skills. Therefore, in the facing this new situation, we are interested to understand how design teachers view use of AI by design students.

# 2 RESEARCH OBJECTIVES AND METHODS

In order to understand Industrial design teachers' perspectives how may AI impact on design students' creative behaviour, this study conducted a questionnaire survey on the teachers of industrial design major, the research consists of four parts:

- (1) Review the role of teachers in the design process of students in different teaching situations, and summarize the influence of teachers on students' creative behaviour.
- (2) Analyse the possibility of AI assuming a certain role in the design process.
- (3) Survey questionnaire's design and distribution.
- (4) Analyse the questionnaire data and draw conclusions.

This study aims to analyse the potential of AI in industrial design student activities through teachers' perspectives towards students' use of AI, so as to further provide more reference suggestions for optimizing teaching activities and cultivating the creativity of industrial design students.

# **3 LITERATURE REVIEW**

## 3.1 The role of the teacher in the student design process

Ababio mentioned that teachers, as guides in the teaching process, play a very important role in teaching knowledge, organizing and planning teaching activities, and evaluating students' creativity development [4]. Kuok et al. advocated that project–based learning (PJBL) and problem–based learning (PBL), can promote student–centred teaching strategies also help students to better understand design problems [5]. Although both PBL and PJBL are defined as student centred difference is that PBL may not incorporate actual project, whereas according to Sofie et al. PJBL core feature is the project, driven by the problem. They suggest that in this mode of teaching the teachers assume the role of mentors or "consultants" [6]. Nevertheless, Lehman et al. suggested that the core relevance of PJBL and PBL is to solve real–world problems [7]. Based on the above content, this paper summarizes the roles of teachers in two different teaching situations as illustrated in Figure 1.



Figure 1. Teacher's role in design process

As the subject of imparts knowledge, teachers need to assume the roles of guiding, motivating, analysing, giving feedback and improving students' design schemes during the design process. Students can decide what design knowledge to apply according to the design problems to be solved through generating creative ideas. Yun et al. pointed out that students' creative behaviour runs through the process of finding problems and using knowledge to solve problems, and knowledge plays a very important role in the production of creative behaviour [8]. Therefore, we argue that the role of the teachers in the student design process is dynamic, and the core of the teachers role is to guide students through the design process to facilitate students to identify, solve problems and to implement new solutions, and ultimately to promote the creative ideas generated by the design students.

## 3.2 Al and the design process

Bellman understood AI as the automation of computer activities associated with human thought processes, decision-making, problem solving, and learning [9]. Sony, Pat and GPT-3 pointed that generative AI has advantages in editing text, code development, and video and renderings production, which can increase the efficiency or creativity of designers engaged in knowledge and creative work by at least 10%. This makes the design output of designers not only faster and more efficient, but also more capable than ever before [10]. However, Miao pointed out that the ability of AI to communicate and solve problems with the language understood by human beings is far from that of human beings. From the generation of design knowledge to the communication and interaction of design teams, design problems are redefined, understood and handled by people in a "real" environment. The generative model constructed by the neural network model cannot, like the human brain, select appropriate concepts to process information correctly according to the language environment and information text [11]. Combining the above advantages and challenges brought by AI and human collaboration, it also further highlights the necessity of in-depth research on whether AI will affect students' creative behaviour. This study attempts to re-examine how students may use AI in the design process from the perspective of the teachers, aiming to investigate the impact of AI on the cultivation of students' creativity in design process.

# **4 QUESTIONNAIRE DESIGN AND DISTRIBUTION**

#### 4.1 Questionnaire content

The questionnaire was compiled, with a total of 15 questions. The questionnaire was divided into two parts. The first part consisted of 3 questions to investigate the level of design skills the teachers think students majoring in industrial design should possess; the second part consisted of 12 questions,

specifically investigated teachers' attitudes toward students' use of AI, the fields in which students may use AI and the perceived ethical standards for students' using AI.

The second part of the survey contained two scale questions. Cronbach's coefficient was 0.804, which indicates high reliability, and the KMO value was 0.5, which met the to the standard values of the two scale items. The P value was less than 0.01, which reached a significant level, indicating that the reliability and validity of the two scale questions were good. Secondly, in order to ensure the validity of the overall questionnaire, two experts were invited to adjust the dimensions and contents of the questionnaire which was distributed online through WeChat and other online apps. To supplement the survey data, 6 teachers with long term teaching experience were interviewed. All interviewed teachers work in the top 20 universities of industrial design as indicated by the Soft Science Ranking 2023. The questionnaire was made available online for about 5 weeks. A total of 170 questionnaires were collected, of which 168 were valid. Excel 2010 was used for data entry and screening, and SPSS.29 was used to undertake the statistical data analysis.

#### 4.2 Survey data analysis

#### 4.2.1 Teachers' evaluation criteria for industrial design students

In the first part of the questionnaire, questions in  $1^{st}$  and  $2^{nd}$  parts consisted of multiple-choice questions, and the  $3^{rd}$  part of the survey included an open textbox to allow the survey participants to provide textual data. The first two parts of the survey investigated design skills that teachers thought industrial design students should have by end of their graduation, and  $3^{rd}$  part of the survey asked the participants to describe 5 criteria for evaluating industrial design talents. The Figures 2 and 3 provide sorted results according to the frequency each of the items was selected).



Figure 2. Evaluation criteria for industrial design students' skills

As indicated in the Figure 2, the most teachers perceived that the professional skills required by industrial design students are more reflected by the prototyping process of products, from developing product concepts (ranked 4<sup>th</sup>), drafting (ranked 3<sup>rd</sup>), building product models (ranked 1<sup>st</sup>) and testing product models (ranked 2<sup>nd</sup>), only a few teachers focused on products cost budget (ranked 25<sup>th</sup>), product support (ranked 29<sup>th</sup>), user trials (ranked 30<sup>th</sup>) and the use of new technologies (ranked 28<sup>th</sup>), such as AI.



Figure 3. Skills to be improved for industrial design students

As indicated in the Figure 3, the most teachers selected areas that students should focus on to improve when design a product are: (i) product safety, (ii) perceived value, (iii) quality and (iv) product usability. Some teachers mentioned the importance of innovation when choosing other options, but did not mention the impact of new technology on product design. According to the data collected in Q3, 75% (n=126) of teachers mentioned creativity, teamwork, communication and drawing skills as the key indicators of industrial design talent training, and only 9% (n=15) of the teachers stressed the importance of personal moral literacy and new technologies such as AI for industrial design talent training. Nearly a third of the respondents (29%, n=44) have not provided answers to this question. Potentially indicating that they may have no clear idea on the specific skills their industrial design students should be able to demonstrate. To sum up, it was found that most teachers have not perceived the impact of new technologies such as AI on the training of industrial design students. How to optimize the performance of products is still perceived by the teachers a key design skill that industrial design students need to demonstrate, and teamwork is seen as an important way to solve design problems. For students, the ability to collaborate and communicate among teams on the basis of professional drawing skills is also perceived as important ability for students to have demonstrate during the design team cooperation to achieve generation of creative ideas.

#### 4.2.2 Teachers' evaluation of students' use of AI

This section covers these four categories: (a) teachers' attitudes towards students' use of AI, (b) areas in which students use AI, (c) assessing students' use of AI, (d) ethical standards for students' use of AI. The data extracted from (a) indicate that 82% (n=137) of teachers support students' use of AI in design activities, while 18% (n=30) are opposed. This indicates that most of the teachers are optimistic about the development of AI in the field of industrial design teaching especially in the context of big data information.

In category (b), 55% (n=92) of teachers believe that students should know how to use AI, which is necessary for students to rationally use AI technology in the design process. In contrast, 59% (n=99) of teachers believe that students should know more about the operation process of AI technology, but this has no significant impact on students' literacy ability to use AI. Just as when we use a mobile phone developed by a new technology, we don't need to understand how the technology was developed and used in the mobile phone, because it will not help us to use the mobile phone.

More than 55% (n=92) of teachers believed that students frequently used AI in the fields of providing creative ideas, completing renderings, video production, designing questionnaires and writing thesis (as shown in Table 1); Secondly, 70% (n=117) of teachers believed that AI helped students complete design schemes faster, 63% (n=105) believed that AI helped students produce more creative ideas, and 54% (n=90) believed that AI helped students improve their design abilities. From the perspective of teachers, AI can help students save time in processing information, most replacing students' work of thinking about problems and putting forward design ideas in the design process, which is also the most important link for students to generate creative ideas. Amabile mentioned that finding problems is a part of creativity. The process of creations is not a current process (algorithm) with clear goals, but a heuristic [12]. Therefore, AI can't provide students with more opportunities to cultivate creativity in the design process, and even limit the development of students' creativity to a certain extent.

More than 80% (n=136) of teachers indicated that AI may make students overly dependent on technology, thus affecting students' ability to think independently, and 32% (n=53) of teachers mention that AI may leak students' personal information, potentially causing security risks.

Multiple questions	Category	Frequency	Percentage
	Provide creative ideas	111	66%
(Teachers' viewpoints)	Complete renderings or video production	108	64%
How will students use	Design questionnaire	96	57%
AI?	Literary creation (thesis)	93	55%
	Write and debug computer programs	66	39%
	Derive data	63	38%
	Others	0	0%
	Category	Frequency	Percentage
	Quickly complete the design scheme	117	70%

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(Teachers' viewpoints)	Generate more creative ideas	105	63%
In what ways can AI help	Improve students' design ability	90	54%
students?	Improve student learning effect	54	32%
	Discover the nature of design problems	51	30%
	Others	0	0%

In category (c) of the survey, 73% (n=122) of teachers indicated that they can independently distinguish the works completed by AI from those completed by students. They stated that compared with the works completed by students, teachers believed that the works completed by AI lack the emotional of human integration. Secondly, they stated that the works completed by AI are more perfect in terms of integrity and professional skills. In addition, in the teaching process, teachers are familiar with students' design ability to a certain extent, and teachers can independently identify whether the works submitted by students can meet students' design skills. However, 27% (n=45) of teachers believe that students will independently modify the work of AI participation, which will make it impossible for teachers to distinguish the authenticity of students' work, and it also involves whether students adhere to moral and ethical standards when using AI.

In category (d), the data for setting ethical standards showed that 64% (n=107) of teachers believed that students would not conduct ethical reviews of information collected by AI, because when students use AI in the design process, students will not mark the role and function of AI in their completed design works. This also indirectly showed that there is a lack of laws and regulations in the regulatory system for the development of AI in China. The imperfect supervision policy and system of AI also indirectly affect the norms of students in the use of AI, and students lack the cognitive norms and standards of ownership of knowledge output.

In addition, 93% (n=156) of teachers believed that universities should include "AI Literacy" in the evaluation criteria for training industrial design talents. However, the top 5 design skills indicated by the teachers (see Figure 2) are building product models, testing product models, drawing (technical drawings), developing product concepts, and proposing different design schemes, rather skills supporting use of AI during the design process. Plus, the use of new technology (AI) for students is only mentioned 6 times. In summary, most of the surveyed teachers believed that industrial designer students need to focus on optimizing products, and that the AI technology can only play an auxiliary role in the design process, and it cannot replace a certain role of design students in the design process.

# **5 CONCLUSIONS**

Based on the above data, the surveyed industrial design teachers (n=168) indicates that AI can't directly affect students' creative behaviour in the design process, and may even hinder to some extent students' ability to reflect on their design practice. Although, AI can greatly improve the speed of students to solve design solutions, the reason is that the AI can quickly complete information collection through input instructions and codes, thus replacing part of the process of students thinking about design problems. When describing the impact of AI on students, some teachers mentioned that along with the instructions and codes input by students, there is a cognitive deviation between AI and human brain's understanding of information, which indirectly leads to students spending more time on how to accurately describe the problems that AI can understand to complete the task instructions. This means that the teachers believe that AI can't completely replace the designer's thinking to complete the design process. As a design tool that plays an auxiliary role, AI has more advantages in completing design performance, video production and text processing. However, AI can't replace students' role of collaboration and communication in team cooperation, because designers' unique design thinking and cognitive mode are difficult to simulate by computers, such as: The ability to relate things, the personal quality to achieve innovation and creativity, the ability to make judgments and choices in a variety of complex situations, these are difficult to do through algorithms and coding, which is precisely the characteristics of designers. Designers have design experience and design cognition is an important part to promote and realize the creation of creative ideas. Finally, based on literature review and data, it shows that at present, AI cannot replace the role of teachers. Teachers still play an irreplaceable role in the design studio education environment. As Saris pointed out, three attributes of designers may be associated with the creative design process: implicit knowledge, reflective practice, and designer-like knowledge [13]. As an intermediary between students and design tools, teachers can create a space for students to meet the development of creativity at the right time, and encourage students to independently

discover knowledge that cannot be taught (tacit knowledge) in design practice. Students need continuous experience and reflection in action to generate new ideas. At the same time, teachers also need to supervise students to complete their own original design, and help students distinguish and deal with the information with cognitive bias and bias provided by AI.

In the face of the popular application of AI, this study explores Chines industrial design teachers' perception of students' use of. Although, the data samples obtained in this paper cannot represent the attitudes of all industrial design major teachers, it presents the potential limitations of the current use of AI in the design process. So, further research on how students assign teachers and the role of AI in the design process is still a topic worth exploring. In general, we must re-examine the role of AI in design activities.

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# EXPLORING THE RELATIONSHIP BETWEEN SELF-PERCEPTION OF SECURITY, CONFIDENCE, AND MOTIVATION WITH REPRESENTATION EXPERIENCE: A STUDY OBSERVING SPATIAL INTELLIGENCE

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# ABSTRACT

Entry-level drawing abilities have significantly declined, a phenomenon that is largely due to the lack of observation of the principles and practices of teaching and learning new designers. This exploratory study examines the self-perceived security, confidence and motivation of design students who possess Spatial Intelligence (S.I.), by using three well-known brand markers, through three drawing activities (D.A.), students assessed their performance. Initial findings indicate positive effects on motivation, confidence and security aspects. Our study delves into S.I. possession, drawing experience, and global experience impact on exercises, revealing no statistical difference in motivation but significant disparities in confidence and security. Non-S.I. students exhibit higher confidence and security levels, indicating a correlation between emotional aspects, self-perception, and tool familiarity. The findings open new avenues for investigation on how to approach the student profile, the choice of tools, and the teaching process to improve students' aspects in D.A. for design education (D.E.).

*Keywords: Design education, representation, spatial intelligence, higher education, educational innovation* 

# **1** INTRODUCTION

Since the last decade, there has been a notorious decline in entry-level drawing skills, which is believed to be mainly due to the methods and principles used in teaching and learning [1]. Therefore, there is a generalized deceleration in the development and progress of the students' essential skills [2]. However, the D.E. transformation focused on several aspects, e.g., on thinking by drawing and making as an ordinary skill [3]. Academic progress has been changed, which has led to studying the relationship between executive functions, motivation or self-esteem, and self-efficacy, potentiating a notable connection between beliefs in their abilities and improved academic performance [4]. For our research and in D.E. is the ability to create representations using the most appropriate tools [5]. Representations are considered the results that come from the skills of drawing, sketching, and objective and subjective drawing [6]. However, there is a debate about the importance of traditional representation, as part of D.E. focuses more on understanding information from other perspectives [7]. Nevertheless, the value of representation through drawing or sketching should always be present in different disciplines [8, 9]. Thus, representations in any of their physical variants represent an essential component in D.E. or problem-solving education, whether from an engineering perspective [10] or a more humanistic approach [11]. In either scenario, representation is a vital competence; from an early age, any design student must undergo experimentation with any tool to experience the dynamics of expressing their ideas [12]. A particularity to emphasize is, that representation competence is linked to S.I. possessing this intelligence enables an advantage for those who have an affinity with creative disciplines as there is evidence that supports the relationship between intelligence and the performance of project design [13]. S.I. brings a range of skills favouring the stimulation of relevant solutions [14, 15]. Consequently, students improve their academic results and experience by *continuously* believing in their competencies and abilities [16], and it can even represent a factor of self-confidence and security [17].
## 2 PILOT STUDY

#### 2.1 Objective

This research aims to explore the self-perceived security, confidence, and motivation of design students who possess S.I., through using different markers in multiple exercises that stimulate their representational skills.

#### 2.2 Participants

This study was conducted within a group of 50 design students from Tecnologico de Monterrey, México. All students were informed of the tasks they were going to perform. All students reported having normal vision and no colour recognition problems. The group consisted of 39 women and 11 men. These include 26 with S.I. and 24 non-S.I. Additionally, the study examined the students' drawing experience, a crucial skill for designers; 25 reported having medium-level drawing experience, while 19 claimed low-level knowledge and six claimed high. All percentages can be seen in Figure 1.



Figure 1. Graphs of participant data

## 2.3 Exercises

The core research is conducted by applying three exercises on a sheet of bond A3 paper (see Figure 2): (1) The first exercise is to identify the points of light and shadow in a three-dimensional object from an isometric perspective. A set of two solid shapes was placed in an isometric view with a sun icon for where to apply the light and shadows. Boxes must be filled with colour by given markers. (2) The second exercise is based on the basic principles of constructing an object, where students must devise an idea represented in detail based on a defined criterion. A creation of a representation of a mug, apply light and shadows to it, and preferably add a contrasting background with the given markers. (3) The third exercise was designed could raise preliminary ideas, develop a concept, and execute that idea to create a unique detailed proposal. Post-its guided the student to develop simple first ideas [18] and combine them later. Using these types of materials leads to the notion of pre-inventive structures, which focuses on internal "mental" representations, ensuring the externalization of the idea [19]. A chart divided into three sections to promote the creation of different proposals for the three parts of a lamp (the screen, body, and base) using only one marker and repeated with the other markers. Concluding the exercise, the students had to choose their favourite ideas and draw a new lamp using the best marker.



Figure 2. Exercises Sheets

## 2.4 Drawing tools

To conduct the exercises, we based our tool selections on similar studies [20, 21] that performed parallel research on D.A. In exercises aimed at enhancing four subject skills, utilizing traditional tools like markers improves conceptual outcomes in the initial design stages [22]. The given markers to each student were from the brands Chart pak© Spectra, Copic© Sketch, and Prismacolor© Premiere. To

ensure fairness and accuracy in our protocol process, we were provided colours and markers from each brand that were most similar in type and purpose (see Figure 3).



Figure 3. Photographs of the marker's lines

#### 2.5 Implementation

The exercises were applied in a well-lit classroom. The protocol begins with welcoming and explaining the process and answering any doubts before moving on to the implementation. All data and question responses were collected in an online survey using Qualtrics® (www.qualtrics.com) via each student's cell phone. The exercises lasted 35 minutes; time was assigned to each section, and every 30 seconds, the time left was announced. When an exercise was concluded, students had to answer the questions related to the exercise conducted. These questions are used to explore the student's self-perception. The employed rating scale ranged from 1 to 5, with 1 representing the lowest and 5 signifying the highest value for markers' experience:

- How much has the marker helped you to carrying out the exercises?
- How much confidence has the marker given you?
- How much motivation has the marker given you?
- How much security has the marker given you?

Following the evaluation of the tools, three global questions about self-perception were asked using the same scoring system applied in the previous questions.

- According to the following definition (Motivation): Stimulate someone or awaken their interest.
- How motivated did you feel when carrying out all the exercises?

• According to the following definition (Confidence): Satisfied with himself.

How confident did you feel carrying out all the exercises?

• According to the definition (Security): Said of a person - Who does not feel doubt.

How secure did you feel carrying out all the exercises?

Finally, the protocol ended with a quiz on the user's intelligence based on Howard Gardner's Multiple Intelligence Theory [23]. The questions were taken from existing tests to determine the type of intelligence people possess. By eliminating the prompts where "no" was the answer to the question, the test would only consider the intelligences the students felt identified with. By summing up the yeses to their respective intelligence, the test determined which type of intelligence appeared the most. The whole protocol can be seen in Figure 4.



Figure 4. Scheme of the protocol process

## **3 DATA ANALYSIS AND RESULTS**

The data analysis collected by the survey was divided into three parts of observations to detect all aspects considered during the exercise's execution with the markers. Statistical analysis was performed using SPSS 17.0 for Windows<sup>™</sup> (IBM SPSS Inc., Chicago, IL, USA). The initial results are drawn from the self-perception questions after each exercise. Table 1 shows the rating for each exercise for each marking. In the same table, we can see the result of the three global questions of students' self-perception for motivation, confidence, and security.

Table 1.	Descriptive	statistics o	of all	questions
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Exercise #1	Exercise #2	Exercise #3

	Questions (Qs)	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
olor	How much has the marker helped you to carrying out the exercises?		1.414	3.48	0.886	3.72	1.107
nac	How much confidence has the marker given you?	2.60	1.107	3.30	1.074	3.52	1.035
risn	How much motivation has the marker given you?	2.70	1.182	3.24	1.061	3.62	0.967
P.	How much security has the marker given you?	2.64	1.139	3.34	0.917	3.56	1.013
0	How much has the marker helped you to carrying out the exercises?	3.46	1.014	2.88	1.043	3.60	0.833
opi	How much confidence has the marker given you?		1.061	2.82	1.101	3.54	1.014
Ŭ	<sup>U</sup> How much motivation has the marker given you?		1.080	2.86	1.088	3.58	0.992
	How much security has the marker given you?		1.011	2.92	1.066	3.56	1.091
ak	How much has the marker helped you to carrying out the exercises?	3.42	1.108	3.50	0.953	3.30	1.111
ц	How much confidence has the marker given you?	3.30	1.074	3.74	0.853	3.22	1.148
Cha	How much motivation has the marker given you?		1.154	3.58	0.785	3.20	1.107
How much security has the marker given you?		3.40	1.195	3.54	0.862	3.14	1.212
How motivated did you feel when doing all the exercises?		Mean: 3.54		Std.Dev: 0.706			
Qs Q	How confident did you feel performing all the exercises?	Mean: 3.08		8	Std.Dev: 0.778		
How secure did you feel carrying out all the exercises?		1	Mean: 3.3	4	St	d.Dev: 0.7	717

The following result was made to observe the self-perception of the global questions segmented by drawing experience and S.I. possession. The data were verified to follow a normal distribution with a Kolmogorov test. A MANOVA test was performed to obtain the statistical differences of the students' answers. Table 2 shows the result of significant differences (p < 0.05) for the questions "How confident did you feel performing all the exercises? [F (4.329), p=0.019]" and "How secure did you feel doing all the exercises? [F (4.625), p=0.015]".

Table 2. Descriptive statis	tics and MANOVA results
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Global questions	Drawing Experience	S.I. (not) possess	Ν	Mean	Std. Dev	F	Sig.
	Law	Does not S.I.	10	3.20	0.789		
TT	Low	Possess S.I.	9	3.67	0.707	]	
How motivated did	Madium	Does not S.I.	14	3.64	0.745	0.622	0.541
you leef when doing	Medium	Possess S.I.	11	3.64	0.674	0.622	0.341
all the exercises?	Uich	Does not S.I.	2	3.50	0.707	]	
	nigii	Possess S.I.	4	3.50	0.577		
	Law	Does not S.I.	10	2.40	0.516		
II	Low	Possess S.I.	9	3.33	1.000		
How confident did	Medium	Does not S.I.	14	3.36	0.633	4 2 2 0	0.010
all the exercises?		Possess S.I.	11	3.09	0.701	4.329	0.019
	High	Does not S.I.	2	3.50	0.707		
		Possess S.I.	4	3.00	0.816		
	Law	Does not S.I.	10	2.80	0.789		
TT	Low	Possess S.I.	9	3.89	0.928		
feel doing all the	Madium	Does not S.I.	14	3.64	0.633	1 652	0.015
	Medium	Possess S.I.	11	3.36	0.674	4.032	0.015
CACICISES !	Uich	Does not S.I.	2	3.50	0.707	]	
	пign	Possess S.I.	4	3.25	0.957	]	

## 4 **DISCUSSIONS**

This work is the beginning of a series of studies, where the drawing activity and the self-perception of the student's skills are at the center of the research development. This work focused on observing the development of the methodology to solve the stated objective. Some student exercises can be observed in Figure 5. The markers used were evaluated, where a positive evaluation was observed according to the exercise performed, regardless of the order of application. This finding marks the possible relevance of the tools according to the drawing activity performed. Inviting us to deepen in the perceptiveness of a tool and a drawing exercise.



Figure 5. Examples of the best (top) and the worst executed exercises (bottom)

The most striking results emerge from understanding the impact that S.I. possession, self-perception drawing experience, and global experience may have on the drawing exercises. In Table 2, the results reveal that for "motivation" there is no statistical difference between drawing experience and S.I. possession. However, the results reveal relevant information about "confidence" and "security", where statistical differences were observed in the assessment. The findings reveal that students who do not possess S.I. for medium ( $M_{np}$ =3.36) and high ( $M_{np}$ =3.50) levels in drawing experience were more confident than those who possess S.I at the same medium ( $M_{po}$ =3.09) and high ( $M_{po}$ =3.00) levels. The same effect is observed for the security of students who do not possess S.I. for medium ( $M_{po}$ =3.64) and high ( $M_{np}$ =3.50) levels, and those who possess S.I. at the same medium ( $M_{po}$ =3.36) and high ( $M_{po}$ =3.25) levels. These findings suggest a starting point of interest to understand how students self-perceive their abilities and emotional aspects when they execute a drawing practice with specialized tools. We can affirm that there is a close relationship between the emotional aspects of motivation, confidence, and security, their level of self-perception of their drawing experience, and familiarity with the tools, in our case the markers. Figure 6 shows all the aforementioned factors.



Figure 6. Assessment graphs for global experience, drawing experience, and tools knowledge

Limitations for this preliminary work are considered. In order to deepen the research, a larger sample will be enlarged, equating the students with the intelligences, and exploring aspects that influence their self-perception of emotional aspects related to drawing. An issue that was not addressed in this study was not include another representation tools like pencil or pen. In conclusion, this work provides an opening for further research on how to approach the student profile, the tools selection, and the teaching process to enhance motivation, confidence, and security to practice and learn drawing for D.E.

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# HOW TO DEPLOY A SERIOUS GAME IN THE ACADEMIC WORLD? APPLICATION TO "LINO HAS AN IDEA"

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## ABSTRACT

Serious games are not only designed for entertainment but also to convey an educational message. From childhood to the professional world, this new form of educational gaming is popular but insufficiently developed for children. Previous research indicates a particular gap in innovation within this landscape of educational games. In response to this issue, the game "Lino has an Idea" was created and experimented with in several classrooms, in both physical and digital forms. However, this game exists in only one copy and needs to be disseminated. In this article, the first step is to highlight a deployment method for a serious game in the educational world by understanding the various stages that compose it. Once established, it aims to apply this method to the case of the serious game "Lino has an idea" in France. The focus of this article is centred on the dissemination of a serious game.

Keywords: Serious game, school, resources, dissemination, innovation

## **1** INTRODUCTION

The shift towards innovative and engaging teaching methods is crucial in today's educational landscape, with serious games emerging as a pertinent solution. The serious games market is projected to grow significantly from USD 12.74 billion in 2023, with a CAGR of 28.99% during the forecast period (2023-2028). This growth highlights the increasing relevance of serious games in educational and professional settings, supported by widespread adoption across global markets [1].

Serious games like "Lino has an idea" offer a promising solution to enhance learning and skill development among students aged 6 to 9 (cycle 2) and 9 to 11 (cycle 3) in France [2], [3], [4]. However, developers often face challenges in determining the optimal deployment method within the educational system [5]. This article addresses these challenges, focusing on the deployment strategy for "Lino has an idea."

The article first explores the general strategy for integrating serious games into educational programs, emphasizing communication, program integration, and the necessary resources and budgets for successful implementation. It then uses the case study of "Lino has an idea" to examine the key steps in deploying this game in France.

Through this comprehensive analysis, the article aims to provide insights into how serious games can effectively be adopted in schools, thereby promoting interactive education tailored to the specific needs of students.

## 2 STATE OF THE ART

A fundamental aspect of serious games lies in their ability to transform the act of learning into an immersive and engaging experience. Rather than adopting a traditional didactic approach, these games integrate playful elements to foster active learner engagement. This approach, combined with interactive scenarios and contextualized challenges, aims to enhance the understanding of concepts while stimulating the development of practical skills. Educational serious games have evolved in response to the growing demand for interactive learning tools.

Active learner engagement enhances understanding and knowledge retention, contrasting with traditional lecturing and passive learning. Classroom discussions, collaborative projects, and interactive tools have become vital for modern education, prompting the adoption of serious games and educational technologies. This shift aims to create dynamic, stimulating learning environments aligned with 21st-

century educational goals. Educators must ensure new resources meet standards and pedagogical objectives, choosing reliable tools that complement existing curricula. "Lino has an Idea" has been optimized in a previous study [7], focusing on its professionalization.

Serious games are widely used in professional training across various fields such as medicine, industry, and universities, enabling learners to practice in realistic scenarios. However, their adoption in primary and secondary schools remains relatively low despite efforts to increase their visibility [8]. "Lino has an Idea" fills this gap by offering an innovative educational experience for children aged 7 to 11, successfully tested in classrooms with positive results in student engagement and fostering innovative thinking [9]. Yet, questions persist about how teachers find and adopt new educational materials and the best strategies for disseminating serious games in education.

The upcoming study aims to explore these mechanisms, using "Lino has an idea" as a specific case, to adapt the game based on identified needs and contribute to the literature on the effective dissemination of innovative educational serious games for children. Thus, following other articles using the application of this game to address serious games-related topics, we will first develop a general dissemination method within the education system.

# **3 PROPOSITION OF A METHODOLOGY TO DIFFUSE A SERIOUS GAME**

The proposal of a dissemination methodology for a serious game starts from its creation to its distribution. It begins firstly with a market study, its development, its potential for use in educational programs.



Figure 1. Schematic representation of the methodology for disseminating a serious game

Figure 1 represents the methodology for disseminating a serious game in the educational environment, which will be explained in the following points. Starting with the game's functionality, the first step is to integrate it into educational programs and establish a communication strategy. Next, a financial analysis examines available resources. Monitoring and iterative improvements ensure the game's sustainable longevity.

In this section, we will detail what each of these points entails.

## 3.1 Integration into Educational Programs

Serious games align with educational standards, enhancing credibility and relevance. Adapting to these standards ensures a consistent learning experience that contributes to educational objectives. Incorporating serious games into national educational programs is crucial for maximizing their impact [7], [8], involving adaptation and pedagogical justification. Successfully integrating these games validates students' skills, emphasizing their role as innovative learning tools essential for developing key skills. The accessibility of serious games presents a complex challenge due to varying technological infrastructures and digital resource access, necessitating a comprehensive approach to address alignment with standards, systemic inclusion, and accessibility challenges. This approach fosters a unified educational environment, maximizing the pedagogical benefits of serious games for students.

## 3.2 Communication Strategy

The communication strategy for a serious game is crucial for reaching the target audience and maximizing educational impact [2]. This involves channels like educational conferences, teacher association collaborations, webinars, educational journal publications, online platforms, and partnerships with national educational authorities. The target audience includes teachers, school principals, educational administrators, parents, and students, each with specific information and training needs to ensure a clear understanding of the game's pedagogical benefits [10]. Key messages should

highlight the game's benefits for student learning, alignment with educational objectives, adaptability to teaching contexts, potential to enhance student engagement, and integration into curricula, emphasizing its enjoyable and educational aspects. Engaging communication materials, such as online platforms, social networks, testimonials, practical guides, and other resources, are essential for an effective strategy to maximize the game's diffusion and promote its integration into the educational environment.

## 3.3 Resources and budgets

Implementing a serious game diffusion strategy requires understanding educational financing. Funding sources include municipalities, school cooperatives, teachers, and cooperative classes. Public funding covers teacher salaries, infrastructure, and educational equipment, supplemented by local funds to meet local educational needs. This collaboration supports initiatives like integrating serious games, improving digital infrastructure, purchasing technology, and providing teacher training. Parental involvement through fees, contributions, or purchases varies, with additional support from government grants, private funds, and donations. Understanding budget allocation for staff salaries, operating costs, and educational activities ensures successful integration of serious games into national educational systems.

# 4 CASE STUDY: "LINO HAS AN IDEA"

Once this general method is established, it is possible to put it into practice. This article will address the case study of the serious game « Lino has an idea » We will then revisit the various steps and apply them for nationwide dissemination in France.

## 4.1 Presentation of the serious game "Lino has an idea"

The serious game introduces concepts for subsequent study [12]. Designed for children in grades 2 and 3, it teaches innovation processes and creative techniques, fostering skills like communication, autonomy, and teamwork. The game includes a board, dice for idea generation, a pawn representing character Lino, a notebook for jotting ideas, and trick cards. It starts with Lino sharing a dreamt innovation idea. Children follow Lino's 7-step innovation process, using trick cards for creativity. They work in groups, sharing ideas under adult supervision.

## 4.2 Integration into Educational Programs

The game « Lino has an idea » is a comprehensive educational resource designed to develop various skills in students [7], [8], [12]. It is crucial to ensure its pedagogical legitimacy and adaptability to educational programs. The game « Lino has an idea » naturally aligns with the educational programs for students aged between 6 and 11 years old (cycles 2 and 3 of the French national education system). Its pedagogical integration aims to cover a broad range of skills, thereby promoting the development of students.

Domain	Evaluated Skills	Number of Skills Fulfilled by the Game
	Cycle 2	
Language for thinking and communicating	Understanding and following short and simple instructions	3/11
Methods and tools for learning	Finding solutions to solve a comprehension problem	1/3
Personal and citizen formation	Defining and respecting organization and task sharing in group work	3/3
Natural and technical systems	Understanding and respecting the rules of a game	1/3
Representations of the world and human activities	Expressing felt emotions, formulating opinions	1/3
Proportion of the numb	per of skills addressed across the entire curriculum <sup>1</sup>	9/23

Table 1. Evaluation of the skills addressed by the game across the programs of cycles 2

<sup>&</sup>lt;sup>1</sup> Data obtained by extracting the skills from cycles 2 and 3 filled by the game "Lino has an idea," the percentages represent the proportion of skills covered by the game compared to the total number of skills.

Domain	Evaluated Skills	Number of Skills Fulfilled by the Game
	Cycle 3	
Language for thinking and communicating	Understanding written instructions, identifying relevant information in descriptive writings, reacting to proposals, dialoguing	8/15
Methods and tools for learning	Finding solutions to solve comprehension problems, planning steps and tasks for the realization of a production	2/4
Personal and citizen formation	Defining and respecting organization and task sharing in group work	3/3
Natural and technical systems	Understanding and respecting rules, applying a scientific or technological approach to solve problems	2/3
Representations of the world and human activity	Expressing emotions, formulating opinions, perceiving moral issues, demonstrating critical thinking	3/4
Proportion of the numb	per of skills addressed across the entire curriculum <sup>1</sup>	18/29

Table 2.	Evaluation of t	the skills addressed	by the game acro	oss the programs	of cycles 3
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Based on our findings, "Lino has an Idea" effectively integrates into educational programs for cycles 2 and 3, covering a broad spectrum of skills (Table 1 and 2) from understanding instructions to applying scientific methods. As a versatile serious game, it fosters creativity and critical thinking, demonstrating its relevance in education and its ability to meet specific educational requirements. Our research indicates that "Activités Pédagogiques Complémentaires" (APC or Additional Pedagogical Activities) are ideal for implementing "Lino has an Idea," supplementing traditional teaching methods to deepen students' knowledge and enhance skills. The game aligns perfectly with APC objectives in cycles 2 and 3, focusing on creativity, teamwork, problem-solving, communication, autonomy, and innovative pedagogical practices. Engaging teachers in discussions about the game's objectives and adapting content based on their feedback ensures effective integration of "Lino has an Idea" into education, enhancing student learning and development.

## 4.3 Communication Strategy

Developing an effective communication strategy is crucial for disseminating "Lino has an Idea." We used information from interviews and conducted research on preferred information channels, online educational content, and similar initiatives. This helped identify the best channels for large-scale deployment of "Lino has an Idea.".

Personal research indicated that in France, social networks and websites are key for promoting educational activities. For websites, we created a ranking (Figure 2 left) based on site popularity (ranking in the global educational sector) and traffic rate (monthly visits). These criteria show the site's usage in France, professionalism, and recurrence in education. A scatter plot (Figure 2 right) ranked websites based on these criteria, with higher and more left points indicating more relevant sites, highlighting the top five. This analysis targets platforms best suited for disseminating "Lino has an Idea," ensuring visibility on sites frequented by the educational community.



Figure 2. Ranking and Evaluation of Educational Websites (SimilarWeb)

Here are five key sites for our study. Eduscol, from the French Ministry of Education, provides resources and promotes best practices. Lumni (formerly France.tv Éducation) offers diverse educational content for free, emphasizing accessibility and equal opportunities. Instagram and LinkedIn are popular in France, reaching teachers and education professionals. The communication strategy must adapt to each platform, using evaluation tools to position "Lino has an Idea" as an essential educational resource.

#### 4.4 Resources and Budgets

In France, serious games can be funded through various channels. According to the Ministry of National Education and Youth's "Repères et références statistiques 2023" [13], education expenditure in 2021 is structured across different funders, including:



Figure 3. Distribution of education funders in France in 2021

Among these funders are local authorities (especially municipalities), school cooperatives, cooperative classes, and direct contributions from parents. The municipality allocates a budget to primary schools for investment and operating expenses. For "Lino has an Idea," the process includes developing a formal proposal with cost, pedagogical justification, integration into classes, and expected impact; presenting this to the school administration; and submitting to the municipality for budget adjustments if accepted. The School Cooperative, managed by teachers and sometimes parents, can contribute through activities, donations, subsidies, and member contributions. In a Cooperative Class, students, under the teacher's guidance, can integrate the game into their projects and propose funding ideas, promoting autonomy. Direct Contributions from Parents allow parents to support specific class projects.

These processes require meticulous preparation, solid pedagogical justification, and effective communication with stakeholders. Speed and accessibility vary by funding source. Collaborating with associations or companies linked to Ecole Nationale Supérieure des Arts et Métiers in Paris, where the game originated, is crucial. The "Main à la pâte" foundation [14] aligns with our expectations for integrating a serious game into cycles 2 and 3 classes. Targeting relevant websites (figure 1) and publishing the game through a publishing house would ensure direct promotion, including school visits, and word of mouth would boost visibility.

# **5 DISCUSSION**

To address our issue, the best method of disseminating a serious game in the educational realm is methodological. Understanding the stakeholders' needs before developing the game, as observed with the implementation of "Lino has an Idea" in France, is crucial. It's essential to align the game with the targeted school curriculum. Thoughtful mobilization of funding is also vital. Therefore, understanding the landscape before developing a serious game in the educational environment is necessary. The distribution of "Lino has an Idea" can be facilitated through financial support from local authorities in schools. An effective communication strategy through social networks or websites allows a serious game to gain recognition. Strategic platforms like Eduscol have proven to be more effective in this regard.

## **6 CONCLUSIONS AND PERSPECTIVES**

The in-depth analysis of integrating "Lino has an Idea" into education highlights several key points. Its alignment with teachers' expectations and educational objectives provides a solid foundation for adoption. Field trials, both physical and digital, support this alignment. The dissemination strategy focusing on social networks and popular websites aims to maximize visibility, specifically targeting

teachers and education professionals on platforms like Instagram and LinkedIn. Integration into "Activités Pédagogiques Complémentaires" (APC) aligns the game's objectives with students' needs in this context.

Collaboration with teachers and content customization based on feedback allows relevant adjustments. Diverse funding approaches, from municipal funding to direct parent contributions, require a strategic approach. The formal proposal, highlighting cost, pedagogical justification, and expected outcomes, provides a framework for local budget negotiations.

In conclusion, the prospects for "Lino has an Idea" are promising. Its potential for integration into cooperative classrooms offers new avenues to diversify pedagogical approaches and enhance impact. The success of its communication strategy, combined with a strategic approach to funding, positions this game as an innovative and adaptive educational tool for cycles 2 and 3.

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# DREAMWORLDS: A CASE STUDY PRESENTING THE POTENTIAL OF TEXT-TO-IMAGE AI IN PRODUCT DESIGN EDUCATION

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# ABSTRACT

This paper presents a two-part case study on the "Dreamworlds" project conducted with first-year BA Product Design Students. It explores the integration of Generative AI tools within a five-week design project, focusing on its role in speculative world-building and subsequent toy design. Part One involved collaborative exploration and creation of speculative worlds in teams of 3-4 students over two weeks. Leveraging Text-to-Image AI, students produced a 5-minute video presenting their visions, showcasing AI-generated visuals that enhanced artistic direction. Part Two shifted focus to designing toys for children aged 4-5, using the speculative worlds from Part One as inspiration. Unlike Part One, Part Two was carried out individually, emphasising consideration of materials, safety, and cultural sensitivity. This case study contributes to the discourse on integrating AI in design education, offering insights into its roles in world-building and practical design. The "Dreamworlds" project serves as a practical example of AI application in both speculative and practical design education.

*Keywords: Product design education, text-to-image AI, worldbuilding, toy design, speculative exploration* 

# **1** INTRODUCTION

In the quickly advancing landscape of Design and Design Education, the integration of generative AI as a design tool represents a paradigm shift, offering freedom and creativity in speculative exploration. The decision to employ Generative AI in the "*Dreamworlds*" project, a five-week design project, focusing on the role of speculative design as world-building and the subsequent design of children's toys, was driven by the desire to go beyond conventional design practises and explore the transformative potential these technologies might have within a BA Product Design undergraduate curriculum. "*Worldbuilding is the process of constructing a complete and plausible imaginary world that serves as a context for a story*"[1] The "*Dreamworlds*" project aimed to foster imaginative world-building through collaboration in addition to challenging conventional design methodologies, in the hope that it would provide valuable insights into the application of AI technologies in design education, enriching the student experience and learning with a dynamic challenge, allowing budding designers to think beyond traditional boundaries.

# 2 METHODOLOGIES

## 2.1 Project Outline

The "Dreamworlds" project was designed to combine emerging technology and practical skills through a two-part process. Part one, called "*worldbuilding*", involved students working in small groups to imagine and create detailed fictional worlds emphasising creativity, collaboration, and speculative thinking through generative AI tools. Part two transitioned into practical "toy design", where students worked individually to design toys inspired by the worlds they had developed in the first part, focused on applying practical design skills, from abstract concepts to tangible products, employing techniques such as sketching, prototyping, and CAD software. This pedagogical approach incorporates collaborative and project-based learning throughout the entire process, and hybrid learning experiences combining both online and offline activities providing students a well-rounded educational experience.

	Week One	Week Two	Week Three	Week Four	Week Five
Monday	Project Launch - Text to Image AI Introduction	Tutorials and Submission guidance for P1	Tutorials focussed on Design Direction	Tutorials focussed on Design Development	Tutorials and Submission guidance for P2
Tuesday					
Wednesday	Concept Development				
Thursday	Concept Review - Introduction to Further Tools for Narrative Building	Part One - Deadline	Lecture from Toy Designer & Rapid Ideation Workshop	Concept Review	Part Two - Deadline
Friday	Adobe Rush Tuition				

Figure 1. "Dreamworlds" Project Outline

## 2.2 Part One: World Building

During "Part One" of the project, students worked together, fostering a collaborative learning experience, through Project-Based Learning [2] This methodology was influential in nurturing a diverse range of ideas and perspectives, attempting to go beyond the superficial, 'aesthetically pleasing' aspects of design and delve into the core of what makes a product captivating, educational, and enduring through the narratives of worldbuilding. The use of AI as a tool in "Part One" was not only a technological exercise to introduce emerging technologies; it was a means to enable students' understanding narrative construction, artistic direction, and thematic development within a group. The AI-generated outcomes created throughout the project served as a springboard for deeper discussion and evaluation, prompting students to consider various design elements and storytelling techniques that could be applied to their projects. The emphasis on speculative exploration within the first part was crucial in allowing students to experiment with abstract concepts and scenarios, pushing the limits of their creative thinking. The imaginative worlds created by the students were not just artistic expressions they were conceptual frameworks synthesising their ideas into coherent and visually compelling narratives through a video output that would later inform and inspire the practical aspect of toy design in the subsequent "Part Two" of the project.

## 2.3 Part Two: Toy Design

Transitioning from the speculative to the practical, "Part Two" focused on applying the conceptual worlds to the design of mono-material toy(s) for children aged 4-5. The outcomes had to be designed and inspired by the imagined world created in "Part One" and encourage imaginative play, allowing young minds to embark on their own creative adventures, fostering open-ended exploration and storytelling. This shift of transferring the emphasis of storytelling from design method to design specification highlighted the versatility of imaginative worldbuilding in design education, demonstrating its utility in both abstract and emergent ideation methods in conjunction with traditional and tangible product development. In contrast to "Part One", "Part Two" was carried out by individuals and encouraged students to consider, materials, safety, cultural sensitivity, and environmental consciousness. These considerations needed to be at the forefront of the toy design, ensuring a wholesome and enriching play experience. The project's outcome showcases how Generative AI can be used in collaboration with design processes as a powerful tool in nurturing the next generation of designers.

# 2.4 Data Collection & Analysis

The choice of methods—observation, documentation, and reflection—was guided by the need to understand the impact of AI tools on student learning and creativity. These methods were selected to provide insights into the educational experience and effectiveness of AI integration. Data was collected from first-year BA Product Design students at Nottingham Trent University. A total of 34 students participated, divided into groups of 3-4 for Part One and working individually for Part Two. Qualitative data was analysed to identify themes and patterns related to the use of AI tools in design education.

#### **3 PEDAGOGICAL APPROACHES**

#### 3.1 Collaborative Learning

"Collaborative learning is an educational approach to teaching and learning that involves groups of learners working together to solve a problem, complete a task, or create a product" [3]. Throughout "Part One", students engaged in speculative "world-building", collaborating to conceptualise and develop "imaginative realms". A core benefit of Collaborative Learning is its active engagement of students in the learning process, fostering the development of a social support system and learning community [4]. Allowing students to form their own groups, enabled them to leverage existing relationships and collaborate confidently, ensuring equal participation within the collaborative space. Shared ownership of work and student-centred instruction further contributes to students' self-esteem and sense of accomplishment [5]. Despite the individual nature of "Part Two", students continued to foster a collaborative approach through tutorials, concept reviews, and in-studio interactions.

#### 3.2 Project – Based Learning

Project-based learning (PjBL) is a method that centres around students working on projects that are complex and meaningful. Here, students actively explore real-world problems, develop solutions, and create tangible outcomes. "It involves students in inquiry, investigation, and collaboration, creating opportunities for them to construct knowledge and develop critical thinking skills" [2]. PjBL is central to both project parts, further fostering active participation and collaboration [2]. In "Part One", students were challenged to go beyond traditional design tools and leverage AI-generated visuals to develop cohesive "speculative worlds". In "Part Two", students collaborated through tutorials, concept reviews, and in-studio collaborations, mirroring real-world design processes and experiences. This empowered students to navigate challenges such as material selection, manufacturing processes, and cultural sensitivity, fostering autonomy and self-directed learning. The "Dreamworlds" project demonstrates how PjBL can promote collaboration and prepare students for professional practice.

## 3.3 Hybrid Learning

"Hybrid or blended learning is defined as a pedagogical approach that includes a combination of faceto-face instruction with computer-mediated instruction" [6]. A hybrid learning environment was established using physical and digital learning spaces throughout the project. Complementing traditional face-to-face workshops and group discussions, digital tools were incorporated. Students were provided with support to use these digital platforms, expanding their creative processes, and giving them the tools to enhance project outcomes. The digital nature of tools such as MIRO -an online collaborative whiteboard- proved advantageous, allowing students to engage in individual work on their personal devices within a shared physical space. The integration of virtual collaboration tools allowed students to work as teams across physical boundaries, enabling them to collaborate effectively regardless of their geographical location. This integration of physical and digital learning components fostered an enriched educational environment that allowed for enhanced engagement, collaborative learning, and innovative problem-solving.

## 4 **RESULTS AND DISCUSSION**

## 4.1 Part One: World building

## 4.1.1 Working in Groups

"Part One" tasked students to engage in collaborative exploration and creation of "*speculative worlds*" in groups of 3-4 over two weeks. The decision to conduct "Part One" in groups was driven by several considerations. As previously mentioned, the group work predominantly aimed to encourage collaborative learning among students. Professional Product Designers often work as teams and so simulating this through project work helps to simulate this experience whilst in an educational environment. The hope was that by working in teams, students would be able to share perspectives and ideas, leading to more innovative and creative outcomes. At the end of the project, students were asked to give feedback on which "Part" they enjoyed the most and why. With several commenting on the group work being a contributing factor to project enjoyment. "*Creating the world was fun and a good team building experience*"; "*All working together and putting thought*" It was also clear from responses that students saw the value of working collaboratively, recognising that working as a team was "*productive*" and that "*ideas were shared*". In addition to the benefits of collaborative learning, the project directly followed an individual summative assessment point and was carried out in the lead-up

to the Christmas break, offering students a project that was enjoyable but not overly demanding, and more importantly an opportunity for social engagement at the end of term. Moreover, due to the introduction of unfamiliar AI tools during the project, authors felt a group setting would be more supportive than having students navigate these individually, meaning students could learn from each other without the pressure of having to individually produce outcomes. This approach aimed to encourage a confidence in AI tools from the outset.

#### 4.1.2 AI Tool Selection

A key aspect of the "Dreamworlds" project was to give students an introduction to Generative AI Tools and exploring the potential role they play for creatives in the future. During the end of project survey, when students were asked about AI and its impact on their future academic careers, many raised a concern that AI would replace the need for Designers "It will remove the need of designers, and projects will be completed fully by AI". The "Dreamworlds" project aimed to tackle this perception by introducing Generative AI as a tool a Designer could use, rather than a replacement. Therefore, a variety of AI Tools needed to be integrated into the project, giving students confidence in them as resources for creative exploration. Generative AI Tools used within the project were Adobe Firefly for image generation, Runway ML for video manipulation, Eleven Labs for generative voiceover integration, Chat GPT for script creation, and Adobe Photoshop Generative Fill Tool for image editing. In using such a wide variety of tools, student groups were given opportunities for the conceptual development of their "speculative worlds". Introducing all tools over a short two-week period meant students had to learn quickly, particularly as most had limited previous experience. However, most adapted well, investing time as groups to understand the tools and their functions, in many cases beyond staff expectations. The selection of Generative AI Tools was guided by practical considerations, with students being limited to freely available software or software accessible through the university (Adobe Firefly & Photoshop). This approach ensured all students had equal access to tools throughout the project, giving all groups equal opportunities to participate. However, this also imposed limitations on the quality of the Generated AI and as such limitations on the "speculative worlds" themselves.

#### 4.1.3 Access to Digital Devices

The project's reliance on digital tools meant that all students needed access to a computer, tablet or digital device. Whilst the vast majority of current students on BA Product Design at NTU have their own device, this is something to consider for future iterations of the project. There are computers available on campus, however, these resources are only accessible during opening hours and are an open resource for all students to use, which potentially creates a barrier to students' participation in the project. On occasions during "Part One", it was observed that some students were using a smartphone to participate, either because they had forgotten their digital device or it had run out of charge. This posed challenges in engaging fully with the project, as these devices either lacked the functionality needed to engage with the AI Tools or because of limitations in screen size. A variation in access and use of technology highlights the importance of digital equity and inclusion in a Generative AI Era. Barriers to access must be considered to ensure that education remains inclusive. As the use of AI Tools becomes more commonplace, educators need to consider the development of inclusive digital learning practices, accommodating a range of circumstances.

#### 4.1.4 Project Outcomes

The final project deliverable for "Part One" was a video introducing each "speculative world" to the cohort, with a specification that all video content needed to be AI-generated. The aim of this was to challenge students to use Generative AI Tools within their design processes, pushing them to look beyond more familiar approaches. All student groups were invited to a screening of the videos, which served not only as a platform to provide feedback but also an opportunity to celebrate the end of "Part One". Students were encouraged to critically reflect on each video, not only for the benefit of the team that created the video but for themselves who would potentially be able to use the content in "Part Two" for inspiration in the toy-design element. In offering critique and insight into each video, students gained a greater understanding of each "speculative world", fostering constructive dialogue and sense of accomplishment amongst the cohort. The videos themselves showcased a combination of technical skill, creativity and a collaborative effort, demonstrating how well students had been able to leverage the Generative AI Tools for design exploration. Whilst instilled with comprehensive narratives, the

*"speculative worlds"* depicted in the videos showcased a significant level of conceptualisation, highlighting the effectiveness of AI-driven design processes. A key example was *"Washbucklers"* (Figure 2), a world developed around *"Sponge Pirates"*. This is just one example of how students' imaginative capabilities were able to be fully realised by Generative AI Tools, within the framework of speculative design.



Figure 2. "Washbucklers" Concept Moodboard

# 4.2 Part Two: Toy Design

# 4.2.1 Originality

The project's start saw students tasked with designing mono-material toys for children aged 4-5, drawing inspiration from their collaboratively constructed worlds. The pedagogical choice to pivot from collaborative to individual projects was underpinned by the desire to investigate the generative AI's potential in sparking novel ideations. Interestingly, the transition to individual design projects, revealed a reversion to traditional ideation methods, side lining the generative AI tools engaged in the initial phase towards further idea generation, whereby 53% (18) preferred "Part Two" reflecting that "AI was more supplementary rather than a focus", "I found in Part One you didn't really have to do any thinking for yourself just relied on AI to do everything for you", and "It felt like we had more of an influence over the design processes". "While a part of the industry encourages its [the use of AI], it doesn't feel like my own work", "becoming too heavily reliant. People will lose their creativity and won't be as motivated" generating a "decreased individuality". This reflects an apprehension towards recognising AI-assisted design as 'original' work with a reluctance to present generated work as one's own, finding more value within independent creative thinking and design practise.

## 4.2.2 Ideation

Despite this shift, it was identified through weekly studio tutorials that the initial engagement with AI was used to bolster confidence in sketching abilities, evidencing an improvement in visual articulation inspired by AI-generated imagery. As students were able to directly observe generated images as inspiration and develop them further; resulting in less sketch work that was simply copying existing products from online research, Part Two *"allowed me to explore on top of the AI"*, *"Using part 1 to create original designs"*. However, due to the nature of "Part One", worldbuilding naturally develops characters, so this enhancement veered the project's focus towards character-driven designs, inadvertently homogenising the creative outcomes, resulting in many similar outcomes, with one student reflecting; *"I struggled to think of more unique and fun designs in this project, I feel like a lot of projects were similar"*.

#### 4.2.3 Mono-Material

The mono-material constraint was a deliberate imposition to steer students towards a sustainable design mindset, challenging them to uncover the latent potential within a single material to foster play and imagination. However, the imposition of a mono-material, though well-intentioned, manifested as a source of frustration for students, which students shared openly through tutorials, suggesting that the

constraint might have been overly prohibitive. This feedback underscores the delicate balance required in framing project parameters to foster creativity without impinging on the of young designers.



Figure 3. "Puzzle Pirates"

# **5 CONCLUSIONS**

This case study "Dreamworlds" has illuminated the transformative potential of Generative AI in design education, affirming its role as a pivotal tool in the hands of first-year Product Design students. The majority of participants recognise AI as a functional asset, integral to enhancing task efficiency and creativity, notably, the consensus underscores the utility of Generative AI in ideation phases, highlighting its provess in fostering novel creative insights. This project reveals a spectrum of perceptions towards Generative AI, ranging from enthusiastic endorsement of its innovative capabilities to cautious optimism. Furthermore, an overwhelming 86% of students acknowledge the tangible benefits of AI integration within the design process, pointing to a positive shift in the academic paradigm. The project's success is also reflected in the satisfaction with the accessibility and support provided by the teaching staff, rated positively across the board. Moreover, the project's trajectory and outcomes serve as ongoing professional development of educators, who, through reflective practice and engagement with emerging technologies like generative AI, continually refine their teaching methodologies. This case study not only navigates the complexities of integrating AI into design education but also illuminates the pathways for future pedagogic explorations, ensuring a dynamic and evolving educational practice that remains responsive to the advancements in technology and societal needs, catalysing a blend of traditional creativity with artificial innovation.

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# MODELLING INTERIOR YACHT DESIGN CONCEPTS CROSSING MULTIPLE AI TOOLS: TEACHING IN AN UNCERTAIN AND FLEXIBLE FRAMEWORK

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## ABSTRACT

Yacht design, a multidisciplinary field blending design, architecture, and engineering, demands coordination across the discipline's diverse competencies. The advent of Artificial Intelligence (AI) tools in design modelling and sketching is transforming the role of yacht designers, sparking debates in the professional realm. AI sketching, once an inspiration tool, is now becoming a design creator, reshaping both daily workflows and curricular training approaches.

Within the framework of the Executive Interior Yacht Design specialization course at the Politecnico di Milano, an instructional module focused on Advanced Drawing Skills was introduced to a cohort of students. It aims at equipping students with AI skills for yacht interior concepts and foster adaptability within a flexible panorama.

This paper delves into the course's pilot case, detailing intended outcomes, methods, tools, and learning exercises. Evaluation encompasses student and lecturer perspectives, collected by a dedicated interview and survey that assesses the overall learning experience. Results are presented and discussed on three levels: output image quality (content adherence, variation, style, interference), student-AI interaction, and learning environment. The study underscores the efficacy of integrating AI education in executive interior yacht design courses, providing students with tools and methodologies for concept creation. It highlights how the course shifted the learning approach from applying knowledge to experimenting with practices. In navigating the dynamic landscape of evolving generative models, the research emphasizes the importance of adaptability and resilience in preparing students for future yacht design careers amidst uncertainty and flexibility.

*Keywords:* Yacht design, interior design, artificial intelligence, AI teaching and learning, image generation

# **1** INTRODUCTION

The integration and adoption of novel technologies in the domain of teaching have undergone rapid evolution over the past three decades [1]. Considering this trajectory, it's likely that recent advancements in Artificial Intelligence (AI) and machine learning will significantly impact future labour markets, competency requirements, and pedagogical practices [2]. In navigating the complexities of epistemological and ontological dimensions of AI, this study defines AI as computer systems or intelligent agents capable of collecting, analysing, and representing data and information to achieve complex goals [3]. These intelligent capabilities may manifest in various forms, such as the ability to memorize and recall information [4], optimization and autonomy of procedures and parameters, and comprehension of human natural language [5].

While the accomplishments of AI heavily rely on data conformity, creativity often leverages human imagination to generate original ideas that may deviate from established rules. Creative professionals draw upon a lifetime of experiences to think innovatively, posing 'What if' questions challenging traditional constrained learning systems [6]. Across the expansive creative industry, AI tools start being implemented in content generation reshaping the landscape. Computational tools for sketching are emerging and continuously evolving, facilitating the generation of fresh design ideas by provoking with unconventional semantic and visual stimuli. Industry leaders like Adobe and OpenAI are at the forefront, introducing innovative tools to the brother public, eliciting mixed sentiments among designers [7].

As happened in other creative industries, yacht design is starting to be challenged by the introduction of these tools. Yacht design is a multidisciplinary sector where skills from design, architecture and engineering education are applied. The designing of yachts has evolved over many centuries and is now acknowledged as an iterative process heavily influenced by the engineering discipline, which can stifle the influences of design and creativity in the process [8]. The students involved in this field need to coordinate highly diversified areas of competence: design, architecture, ergonomics, and materials, with their respective specialised disciplinary articulations.

The rise of AI tools for design modelling and sketching rapidly evolves the role of exterior and interior yacht designers in early-stage concept creation, opening debates within the professional context. While a continuously growing number of AI yacht design concepts are posted on the web – mainly thorough Instagram social network – designers are investigating how AI will shortly impact on their future profession and relation with clients. AI text-to-image concept generation is replacing the traditional approach of tasking a design team to create images from verbal briefings. However, the ongoing debate focus on the ability to discern the viability of AI text-to-image results [9]. This perspective shift in yacht design tasks places emphasis on two key aspects of concept exploration: the precise definition of initial prompts and the evaluation of the technical feasibility of AI-generated concepts. This transition not only poses challenges to the routine tasks of designers but also necessitates a revaluation of the pedagogical approaches in higher yacht design curricula. The paradigm shift underlines the importance of equipping young designers to engage with AI technologies in a manner that extends beyond passive evaluation, requiring a proactive and informed interaction in prompt design to effectively harness the capabilities of AI in the yacht design process.

In the educational domain, the raising interest of AI is demonstrated by EU projects [2] and extensive literature reviews [10,11,12], with the number of article presenting the acronym AIED (Artificial Intelligence in Education) raised from 9 to 210 in the last ten years<sup>1</sup>. The main educational areas where AI applications are in place can be summarized in the following three categories [13]: Planning (receive student feedback, identify student's needs and plan activities), Implementation (give feedback, optimize activities, track progress, and managing time), and Assessment (automate evaluation, predict performance, provide personalized feedback).

Despite numerous studies demonstrating the enhanced productivity, efficiency, and quality of instructors when utilizing AIED, and the ready adoption of AI as a teaching aid, criticalities and challenges have surfaced. These challenges primarily pertain to the modifications in the learning context and the perceived social relevance of AI use in educational settings [13, 2]. The present study looks into AI as an Exploratory Learning environment and Language Learning tool [14] to investigate teaching potentialities in a continually developing design domain.

## **2** STRATEGIES, METHODS AND TOOLS

Within the framework of the Executive Interior Yacht Design (EIYD) specialization course at the Politecnico di Milano, an instructional online module focused on Advanced Drawing Skills was introduced to a cohort of students with architecture, product and interior design background. The module was properly designed to guide students through an educational trajectory with a twofold aim: to provide future professionals skills for mastering AI technologies for yacht interior concepts and to support the development of capabilities to adapt to - and innovate in - the flexible panorama of contemporary yacht design [15]. Throughout the module, students acquired skills in using the program's language, inserting textual prompts, blending tools, and integrating image prompts with textual and descriptive ones. The module instructs students in taking their first steps with AI, by allowing the opportunity to have a flexible design and to operate quickly, simulating the speed of changes required in the contemporary design work. Due to the instrumental nature of the teaching activity, the module was conducted in online mode. The module initially focused on the use of Midjourney, to assist students in creating conceptual images that met the specific needs of yacht design. However, given the rapid evolution of AI tools, it was decided to introduce various instruments, allowing each student to define their own workflow as they see fit. After an initial phase of learning the program's language and basic functionalities, students experimented with inserting textual and visual prompts to guide image generation. Subsequently,

<sup>&</sup>lt;sup>1</sup>data retrieved from Scopus. Research within only English languages articles; keyword: AIED or Artificial Intelligence in Education in title, keyword, or abstract. Last Access 2024, 22 February.

students were provided with specific prompts based on reference images, sketches, and existing 3D models to educate the AI to produce outputs consistent with design expectations.

Specifically, the teaching activities were divided in three steps, for a total amount of 16 hours. The first session focused on Midjourney and communication with artificial intelligence. The second session introduced LookX plugin for 3D modelling software. The final part of the course simulated a short deadline scenario where an imaginary client requested the creation of a concept for their yacht. Students had to produce four images, one exterior, and three interiors, along with a related mood board, in just three hours, integrating manual sketches, 3D models, and reference images they created. The results of teaching activity led to defining a common creative workflow, enabling the realization of designs that best meet expectations.

Qualitative and quantitative feedback from activities was sought from both lecturers and students on the following topics: (i) output image quality (content adherence, variation, style, interference), (ii) student-AI interaction, and (iii) learning environment. The results from the lecturers were obtained through semistructured interviews, while an online survey was administered to students. The survey was divided into five parts. Firstly, participants were asked about their previous knowledge of AI tools in terms of the level of interaction and platform knowledge, rated on a scale from 1 (scarce) to 5 (very good). Sections 2, 3, and 4 inquired about AI tools in terms of student-AI interaction efficacy and openness, quality of output results, and the learning environment, respectively. Lastly, students were asked whether they used AI tools after the course and how it impacted their professional activities.

The survey was administered to participants six weeks after the end of the course while they were involved in professional activities in yacht design.

## **3 LEARNING EXPERIENCE OUTPUT**

## 3.1 AI common creative workflow

One of the key objectives of the course was to provide students with a fast and flexible workflow and to verify, through the results of classroom exercises, whether such an experimental approach could still be valid. From the results obtained, it can be confirmed the following steps.

*Phase 1: Sketches and Initial Design* - Define the guidelines and main features of the project. Communicate the layout of spaces, colours, materials, and essential furnishing elements through a sketch, either by hand or using design software or collages.

*Phase 2: Moodboard and Inspirations* - Collection of inspirational images that define the style and atmosphere of the project. Use photographs, textures, fabric samples, and colours to create a collage. This can be done with graphic software, manually, or with artificial intelligence tools like Midjourney.

*Phase 3: Design* - Design with measurements and elaboration of initial images: Feed the AI with the first design. In this case, LookX was used as a plugin for Sketchup and Rhino, in order to obtain the first interior and exterior images.

*Phase 4: Refinement* - All the images are evaluated and used as input for Midjourney AI (fed with an already good idea of the final design) and refined using text and image reference prompts.

*Phase 5: Correction and Repeat* - As with every iterative process, the first output from Midjourney can be used as a reference for LookX, going back to phase 3 and repeating the design process.

*Phase 6: Final Design* - Upon completion of the iterative process, one ultimately reaches an optimal and satisfactory outcome. At this juncture, the student-designer can generate final output images to showcase their work. In our case, the ultimate tool can be Midjourney itself. However, the produced images can also serve as an excellent foundation for further refinement through post-production processes using photo editing, 2D and 3D CAD drawing programs.

#### 3.2 The lecturer perspective

The results of the course demonstrated that the use of AI-based tools can be extremely useful in the yacht design process, specifically in the first concept generation step. From the lecturer perspective, the most interesting aspect was obtaining results that allowed defining a common creative workflow. The best results were achieved starting from base images created by students, typically simple 3D models or hand-drawn sketches. Three main characteristics describe the proposed workflow: constant iterations, adaptations and continuous refinements. It is commonly observed going back to previous phases of the process. For example, after creating the Moodboard or the renderings, some students modify the initial sketch to fit the inspirations or new ideas that emerged during the creation of the booklet. It is observed as the previously described process is fluid and iterative, allowing students to gain influences by each

phase to inspire the others. This constant evolution of concepts and ideas improved the overall quality of the project from all students.

#### 3.2.1 Output image quality

From the teacher's perspective, the outcomes exceeded expectations. The majority of students encountered AI for the first time, particularly at a fundamental level for generating rendered images. The obtained results did not highlight these blanks, with surprisingly good results for a few hours of teaching. The quality of the obtained images was highly professional, comparable to the field state of the art. Even if some students encountered issues in setting the right prompt to assure content adherence and in managing the interference, a good level of output variation was highlighted. Furthermore, students were able to vary the style of interior design, and to instruct AI tools to meet their personal expectations.

#### 3.2.2 Student-Al interaction

The module inspired students, engaging them in a creative workflow characterized by highly flexibility. Students reached significant levels of competence in interacting with the software, generating a variety of conceptual images reflecting their creative visions. The integration of textual and visual prompts allowed students to guide AI in producing images consistent with project objectives. Additionally, the use of prompts based on reference images and 3D models enabled students to obtain more precise and refined results, facilitating communication of their ideas to clients and other design team members.

#### 3.2.3 Learning environment

The module's high engagement level proved effective in overcoming challenges and communication gaps inherent in the online modality. Participants' experiences in the course underscored the potential of AI tools for design education to notably augment student engagement in subsequent design stages, including the creative process, accelerated concept generation, and improved precision and coherence of outputs. Thanks to the speed afforded by AI tools, teachers have observed how students are able to push design beyond issues related to mere representation, managing to bypass that 'Lost in Translation' often caused by a lack of drawing skills or proficiency with modelling tools. This were mainly present in designers who have not yet mastered the traditional 3d modelling tools proper of yacht design. The use of AI tolls has accelerated the improvement of design skills, not only within the pilot module but also with positive outcomes across different atelier of the entire course.

## 3.3 The student perspective

Through a questionnaire, qualitative and quantitative feedback were gathered from students who participated in the module. Overall, the responses were largely positive, reflecting a high level of satisfaction with the learning experience.

#### 3.3.1 Output image quality

One aspect that particularly impressed the students was their newfound ability to produce professionalquality images without the need for extensive knowledge of rendering software. The overall satisfaction with the quality of images generated by AI text-to-image tools during the course indicates a positive sentiment among the participants. Specifically, 60% of participants expressed satisfaction, with 5% reporting little satisfaction and 35% being moderately satisfied. Satisfaction levels were analysed across categories, revealing an 80% approval for content representation, a 50% moderate satisfaction with variation, a commendable 75% satisfaction with style, and a 40% satisfaction rate indicating room for improvement in managing external elements.

#### 3.3.2 Student-Al interaction

Students were asked to assess the ease of use of AI tools in the creative workflow. Accessing and installing AI text-to-text or text-to-image tools is perceived to be relatively easy by a substantial portion of the surveyed audience, particularly those potentially lacking expertise in prompt design. Specifically, 50% find it relatively easy, 35% find it easy, and 15% find it very easy. The impression regarding the ease of use of the AI tools presented in the course indicates that 40% of respondents found it relatively easy, 30% found it easy, and 10% found it very easy. Despite that, students point out complexities associated with various aspects of interacting with AI tools, particularly in terms of precise instruction,

prompt formulation, and obtaining desired outcomes. The aspects perceived as challenging in understanding AI tools include:

- Achieving precise program output: Some respondents struggled with getting the program to generate exactly what they desired, emphasizing a difficulty in achieving specific and accurate results.
- Obtaining specific details: Participants faced challenges in instructing the AI to produce specific and precise details in its output. Moreover, removing undesired elements generated by AI, especially when the AI was not adequately trained with reference images, resulted critical.
- Understanding prompt writing for AI comprehension: There was difficulty in comprehending how to write prompts effectively to ensure clear understanding by the AI, or how to split prompts to have more accuracy.

Despite these challenges, they acknowledged the potential of AI tools like Midjourney to create inspirational mood, and LookX to address issues related to image perspective, leveraging base 3D models to enhance visualization accuracy.

#### 3.3.3 Learning environment

The utilization of AI tools prompts learning in an educational context. According to survey responses, 70% affirmatively acknowledge that AI tools stimulate learning, while 30% indicate that such stimulation occurs only to some extent. Furthermore, the tools and methods introduced in the course were evaluated in terms of their flexibility to address a continually evolving domain such as AI. Participant responses indicate that 10% of students perceive these tools as somewhat inflexible, while the majority, comprising 80%, consider them flexible. Additionally, 10% of students express a high degree of flexibility, deeming the tools decisively flexible and suitable for the dynamic nature of the AI domain. In addition, many students expressed keen interest in delving deeper into AI applications within their future professional career. At the question "Do you believe that AI tools will impact the way you perform your profession? "survey responses indicate that 70% affirmatively anticipate a potential impact, while 30% expect only partial influence, with uncertainties on the effectiveness of these new tools. However, among those who anticipate an impact, 30% foresee a negative influence, 10% hold a neutral stance, 20% expect a positive impact, and 10% anticipate an extremely positive effect. These results indicate a recognition of the transformative potential of AI in the field and a desire to further explore its capabilities to streamline design processes and enhance creative output. Despite that, the diversity of perspectives on the yacht designer work highlights the complexity of behaviour and expectations surrounding the raising of AI tools on professional practices.

## 4 DISCUSSION AND FUTURE PERSPECTIVES

This study highlighted not only the potential of using AI-based tools in yacht interior and exterior design, but also demonstrated the effectiveness of such tools in facilitating the creative process and improving visual communication in the context of design education.

The integration of AI into yacht design education presents exciting opportunities for students to explore innovative design methodologies and gain practical experience in utilizing cutting-edge technologies. AI can be incorporated into university courses to provide students with tools for rapid idea generation, even for those who may not have mastered 3D modelling or rendering software. By leveraging AI-driven platforms, students can develop conceptual designs, iterate on ideas, and communicate their vision effectively, thereby preparing them for careers in the dynamic field of yacht design. Moreover, AI-based education initiatives can foster creativity [7], collaboration, and critical thinking skills, empowering the next generation of designers to push the boundaries of innovation in yacht design. In this specific industrial context, AI has emerged as a valuable resource, offering young designers new avenues for exploration and experimentation. However, limitations arise from the complexity of yacht 3D geometry, posing challenges in maintaining control and precision during the design process. While AI tools can assist in generating initial concepts and refining designs, human expertise remains essential in navigating intricate details and ensuring the feasibility and functionality of yacht designs [8].

In conclusion, the utilization of AI in the EIYD university course proved to be highly beneficial and promising. The results demonstrate a significant improvement in students' competence in interacting with AI software and generating diverse conceptual images aligned with project objectives. Feedback from students highlighted the remarkable potential of AI tools in simplifying complex design tasks and producing professional-quality outputs. Despite encountering challenges such the communication with

the AI about the desired output or eliminating unwanted AI-generated elements and defining materials, students expressed keen interest in further exploring AI applications in their future professional career. From the instructor's perspective, the outcomes were highly satisfactory, underscoring the effectiveness of the course curriculum in bridging students' knowledge gaps and fostering proficiency in AI-based design methodologies, with participants showcasing impressive results within a limited timeframe.

Although the results have been satisfactory, the rapid advancement of AI image generating tools leaves ample room for a more in-depth development of design teaching in this area [3]. From this pilot project, potentiality emerged not only for the conceptual and visualization phase but also for a critical understanding of the creative process and for accelerating the learning curve. An additional module in Advanced Drawing Skills, based on AI text-to-image tools, is now introduced to a new cohort of 30 students in yacht design. This Further experimentation aims to refine the teaching strategy to fully exploit the potential of AI tools and seamlessly integrate them into the yacht design workflow. The module is scheduled at the beginning of the master's program. In this instance, the docent immediately initiated students into the use of AI at the outset of the course, enabling students from diverse academic backgrounds to approach to AI image generation tools. This paves the way for intriguing developments in the continuation of the master's program, rely on AI tools not only for the production of final images but also as sparring idea generators in the design process itself.

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# USER ENGAGEMENT IN PHYSICAL-DIGITAL INTERACTION DESIGN

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## ABSTRACT

This paper describes the development of a physical-digital demonstrator that makes use of augmented reality (AR) technology, to convey complex systems and engineering information for design education. As well as acting as an educational and client-facing tool for the industrial partner, the configuration and principles of the demonstrator point towards how physical-digital installations can be used in design education settings more generally. We will outline the development of case study material for human-centred design and product modelling and visualisation education. Initially we describe the nature of the bespoke tool, its features and user interaction. This segues into a discussion about how information is conveyed to the user through a series of engagement phases that are developed into a three-stage "Order of Engagement" framework. The real-world application of physical-digital interaction means the lessons learnt from the AR demonstrator design and Order of Engagement framework evaluation have clear practical and commercial applications for future digital interaction design.

Keywords: Interaction design, augmented reality, physical-digital interfaces, new educational tools

#### **1** INTRODUCTION

In this paper, we explore the application of a physical prototype used in conjunction with an AR app. AR blends the real, physical world with digital, computed-generated elements, adding contextual layers of information to the users' sensory experiences of their physical environment [1]. Its ability to integrate additional information, instructions and explanation while retaining real-world interaction has enabled it to find broad applications in training and education [2]. The case we focus on in this paper relates to a specific technological use case, the dynamics of which could be applied within other contexts and settings. The physical prototype 'demonstrator' explored in the work is designed to be a tool in which a specific set of environmental conditions can be simulated and then augmented utilizing an AR app. The context of use can vary, but the core reason the demonstrator was developed was as an engagement and communication device i.e. allowing stakeholders to comprehend technological concepts and engage with interactions within particular constraints.

Firstly, we set out the case for physical-interaction and the Orders of Engagement framework that describes how physical-digital interaction experiences can effectively capture and retain user attention. We then describe its application in our specific case study, where the demonstrator prototype is used to convey the functionality of a complex engineering installation. Finally, we consider the implications of this by reflecting how design education and aspects of stakeholder engagement and buy-in can be positively impacted by bespoke prototypes of this nature.

## 2 WHY PHYSICAL-DIGITAL INTERACTION?

#### 2.1 Engagement through information, narrative and context

Modern product experiences (particularly software dependent devices) is dependent upon a carefully configured bi-directional physical-digital exchange between the user and the artefact [3]. Since the emergence of digital interface and particularly smartphones, there has been an emphasis within a product development context of creating seamless digital "narratives" in which users can freely navigate a device without much prior knowledge of its functions [4]. Using design features such as physical vibration or skeuomorphism [5], modern digital devices aim to use an architecture of intuitively understood emotional markers and culturally distinct symbolic signifiers to generate a seamless use experience [6]. Users are now expectant of a coherent, compelling experience that means the digital information flow should be appropriate, timely, and sensitive to context. Concepts such as the diegetic interface can be

helpful in creating an integrated physical-digital experience, and in creating a strong narrative to the interface design [7].

AR represents a distinct case as the user is still interacting with the physical environment. However, it remains critical that the AR overlays are designed in such a way that they do not impinge on or detract from the natural interactions. What is crucial for AR is achieving a form of immersion despite the presence of an outside real world [8]. While older understandings of immersion and engagement proposed and single and unidirectional framing [9], more recent work has brought the context of individual personality and wider society into the frame [10]. Subsequently we can say engagement is a distinct subjective positioning of the user within the matrix of inputs delivered by the system resulting in experiences of flow, presence and immersion that are significantly influenced by the users' idiosyncrasies and societal influences.

#### 2.2 Perspectives from human-centred design

Giacomin [11] has described how the apex of HCD thinking is meaning stating that "human centred design leads to products, systems and services which are physically, perceptually, cognitively and emotionally intuitive" (p.610). This approach has been fundamental to the development of digital computing tools and novel tools integrating the physical and digital realms. Early exploration of this such as the 'Triangles' project from MIT's Media Lab [12] took simple physical artifacts that could be electronically connected and created digital 'events' from their interactions. Similarly, the ATILIER project explored the use of digital augmentation in an architectural design context such as the application of virtual paint textures onto physical models [13]. The conceptual shift has even been explored in a digitally augmented version of the game Go [14] and within a museum context – itself now a commonplace feature within interactive educational environments [15]. Figure 1 shows the relationships between physical engagement and its cognitive and emotional value to users. In essence there is a constant state of flow between the cognitive and emotional that is mediated by the physical engagement.



Figure 1. Figure showing key characteristics of physical-digital interaction

In relation to design several interesting projects track closely with the demonstrator we are presenting. Mazalek et al for example developed "Architales", a physical-digital co-design tool for interactive table for "tangible story telling" [16] and similarly Hartmann et al developed "Pictionarie", a tabletop device that allows design teams to transfer sketches, notes or images from the physical to the digital realm [17]. Following this vein, we have previously developed a VR-based prototype, the "Control Carousel", that allows design teams to review products in an interactive digital environment. The work identified several characteristics in relation to a successful engagement with a VR based prototype: accessible, reassuring, contextual, satisfying, collaborative [18]. This tracks closely with other work from the University of Bristol on physical-digital integration in relation to digital twins who concluded learning, evolution, intersection, dependence are the key factors for a successful engagement [19].

## **3 ORDERS OF ENGAGEMENT FRAMEWORK**

To formalize the properties of user engagement with physical-digital interaction, we have generated an "Order of Engagement" framework that characterises the nature of interaction with physical-digital interfaces (Figure 2).

	Order 1	Order 2	Order 3
Physical	Configuration of basic model composition	Manipulation of representative elements and artefacts	Interaction with detailed data streams
Digital (information)	Abstraction of design context via extraction of visuals, dimensions	AR overlay representing functional elements of system	Live data and analysis of system performance
Product interaction example	Manual typewriter inputs	Inputting of text into a computer interface	Interaction with a gaming controller and game architecture/narrative

Figure 2. Orders of engagement in relation to physical and digital interaction

- *I.* Observation of system architecture and location conveyed through static representation, which can also be mapped in physically prototyped, adjustable models.
- 2. Interaction with information and representations of system functionality through AR artefacts via the mixing of physical prototype models and digital interfaces. E.g. apprehension and manipulation of design features
- 3. Integration of dynamic conditions and performance captured in-situ, which will be communicated through live simulation. E.g. convergence of real-time and historical data

# 4 OVERVIEWS OF PHYSICAL-DIGITAL TOOL

Working in conjunction with Siskin Asset Management, a company that specialises in developing lotech solutions for coastal erosion problems, we developed a prototype tool that allowed for the simulated visualisation of this technology. The prototype tool utilises the Order of Engagement framework (Figure 4) in order to create a more compelling way for Siskin to communicate with clients and external stakeholders when explaining the function and installation of their system. It consists of several features that allows the user/s to build a representation of the target coastal site and then to digitally visualise, utilising augmented reality, how the Siskin technology would appear within the environment.

The representation of the target environment is created by adjusting a set of levers, the position of which broadly conform to the sea, beach and sand-dune that make up the real environment. By moving the relative position of the levers along the rails and using the wheel-cranks to adjust the high of the surface, a range of landscapes can be created. As the surface was prototyped using a magnetic sheet, custom AR markers could be deployed and placed at any point on the sheet without sliding off.



Figure 3. Elements of the physical-digital visualisation tool

A diagram of the tool's key features in relation to the Order of Engagement framework is shown in Figure 3. The first order is defined by observation and building a static representation of the target site. In essence, this is a process of abstracting the real world. The second order is defined by initial interactions with the AR representations that provide an insight into how the Siskin technology might

look within the real world (albeit as abstracted version). The third order is defined by the integration of more intelligence into the AR digital interface that allows the user dynamic control over the visuals such as installation detailing or time-lapse sequences showing the growth of sand dunes, vegetation and biodiversity markers.



Figure 4. Orders of Engagement model for interacting with the prototype

The tool is designed so that the user can freely move around it i.e. it does not need to be attached to a wall and does not require electrical input. Ideally it is placed centrally on a small table and the user(s) can move around its perimeter and interact with it both physically by adjusting the landscape parameters or digitally by using the simple AR app and freely changing the positions of the AR markers of which we created 8 unique variations, each loaded with a different visualisation model similar to that shown in Figure 3.

Linking back to some of the earliest examples of physical-digital tools such as MIT's Triangles, the demonstrator moves between the physical and the digital as the user moves through the phases of use. There is an initial manipulation of the model – the relevance of the digital here is negligible as the user negotiates the physicality of the device. Then there is the introduction of AR which brings two narratives together, one abstract but real, the other conceptual or hypothetical. This is similar to a process of world-building in the user's mind [20]. This AR dimension can then be directly manipulated in various ways – almost like an opposing force, the physical reasserts itself as the user can reconfigure the parameters of the AR presentation. This "negotiation" between the physical, digital and the interaction between them links with the model presented earlier (Figure 1) whereby the engagement is the "engine" behind cognitive and emotional payoff for the user.

## **5 APPLICATIONS TO DESIGN EDUCATION**

## 5.1 Technological acceptance and user satisfaction

We can now explore a number of scenarios that relate to design education. Since the relation between users' physical engagement and cognitive value was previously discussed in Section 2, the first explored scenario concerns the adoption of the developed framework in modules following Human-Centred Design approaches. In particular, the engagement orders can contribute to the planning of user-led design investigations and tackle issues related to technology acceptance and user satisfaction. Providing that the application of VR/AR in HCD projects has been quite prevalent over the last years, in the existing scenario students could focus on the design of the tangible element of the product that is integrated into VR/AR environments and enhance the overall user experience. Consequently, design assignments of such nature predominantly address the first two engagement orders through 1) observation of user experiences through HCD methods and 2) merging of physical-digital worlds based on identified context and user requirements and should aim to promote the delivery of "physically, perceptually, cognitively and emotionally intuitive" solutions for distinct problems.

#### 5.2 Learning and technical familiarity

The second educational scenario concerns students' learning and familiarity with such emerging technologies and aims to advance the way in which they perceive digital interactions during CAD and 3D modelling related courses. Insights from previous case studies [21] have already been implemented to introduce students to the benefits of VR applications in design reviews, and model exploration in immersive environments. Outcomes from the aforementioned case study can be framed to structure the lecture contents of a digital visualisation class and show how the three engagement orders can exploit the benefits of such interactions. In detail, Orders 1 and 2 can be used to develop technology-related challenges and prompt students to reimagine AR controllers beyond digital interfaces and explore how different types of physical props can be used for manipulation and refinement of digital models or navigation of virtual environments, through multiple modes of haptic feedback. Following that, Order 3 should focus more on adding new knowledge dimensions via studying the ways in which real-time data can be transferred and visualised through the convergence between AR and Digital Twin technologies.

#### 5.3 Prototyping roles through the framework

Lastly, the third scenario belongs to the theme of prototyping and addresses the ways in which distinct prototyping roles can be served through the application of our framework in academic design projects. In detail, the three "Orders of Engagement" can have a valuable impact in students' decision making when it comes to selecting suitable formats for their prototype models [22] for demonstration, communication and design refinement purposes. Students' prototyping tasks can be alleviated through the process of augmenting physical models with useful digital information, to efficiently communicate their properties and function to project stakeholders, e.g. end users during testing and educators during critique assessments. Exemplars may include the overlaying of a quick mock-up model with rendered appearances to present aesthetics, integrated animations to demonstrate function and employment of Digital Twin to visualise potential impact and performance of concepts. On the other hand, the same mechanisms can also be applied to iteratively refine and evolve their ideas through testing in later design stages, as AR-based simulations can support optimisation of a concept's performance by acquiring real-time experimental data through Digital Twins. Thus, the three engagement orders could also contribute to the evaluation and validation of technical specifications and requirements, while ensuring the whole system's functionality and compatibility of its parts.

## **6** CONCLUSIONS

This paper has outlined a conceptual model in which physical-digital interaction can be understood within an "Orders of Engagement" framework. By firstly exploring the key theory of interaction and highlighting a number of prominent research example we developed a three-fold engagement framework that emphasizes the exchanges between physical and digital interaction and the cognitive and emotional payoff a user can get from these interactions. We then introduce our demonstrator prototype, used to explore these concepts in more detail and showcase how augmented reality can be used in interesting ways in conjunction with a physical prototype arrangement.

Providing that emerging technologies such as Augmented Reality and Digital Twin are constantly developing, it is vital for design and engineering education to parallel with their changing nature and ensure that they are capably integrated into teaching practices and curricula. In STEM subjects particularly, AR can be employed to enhance spatial ability, conceptual understanding and visualisation skills by functioning as a blended learning and teaching tool [23]. Consequently, future study will investigate how its potential applications in engineering and product design educational settings can enrich the adoption of digital tools in design workflows through exploring the intersections between physical and digital technologies. The intersection of physical and digital continues to be a compelling area. This case study shows how these technologies are redefining our relationships with society and the environment and offer new possibilities within the space of design and engineering to create new tools of creativity and education.

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# DESIGN FOR THE ELDERLY: AN IMMERSIVE HUMAN DIGNITY EXPERIENCE FOR UNIVERSITY STUDENTS

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#### ABSTRACT

Various population groups present conditions that require special considerations in the design process, such as the elderly. The present research focuses on developing and implementing a structured design process for this group, which is divided into four stages: research, conceptual design, detailed design, and implementation. The methodology was implemented in a sample of two student groups (31 students total) studying Product Design in their sixth semester at Tecnologico de Monterrey. They developed 14 product design projects for a nursing home in Monterrey, Mexico. The students visited the nursing home during the course, identifying problems through observation and interviews with the residents and their caregivers. At the end of the course, the students responded to a survey-type instrument to evaluate the impact of the model on their educational experience. The students positively assessed the nursing home personnel's participation in the project's development, emphasising its importance during the research. However, the students recognised the differences between this design process and previous experiences in Design courses.

The impact of project development transcends practical aspects. Working with older people implies deepening empathy, comprehending their vulnerability, and preserving their human dignity as they depend on others. Ultimately, it was possible to determine that the design process proposed in this research facilitates developing products that meet real user needs that would tend to go unnoticed.

Keywords: Human dignity, design process, elderly, higher education, educational innovation

## **1** INTRODUCTION

Various population groups present conditions that require special considerations in the design process, such as the elderly. The UN defines an "elderly" person as someone over 60 [1]. Older people generally present degenerative diseases that diminish their functions, limiting mobility, movement capacity, and independence. Aging is associated with dysfunctions such as hearing loss, cataracts and refractive errors, back and neck pain, osteoarthritis, chronic obstructive pulmonary diseases, diabetes, depression, and dementia, which hinder their ability to carry out daily activities and interact adequately with the spaces and objects around them [2] [3]. This population group is increasing; it is estimated that by 2030, one in six people in the world will be 60 years of age or older. By 2050, the world's population of people 60 and over will have doubled (2.1 billion). People aged 80 and over are expected to triple between 2020 and 2050 to 426 million [4].

On the other hand, life expectancy is increasingly longer, allowing opportunities of great benefit to society through the population's increase in productivity, contributing to economic and social development; in addition, older people contribute in numerous ways to their families and communities [3] [5]. This is why paying attention to this population group is essential, as they are a vulnerable group usually neglected in Latin America, where their needs are overlooked, reducing their chances of preserving their independence and remaining productive. By 2050, two-thirds of the world's population over 60 will live in low- and middle-income countries [4].

The teaching of design has continuously evolved. Students learn various design methodologies, from the one proposed by Bruno Munari in 1980 to systematically identify problems and solve them logically [6]to the human-centred design [7], which aims to provide tools for solving complex problems placing the user in the center, the method is based on creating empathy, generating prototypes and iterating solutions. However, in recent years, authors have emphasised participatory design or co-design

involving the users deeper in the process where they become a fundamental part of the design process by collaborating directly in the solution. Moreover, design education addresses other perspectives, such as design for aging [8], which seeks to implement solutions for the elderly living in retirement homes.

This work employed a mixture of these, seeking to collect the best practices of various authors, while incorporating the learning experiences of each student during the process, helping each to discover the importance of designing with empathy. It is important to emphasise that the research stage is where students delve into the users' particular needs for a better understanding of the elderly's problems in everyday life, valuing their different perspectives [9].

Designing products for the elderly opens great opportunities to positively impact the quality of life for this growing group of users. Designers are challenged to create value through spaces, products, services, and experiences from a universal design perspective [10], adapting to the physical and cognitive characteristics of older adults performing their daily activities while simultaneously meeting the general population's needs [2].

Beyond the economic aspect that this opportunity presents through creating a good offering of products and services for older people, it aims to motivate them and affirm their capabilities and autonomy for dignified aging [2] [10]. Likewise, the methodology seeks to awaken students' genuine desire to generate value for the various user groups through their discipline and assume their social responsibility as design professionals.

This research focuses on developing and implementing a specially structured design process for the elderly and their needs. The process was divided into four stages to guide university students during their projects, emphasising user interactions and detecting their needs. The four stages are Research, Conceptual Design, Detailed Design, and Implementation.

# 2 **METHODOLOGIES**

As part of the methodology, a literature review was carried out to define the stages and elements necessary to apply the proposed design process [12]. In addition, the structure suggested in the subject syllabus was used to define the stages and activities that would be considered in the process.

#### 2.1 Description of the process generated for this research

The subject syllabus divided the activities into four stages, namely: (1) preparation, (2) research and analysis, (3) synthesis and definition of requirements, and (4) creativity and specification. These stages were distributed over fifteen weeks, each with a different duration. Based on these stages and the set of activities that each involved, an adaptation was made for a better approach to the project and the type of user that had been previously defined, also considering the theoretical proposals consulted about the design process, the methodology, and the methods themselves [13]. In this adaptation, four new stages redistributed the activities and adjusted the times of each (see Figure 1).

The first stage, Research, established eight activities to facilitate the approach to the user and raise awareness about their living conditions; it concluded with a brief [14]. The second stage, Conceptual Design, was where the design proposals were generated with different validations per type of user [15]; the aim was to develop an understanding of the specifications that meet the users' requirements and fully respond to their expectations. The third stage, Specification Design, validated aspects of the product such as colour, materials, and finishes (CMFs) [16] and developed a Beta prototype with excellent fidelity to what the industrially manufactured product would be [17]. Finally, the fourth stage, Implementation, tested the prototypes with users and developed another series of additional elements to complement the user experience, such as packaging, instruction manuals, and digital supports (apps and websites).

Stage 1:	Stage 2:	Stage 3:	Stage 4:
Research	Conceptual design	Specification design	Implementation
Gather information about user and context	Conceptualization	Design improvements	Selection of materials and manufacturing suppliers
Research in secondary sources	Look & feel moodboard	Medium fidelity prototype/ making improvements	Supervision and follow up
Ethnographic research /	First idea generation	Virtual prototype	for the manufacturing of the high fidelity prototype
observation/user interviews / expert interviews	Evaluation of ideas based in the design for the elder requirements	(Ergonomic and usability validation)	Visual communication and rendering
Identification of user needs/ first and second order users	(Internal validation (design team and professors)	Material selection	Branding and extended user experience
Problem definition	(Idea selection base on feedback)	Technical drawings and production manual	High fidelity prototype testing/
considering the human dignity of elder users	Rapid prototyping/ low fidelity models		ergomomic and usability testing
Benchmark			Project documentation
Design requirements definition	First and second users validation of prototypes / validation with experts		
Design brief			

Figure 1. Design process generated for this research

## 2.2 Implementation

Once the process was defined, it was implemented in a sample of two groups of sixth-semester Product Design students at Tecnologico de Monterrey (31 students total), who developed 14 product design projects.

The projects were designed to meet the needs identified in a nursing home in Monterrey, Mexico. During the course, the students visited the nursing home on several occasions, identifying problematic situations through observation and interviews with the residents and their caregivers. Observations were made using a designed guide focusing on specific categories such as space, illumination, environment, relationships, activities, roles, attitudes among others; interviews were conducted individually and also a focus group with the personnel was carried out. Students also had numerous interactions to present their ideas and validate prototype iterations with users [9].

The elderly residents were divided into three categories depending on their autonomy to perform daily activities. The first group of dependent patients encompassed those users who required assistance to carry out all their activities and usually had limited or no mobility. The second group was semi-dependent; they could perform some activities by themselves or with the help of devices but required assistance with some, such as changing diapers, bathing, or dressing. The third group was the autonomous patients, who required occasional aid.

On the other hand, a differentiation was also made between first and second-order users [15][18], considering the elderly residents as primary or first-order users and the caregivers as secondary or second-order users.

1. Wheelchair safety harness	2. Adjustable tray with support	3. Adjustable support for diaper
	for upright eating	change
		IL.

Table	1.	Students'	pro	jects
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The dependent and semi-dependent patients require the support of their caregivers to operate the products and carry out their daily activities, which generally leads to an invasion of their privacy and a decrease in their human dignity because they require assistance to perform their most essential activities. Another aspect identified was related to the type of materials or devices used when performing therapies to maintain or recover the residents' mobility. In many cases, these activities are conducted with instruments or toys designed for children, with children's colours and figures. This generates

discouragement and indifference among patients who feel that they are treated as children. For this reason, the products designed had to consider especially the dignity of the residents and their emotional state when interacting with the products to prevent them from feeling denigrated or unworthy when receiving support [19]. Some of the results of the projects carried out by the students can be seen in Table 1.

## 2.3 Evaluation

At the end of the course, an online survey-type instrument with dichotomous and Likert scale questions was applied [20] to the students to evaluate the model's impact on their educational experience and validate the unique characteristics of the process proposed in this research [21]. The data obtained from the survey were analysed to produce the results.

# 3 RESULTS

The survey was applied to 31 students in the sixth semester of the design degree at Tecnologico de Monterrey, of which 77% were women and 23% were men between the ages of 20 and 24. The data analysis revealed that 68% already had some experience designing for people with particular conditions on previous design courses.

The students were asked how difficult they considered this project (on a Likert scale where one represents not difficult at all and seven represents very). More than 30% rated it with five; when added to the percentages rated six and seven, the total rises to 75% as a high level of difficulty. However, comparing this with the students' assessment of the impact of this project on improving their professional skills shows a remarkable similarity between the two results (see Figure 2).



Figure 2. Comparison between difficulty and professional improvement

Figure 3. Comparison between difficulty and value in learning

The students were asked about the process stages to identify their perceptions of each regarding the difficulty of carrying them out and the value for their learning. Their assessments presented a significant variation (see Figure 3), where Stage 3 was the one they considered to be of greatest value for their learning. Still, Stage 4 was the one they thought most challenging to perform. Stages 1 and 2 evaluations were similar, although Stage 1 stands out in value for learning.

Students were asked to identify (on a Likert scale where one represents not at all and seven represents a lot) how important they considered function, aesthetics, human dignity, safety, and product cost when making product design decisions. Significant differences can be observed between the aspects evaluated: Figure 4 compares Aesthetics and Human Dignity, in which the latter obtained a much higher rating than Aesthetics.

As a result, they evaluated all the process stages positively, highlighting the Detailed Design stage (3) as the one that contributed the most value to developing their disciplinary competencies and pointed out the Implementation stage as the most challenging. Likewise, the students positively valued the nursing home staff's participation in the project's development, highlighting its importance during the Research stage. On the other hand, students recognised some differences in this design process compared to their previous experiences in other design courses such as specialists participation, difficulties to obtain information directly from users due to their physical and cognitive impairment, also in the design stages there was a significant difference in the number of iterations required to reach a viable solution ensuring

that it improves the patient's quality of life and maintains their human dignity, while other processes focus on market opportunities or designs for commercial purposes.



Figure 4. Importance of aesthetics vs human dignity when designing

#### 4 **DISCUSSIONS**

As can be seen in the results, the students found the project very difficult even though 68% said that they already had experience in projects for people with particular conditions. This could be related to students having to consider several user types as patients, caregivers and family members simultaneously, as Flores suggests [18], and it is reinforced by their appreciation for the increase in their professional skills (Figure 2). Regarding this aspect, it is a valuable indicator that students positively appreciate a project of this type in their professional skills development because it connects the disciplinary task with this type of user.

Regarding the process followed in executing the projects, it is significant that the students rated Stages 1 and 3 as producing more learning, considering that the first stage is when they have the first contact with the users and become aware of their living conditions; moreover, Stage 3 is when they present their beta prototype, a product with a very high level of quality and finish that they also must validate with users. Also, it is striking that the students found Stage 2 to be of lesser value in learning because it is where the most user interactions and concept iterations occur within the process.

Figure 4 shows the highly relevant importance the students gave to human dignity when making design decisions. They aligned with Adolfo et al. [2]and Gossett et al. [10]by seeking to improve the elderly's quality of life by giving them more independence in their activities; this factor prevails over others that traditionally impact design decisions. This allows us to say that the students demonstrated a change in the way they approach social impact projects and that they have the required competencies to achieve them.

#### **5 CONCLUSIONS**

The project's development had an impact that transcended the practical aspects; working with older people implies deepening empathy and considering their vulnerability. Students also paid attention to the residents' human dignity due to their dependence on others to meet their basic needs. They recognised the value of identifying how several types of users interacted with the products. In this, the students noted the relevance of medical personnel and caregivers, who attend to and accompany the older adults in all their daily activities even if they are not considered the primary or first-order users. In conclusion, it was possible to determine that the design process proposed in this research allows the development of products that satisfy real needs that tend to go unnoticed such as personal safety, diaper changing and feeding due to the lack of consideration of the different users, where each may have a different perception of the same activity simply because of how they relate to it, as usually happens in cases involving the elderly residents, their families, and their caregivers in nursing homes.

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# COMPARING UNDERSTANDABILITY OF HAND SKETCHES VERSUS AI-GENERATED RENDERS FOR PRODUCT DESIGN

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## ABSTRACT

Sketching to communicate design ideas is an important step in the design process. Image-generative artificial intelligence (AI) tools are increasing in prevalence and popularity, some of which focus specifically on sketch-based inputs. The primary aim of this study was to investigate whether an AI-based sketch tool would improve the understandability of students' design concepts. In the context of an undergraduate engineering and product design course, we introduced Vizcom, an AI tool which uses sketch-based inputs to generate renders. In this paper, we describe a quantitative analysis of a dataset of students' hand drawn concepts and the resulting Vizcom render outputs. The sketches and renders were rates separately using standardized rubrics. Our analysis of these ratings indicated that there was no significant difference in understandability between the hand sketches and the AI-generated renders. The characteristics of the hand sketches: line quality, proportionality, and understandability, were all positively correlated with the proportionality and understandability of the AI-generated renders. Our results suggest that the use of Vizcom may offer some benefits in quickly conveying realistic materials and contexts. Results may be different for other types of design concepts and other populations.

*Keywords: Artificial Intelligence, product design, design education, design sketching, understandability* 

# **1** INTRODUCTION

This paper describes an application of generative artificial intelligence (AI) to student work in a collaborative undergraduate design course. We describe an initial quantitative comparative analysis of a set of concept sketches generated by hand using digital sketching software (most students used Procreate with an Apple pencil on an iPad), and the analogous concept images generated using an AI-based tool called Vizcom. Vizcom software pairs a visual interface with a text-based input and is designed to create high-quality rendered images from a combination of sketch and text input. The primary aim of this analysis was to investigate whether Vizcom helped the students communicate their ideas more clearly than hand sketches. As far as we are aware, there is not yet any published work exploring the effectiveness of using AI to help designers represent their ideas at the concept sketching stage. Artificial intelligence tools are likely to change the way product designers sketch, and the present work aims to investigate how.

# 2 BACKGROUNDS

## 2.1 The role of design sketching in the design process

Design sketches used at different phases of the design process have different roles, and sketching is treated differently in engineering design and product/industrial design. In product design, *ideation sketches* are used to explore a wide variety of ideas and/or variations of the same idea. These sketches are typically looser and may resemble 'doodles' or 'thumbnails' [1]. *Concept sketches* are more detailed than ideation sketches and begin to explore more technical solutions and feasible ideas [1]. *Presentation sketches* are more detailed and realistic than concept sketches and are typically presented to a client or external audience to provide a clear and inspiring image of what the final product could look like [1]. In engineering design education, artistic sketching skills are not as highly emphasized. While sketching is
fundamental to design brainstorming and documenting ideas, engineering and technology education place little emphasis on the instruction of design sketching [2]. In this study, we analyse a collection of sketches that we will classify as "concept sketches."

While art-based drawing courses might focus on training students to create realistic representations of existing objects, the primary aim of teaching designers to draw is to apply established techniques of drawing to representations of physical artifacts which do not currently exist and therefore must be imagined and communicated outwardly. Thus, design-based sketching instruction relies heavily on methods for "constructing" the new concept on the page, producing a representation of a 3-dimensional artifact using 2-dimensional media. A wide range of student prior background in drawing/sketching means first establishing a foundation of drawing elements — the "must haves" of line quality, plane, volume, perspective, and proportion — before advancing to the "nice to haves" of shading, shadow, materiality, context, sequence, and so on. Application of these basic elements to increasingly complex, existing target artifacts — real objects, products, or devices that increase in formal complexity from simple boxes to hand-held tools, allows students to build up their skill and confidence before approaching the challenges of visually representing non-existent artifacts. Once the basic "vocabulary" of drawing is established, focus shifts to fluency. Through practice and exploration, students begin to learn when, how, and where to employ differing levels of fidelity and resolution of their sketches.

Many design sketching courses begin with analogue sketching by hand on paper with simple tools (pencil or pen), before progressing to digital sketching programs. Digital sketching software applications like Procreate offer an overwhelming array of simulated analogue tools (paint, ink, texture, etc.) along with additional functions not easily available in analogue drawing such as layering, mistake-correction, and automation.

### 2.2 Generative AI in design

Authors García-Peñalvo & Vázquez-Ingelmo define generative AI as the "production of previously unseen synthetic content, in any form and to support any task, through generative modelling" [3]. The use of image-generative AI is increasingly being explored for design applications. Image-generative AI models rely on large datasets of images paired with text-based descriptions which are used to train the models. Diffusion models gradually add noise to image data, then run in a reverse process to denoise the data, resulting in a synthetic image [5].

So far, the applications of generative AI in design have mixed findings. In fashion design, generative AI created many 2D images of designs that were not distinguishable from human-created designs [4], and in architectural design, the generative AI created many designs that would be impossible to construct [5]. Cai et al. investigated the use of a generative AI design tool which creates inspiration mood boards for art and design, and participants found the generative tool more useful for inspiration compared to a traditional image search on Pinterest [6]. Generative AI tools should not necessarily be used uncritically by designers. Bartlett & Camba raised concerns about ethical issues of image-generative AI in product design education, including biased outputs, theft from artists whose work is included in the training data without consent, lack of originality in outputs or "AI copying," hidden labour in generating the datasets used to train AI, and lack of copyright protection of generated works [7].

Vizcom is a web-based application that allows users to import sketches, 3D models, or draw directly into the interface. These image or model-based inputs are accompanied by a text prompt where the user describes what the model is supposed to be depicting. Figure 1 shows an example of a sketch-based input accompanied by a text prompt "white partial glove with green plastic part" on the left, and on the right is an output image generated by Vizcom. Vizcom outputs are typically high fidelity, similar to what a designer might be produce using detailed hand shading for a final presentation sketch or through computer rendering from a 3D model.



Figure 1. Example of Vizcom input interface (left) and output image (right)

# **3 METHODS**

In our course, student teams comprised of both product design and biomedical engineering students interviewed physicians to identify problem areas in various medical disciplines and designed solutions around these problem areas. During this collaborative project, the product design students were tasked with creating concept sketches of the five final concepts each team devised. To aid the students in creating their concept sketches, the instructor introduced the use of a sketch-based generative AI tool, Vizcom. Using the Pro version of Vizcom software, the students transformed digital sketches into higher-fidelity renderings of medical device design concepts.

Nine third year product design students (five women, four men) depicted five concepts as both a hand sketch and a Vizcom render. Students were encouraged to use the digital sketching software Procreate to create their hand sketches, although one student opted to draw with pencil on paper. The students were provided one hour of in-class training in how to use Vizcom to aid in their design explorations. Thus, the students were novice users of the software.

The final set of images for analysis contained 41 sketches and 41 corresponding Vizcom renders, indicating that a few students submitted individually incomplete assignments. Each sketch depicted a medical device concept idea, and each sketch was used as an input to generate the Vizcom render. Examples of sketches and corresponding Vizcom renders are shown in Figure 2. If the sketches included any hand-written notes, these notes were obscured prior to analysis.



Figure 2. Examples of hand sketches and accompanying Vizcom renders analysed in this study

To provide a basis for comparing the sketches and Vizcom renders, we used a rubric devised by Das & Yang for evaluating design sketches [8]. Das & Yang devised this rubric to assess primarily early-stage sketches from the brainstorming stage. The rubric assesses the sketches on three criteria: line smoothness, proportion/accuracy, and understandability [8]. For each criterion, drawings are rated on a scale of 1 to 5, 1 being the lowest, and 5 being the highest.

In this study, three raters independently evaluated the drawings. Rater 1 was the product design professor who taught the collaborative course for which the sketches were created, and thus knew the context of each sketch. The other two raters were product design professors with extensive experience teaching design sketching. Of these other raters, rater 2 was somewhat familiar with the concepts being sketched, and rater 3 was not familiar with the concepts. Each hand-drawn sketch was rated on all three criteria in Das & Yang's rubric: line smoothness, proportion/accuracy, and understandability. Because the Vizcom renderings are more photorealistic and do not include cartoon-like outlines, the Vizcom renderings were rated on only two criteria: proportion/accuracy and understandability. Hand sketches and Vizcom renders were assessed separately. The order of the sketches and Vizcom renders was randomized so that it would not be immediately obvious to the raters which hand sketches had been used to create which Vizcom renders. Following the ratings, we calculated the interrater reliability, the correlations between the different dimensions scored on the rubric, and we compared the means of the understandability scores for the hand sketches and corresponding Vizcom renders.

### **4 RESULTS**

Intraclass Correlation Coefficients were calculated to determine interrater reliability. We used a twoway mixed model because every rater coded every drawing, but the raters were not random in that they were somewhat familiar with the student projects [9]. Average measures were used rather than single measures since average measures will be used in the rest of the analysis. The Intraclass Correlation Coefficients are reported in Table 1.

Rubric Dimension	Intraclass	95% CI Lower	95% CI Upper	Sig.
	Correlation -	Bound	Bound	
	Avg. Measures			
Hand sketch line qual.	.820	.697	.898	<.001
Hand sketch prop.	.875	.790	.929	<.001
Hand sketch under.	.875	.789	.929	<.001
Vizcom prop.	.861	.766	.921	<.001
Vizcom under.	.882	.802	.933	<.001

Table 1. Intraclass Correlation Coefficients between raters

The Intraclass Correlation measures were all above .80, indicating good interrater reliability [9]. Rater 1, who was the instructor of the class, gave the drawings highest average scores for all categories, rater 2, who was somewhat familiar with the projects, gave drawings middle ratings, and rater 3, who was least familiar, gave lowest averages for all categories.

Correlations, based on averages of the three raters' scores, were calculated between each of the different rubric categories. The correlations are reported in Table 2. All correlations were statistically significant at the 0.01 level (2 tailed). All the rubric categories were positively correlated with one another: hand sketch line quality, hand sketch proportion, hand sketch understandability, Vizcom render proportion, and Vizcom render understandability.

	Hand sketch	Hand sketch	Vizcom prop.	Vizcom under.
	piop.	under.		
Hand sketch line qual.	.65**	.68**	.73**	.66**
Hand sketch prop.		.79**	.73**	.57**
Hand sketch under.			.65**	.74**
Vizcom prop.				.70**

Table 2. Pearson Correlations Coefficients between rubric criteria

\*\* p < .001

A paired samples t-test was used to evaluate whether there was a difference in the understandability ratings between Vizcom renders and hand sketches. The results indicated that there was no significant difference between the hand sketch understandability (M = 3.53, SD = 1.08), and the Vizcom render understandability (M = 3.62, SD = 1.00), t (40) = .761, p = .226.

# **5 DISCUSSIONS**

Hand sketches that had good line quality, proportion, and understandability were positively correlated with proportional, understandable Vizcom renderings. Vizcom renders were not significantly different than the root hand sketches in terms of understandability. Taken together, these results suggest that Vizcom, in its' present form, is not likely to replace or diminish the value of being able to sketch by hand. Regarding the strengths of Vizcom, we see a strength in depicting the human form in much greater detail than what the students' hand sketches contained. For example, the person's back shown in image A2 of Figure 2 contains much more detail conveyed through colour and shading than the simple outline of the person's back contained in image A1 of Figure 2. As showing context is very important for design communication, and many concepts in product design relate to the human body, enhancing this imagery may be a valuable strength of using Vizcom in product design. However, it is well-known that imagegenerating AI can also generate uncanny or disturbingly inaccurate depictions of the human body, although newer models are working on improving this. Image B2 of Figure 2 demonstrates another strength of using Vizcom, which is showing materials in higher fidelity. While Image B1 is not a very clear drawing, and the clarity of the lines is not necessarily improved in B2, what is improved in B2 is that the viewer gets a sense that the bag is made of a clear material. The clarity of materials was not something that is captured in the rubric that we used to assess drawings in this study.

We do not believe that the raters' familiarity with the concepts necessarily impacted their ratings on the "understandability" category, because although rater 3, who was least familiar with the concepts, gave the lowest ratings for understandability, rater 3 also gave the lowest ratings in the other categories. Thus, this discrepancy could be related to the interpretation and application of the rubric rather than familiarity with concepts. The rubric we used was developed in the context of engineering design, a discipline in which students receive less training in sketching and the purposes of sketching are fundamentally different than in product design. We chose to use this rubric because it was the most relevant published rubric available. Were we to adapt the rubric for product design, we might add a wider range of scores, since this rubric may lead to a ceiling effect when used with product design sketches.

One limitation of this study is that the participants were third year product design students who had one hour of formal training using Vizcom software. Beyond this training, any learning in Vizcom was done independently, and some students likely spent more time than others exploring the software. However, none of the students would be classified as experts in using Vizcom. It is possible that expert users of Vizcom might produce different results than what was found in this study. Another limitation is the fact that this data set contained only medical device concepts. Medical device concepts are likely to be very underrepresented in the tagged image data used to train the AI models that Vizcom runs, in comparison to more commonly represented objects like cars and shoes. It is possible that a different type of project that focuses on the design of a more common object would yield different results. Another limitation is the fact that the raters were all product design professors with some experience teaching design sketching. Results may be different with different populations of raters.

As future work, we are interested in analysing the drawings at an individual student level. While there is no significant difference in the whole population between the understandability of hand sketches and Vizcom renders, it is possible that some students deviated from this trend depending on their level of sketching skill and style. It would also be helpful to analyse the text-based prompts.

### **6** CONCLUSIONS

At present, the sketch-based AI image-generating software Vizcom does not appear to replace hand sketching skills, though it does offer important benefits. We found no significant difference in understandability between the concept sketches produced by hand and the corresponding Vizcom renders. An individual's ability to produce high quality Vizcom renders appears to be related to their ability to sketch by hand, as the traits of line quality, proportionality, and understandability of hand sketches were positively correlated with proportionality and understandability of Vizcom renders. We did find that Vizcom provided some benefits in representing materials more realistically, and in providing more realistic context for devices used on the body. Our results were obtained in the specific context of novice-Vizcom-user students sketching medical device concepts, and the results may not hold true with other populations or in other contexts.

In the product design industry, the traditional craft of sketching by hand is still highly valued by some professionals and educators. The results of this study suggest that sketch enthusiasts do not necessarily need to be concerned that sketch-based AI tools like Vizcom will fully replace the need for traditional sketching skills. At present, individuals who want to master sketching with Vizcom will likely still need to practice both hand sketching and control of the software tool. However, Vizcom soon may replace the need for creating high-fidelity presentation sketches, which require realistic shading and materials, by hand. Creating such sketches by hand is quite time consuming, so the time savings afforded by AI-based tools like Vizcom is likely to promote their adoption.

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# EXPLORING MY SUSTAINABLE FOOTPRINT: AN INNOVATIVE JOURNAL-BASED METHOD FOR DEVELOPING SUSTAINABILITY AWARENESS AND HABITS

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# ABSTRACT

Sustainable awareness, defined as the perception and understanding of the importance of caring for the environment and adopting sustainable practices, has gained increasing significance in today's context of environmental challenges. Education plays a pivotal role in promoting this awareness, from early stages to higher education. To achieve a meaningful shift toward more environmentally respectful behaviours, various pedagogical strategies have been explored, with the use of journals proving to be an effective tool for fostering reflection and the development of pro-environmental skills. This text addresses the relationship between sustainable awareness and journaling, analysing its importance in the educational process and in shaping individuals and designers committed to environmental preservation. Additionally, it reviews studies exploring how education and knowledge levels correlate with environmental awareness, highlighting the relevance of higher education in promoting sustainable behaviours. Notably, the implementation of this method over the last two years among multidisciplinary students, from the first to the final year of professional education, has yielded highly favourable qualitative and quantitative results. These results demonstrate deep and positive reflections and compelling data on the utility of journaling in cultivating sustainable habits and awareness. Through this exploration, the emphasis is on the importance of instilling values, attitudes, and pro-environmental knowledge through education and journaling, aiming for a meaningful shift toward a more sustainable and harmonious designed future with nature.

*Keywords: Sustainable awareness, sustainable habits, journal, higher education, professional education, educational innovation* 

# **1** INTRODUCTION

The increasing relevance of sustainable awareness, defined as the understanding and consciousness of the importance of environmental care and adopting sustainable practices, is crucial among contemporary environmental challenges. Education plays a pivotal role in nurturing this awareness, starting from early stages and continuing through higher education [1], [2]. Various pedagogical approaches like Problem-Based Learning (PBL), Experiential Learning, Collaborative Learning, Case-Based Learning have been explored to induce significant shifts towards more social, economic, and environmentally friendly behaviours, with journaling emerging as an effective tool for fostering reflection and developing prosustainable skills [3].

This paper aims to explore the relationship between sustainable awareness and journaling, emphasizing its significance in education and the formation of individuals committed with sustainability. It will review studies that investigate how education and knowledge levels influence sustainable awareness, underscoring the role of higher education in promoting sustainable behaviours. The text will highlight the importance of instilling pro-sustainable values, attitudes, and knowledge through education and daily practices to drive meaningful change toward a sustainable future.

Key aspects such as knowledge, attitudes, and behavior interact to achieve sustainable practices, including recycling, reducing energy consumption, and using sustainable materials in product design. These practices promote social, economic, and environmental awareness in society. Knowledge involves understanding information about the three pillars of sustainability, attitudes encompass

emotional responses to contextual situations, and behavior refers to actions and responses to the world we live in [4].

Environmental education has been instrumental in promoting sustainable awareness since landmark events like the 1970 "Earth Day." Reports such as the "Meadows Report" and the "Brundtland Report" have contributed to raising global awareness. The "United Nations Conference on Environment and Development" outlined "Agenda 21," stressing the importance of environmental awareness from childhood to adulthood.

Studies by Vicente-Molina, M. A., Fernández-Sáinz, A., and Izagirre-Olaizola, J. analysed the influence of environmental knowledge on pro-environmental behavior among university students from countries with varying levels of economic development (USA, Spain, Mexico, and Brazil). These studies indicate that environmental education influences sustainable awareness, with higher education playing a significant role in enhancing concern for the environment and commitment to environmentally responsible practices. Despite progress, challenges remain in integrating sustainable perspectives across disciplines and within university leadership. [5].

Classroom activities fostering sustainable awareness are crucial for cultivating professionals dedicated to sustainable development. By raising awareness about resource exploitation and the importance of harmony with nature, students are motivated to contribute positively in their respective fields [6].

Moreover, educators must address the social, economic, and environmental damage caused by human activity by implementing educational programs focused on sustainable practices and serving as role models for sustainably friendly habits [7].

Sustainable education serves as the cornerstone for enhancing sustainable awareness in society. Early promotion of sustainable awareness, fostering respect for nature and people, and imparting knowledge for adopting sustainable practices are essential. Higher education plays a critical role in shaping individuals committed to a sustainable future, emphasizing a shift in attitudes and behaviours for the well-being of the planet and future generations.

Since everything that is not Nature is designed by humans, changes in students' personal behaviours towards responsible consumption and environmental awareness can positively influence their ability to design more sustainable products by integrating eco-friendly practices such as selecting renewable or recycled materials, creating durable and repairable designs, minimizing waste and emissions, and considering the full product life cycle. This holistic approach to product design balances functionality, aesthetics, and environmental and social aspects, encouraging innovation and continuous improvement. Through journaling, students can identify opportunities for new ideas and creative approaches to address the environmental and social challenges associated with product production and consumption today.

Further research will delve into the practical application of journaling in fostering sustainable awareness, drawing on insights from various disciplines and educational contexts. Understanding the efficacy of journaling in promoting sustainable behaviours can contribute to developing innovative educational strategies for addressing environmental challenges.

In this research, the dependent variable is **sustainable awareness**, and the independent variable is the **use of the journal** as a tool to improve the teaching-learning process [8].

# 2 METHODOLOGIES

# 2.1 Educational innovation implementation process

Within the climate emergency and the global environmental crisis, we are facing, there is a concerted effort within higher education to cultivate students with leadership, innovation, and entrepreneurial competencies. The goal is to foster a culture of environmental sustainability that generates impactful actions.

From a Design perspective, there is a focus on reducing and managing generated waste, trying to achieve Zero Waste [9]. Various initiatives have been undertaken, yielding diverse outcomes from those anticipated. One conclusion drawn is the lack of sustainable awareness within the community. Hence, there is an interest in integrating this activity into educational units to develop the transversal sustainability competence, not only within Design but across all disciplines. The development of a journal is proposed as a learning and reflection method to instil sustainable habits and awareness in students.

The activity presented below takes place over the entire semester, which spans 17 weeks. It has been implemented with 176 students over two semesters: across 7 groups comprising students from higher education, spanning various disciplines and academic levels.

They are asked to make an individual journal where they record everything they do for this educational innovation activity.

- At the beginning of the semester, an initial survey called "MY FOOTPRINT START" (1) is conducted to assess students' familiarity with journaling, sustainable awareness, and habit formation. This survey is specifically designed for this educational innovation.
- As an introduction, students take two existing tests: the Ecological Footprint Measurement (2) and the Slavery Footprint Measurement (3). They record screenshots of their results, providing a baseline for measuring their footprint.
- The next activity is to watch the video (4) that explains in a general way what the SDGs (Sustainable Development Goals) are; this puts the student in context for the next activity.
- The student reads the document "Students as Invaluable Participants in Achieving the SDGs"(5), which is a student action guide created by Tecnologico de Monterrey (Miguel Ruiz Cabañas Izquierdo, Mariajulia Martínez Acosta, and Karina Mayela Ruíz Aguilar) in collaboration with Benjamin Auger (George Mason University) and Mary Lou Coil (State University of New York). The student must choose 3 actions suggested in the guide and carry them out during the semester. The record of these actions must be in the form of a Journal, from the beginning of the semester to the end of it (15 weeks).
- As a reflective part of this Activity, the student is asked to watch the video "The Lightbulb" (6), which talks about planned obsolescence, and read the article "Cradle to Cradle movement" (7), which talks about the circular economy and regenerative design. He/she is asked to write an essay explaining his/her point of view on both topics.
- At the conclusion of his journal, the student redoes the two ecological (2) and slavery (3) tests, recording the results with screenshots. This allows them to compare their results before the Activity with those obtained after it. Based on this and what they have learned and experienced, reflect on what they have achieved in the Activity throughout the semester.
- To quantitatively measure the results of this innovation, a final survey called "MY FOOTPRINT CONCLUSION" (8) is conducted. This survey is specifically designed for this educational innovation and serves as a reflective exercise to raise awareness among students.

The material used to impart sustainability knowledge to students may vary and will be updated over time. Figure 1 below shows a diagram of the methodology used for this activity:



Figure 1. My Footprint Activity Methodology

### 2.2 Evaluation of results

The results of Starting and Final Surveys can be seen in Figure 2, and revealed that for 53.6% of students, keeping a journal is not easy. The main issue reported by students was the lack of consistency and forgetting to record their daily activities. However, reminders helped increase consistency in the record.



• Did you have any problems keeping your Footprint Journal?

Figure 2. Did you have any problems keeping your Footprint Journal?

89.1% of participants considered that the journal allowed them to become more aware of their habits and helped them develop sustainable habits, and 90% of the students considered that the journal helped them create SUSTAINABLE HABITS, as shown in Figure 3.



Figure 3. Do you think a journal helped you generate AWARENESS of your habits? /Do you think a journal helped you create SUSTAINABLE HABITS?

Additionally, in Figure 4, the results reflect a reduction in ecological and slavery footprints in 87.3% of respondents, compared to those obtained at the beginning of the activity.



Figure 4. Did your results of the Ecological and Slavery Footprints improve, comparing the initial with the final tests?

Comparing the results of the two surveys, the level of knowledge and sustainability awareness increased. As supported by the theoretical research of this educational innovation, there is an observed relationship between sustainability knowledge and the level of sustainable awareness expressed by students. Figure

5 suggests that the use of the journal facilitated the development of sustainable awareness and habits in most students, increasing 33 percentage points in knowledge about sustainability, 32 percentage points in sustainable awareness and 33 percentage points in sustainable habits.



Figure 5. Quantitative results of My Footprint Activity

Some comments that reflect the qualitative data expressed by the students were: "... I really **had no idea** how much it affected my actions thinking that I was just one more and that they weren't going to affect." AEN

"I feel like I've become more conscious about what I do and how my actions affect the environment." VS

"Like in part one, I kept refilling my bottle on campus and I've already stopped buying water bottles. I think this time it was a little easier, as it **became a habit for me.**" CMO

"In conclusion, this **process of self-assessment and change has been transformative.** It has led me to question my choices, reevaluate my priorities, and act on my values. I'm excited to continue this path towards **a more sustainable lifestyle.** IO

# **3 RESULTS AND DISCUSSION**

The qualitative and quantitative results from the activity indicate that journaling may effectively fosters sustainable habits and awareness among students. Education is essential for promoting sustainable practices, with higher education playing a crucial role in developing responsible individuals committed to environmental preservation. Journaling helps cultivate a holistic approach to sustainability, impacting students' ability to design more sustainable products by integrating eco-friendly practices.

The "*My Footprint Activity*" aids in knowledge acquisition, awareness generation, and habit formation. Although underexplored [10], journaling as an educational tool can significantly shift students' learning processes across disciplines. It is flexible and adaptable, suitable for various contexts like environmental education, social sciences, health, engineering, and business, promoting lasting change toward sustainability.

While the study shows positive results, its limitations include potential biases from self-reported data, the short study duration, and external factors influencing outcomes. Future research should address these limitations for a comprehensive understanding of sustainable education's long-term effects.

Quoting Munari, we must see "Design as creation of objects, events and environments inspired by the observation of everyday life and natural phenomena." [11]

# 4 FUTURE WORK

The author aims to continue implementing the journaling activity in all future training units and seeks support for developing a robust application usable by students and the entire Tecnologico de Monterrey community. This entails considering features such as Automatic Reminders, Platform Customization,

User Interface design, Training, and Support to facilitate long-term monitoring and customization for different contexts like Social Sciences, Health, Engineering and Technology, and Entrepreneurship. Such efforts would contribute to fostering sustainable awareness and promoting a healthier, more vibrant world. Additionally, the intention is to survey students constantly to validate its long-term effectiveness. Collecting and analysing data over time can provide a more comprehensive assessment of the long-term impact of journaling activity on students' development of sustainable habits. This process can identify successful areas and opportunities for improvement, correct decision making when designing, informing future environmental education and sustainability initiatives. Long-term evaluation strategies may include monitoring sustainable behaviours, direct observation, tracking sustainability indicators (footprints), and conducting monitoring surveys.

Artificial intelligence (AI) has the potential to enhance the effectiveness of journaling in generating sustainable awareness by offering advanced data analytics, personalized user experiences, increased engagement, and predictive behavior modeling. Integrating AI into the journal activity can promote positive Behavioral changes and foster greater sustainability engagement among users.

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# TRANSFORMATIVE LEARNING IN PRODUCT DESIGN WORKSHOPS: A GENERATIVE AI ASSISTANT APPROACH

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# ABSTRACT

Product design workshops represent environments where technological progress has had a significant impact, especially in prototype creation processes, encompassing both the technology employed in construction and integrated components. However, project management activities persist in being conventionally addressed, susceptible to increasing the margin of error in product manufacturing and extending the time required to conclude the planning phase.

This paper delves into the initial integration of a generative artificial intelligence assistant in the search for relevant information for the execution of product design projects in manufacturing workshop environments. The advanced capabilities of generative data processing are harnessed with the aspiration that this assistant becomes a dynamic collaborator, efficiently supporting and guiding the student throughout the prototype creation process.

This research is a pilot conducted with a limited group of Product Design students, which represents a small subset of the total population of the school. The aim of this study is to gather the overall perception of students to enhance their experience when seeking information.

*Keywords: AI assistant, product design education, design workshops, educational innovation, higher education* 

# **1** INTRODUCTION

Since its inception, Industrial Design has integrated technological advancement as one of its elements, allowing the design process to become increasingly efficient in product development. Recent technologies are often integrated into manufacturing, as it is common for new materials and methods of transforming them into products to emerge in production processes. However, the rest of the stages of the creative process have undergone a transformation in their practice thanks to the constant emergence of new tools and applications that facilitate and expand the potential, making the designer's exercise more efficient.

With the recent popularity of Artificial Intelligence, this is favourably seen as a watershed moment in the discipline, opening new possibilities, despite the reluctance that still exists regarding the ethical risks associated with the misuse of this technology.

It will be interesting to see how the new generations of designers will use these new tools in a way that allows them to work more efficiently without sacrificing the creative proposal or the process of conceptualising the products they will be generating. At the same time, educators should understand that these new tools do not jeopardise the creative integrity that the designer uses when developing product proposals; on the contrary, they should learn to use this pedagogically to provide their students with a methodology to expand the possibilities for the stylistic generation of their design proposals.

# 1.1 Artificial Intelligence

A remarkably simple definition of Artificial Intelligence (AI) is the science of having machines perform human tasks and dates to the 1950s, when scientists began to question whether computers could solve problems on their own [1]. Since then, and along with advances in computing, AI has been present increasingly closer to people. In the last three decades, smartphones, virtual assistants like Siri, smart speakers like Alexa, and chatbots emerged, just to name a few examples. AI, for several years, has impacted production processes of distinct kinds, including (of course) education [2], [3]. Generative AI has a very promising future to enhance education, but collaboration between educators, policymakers and AI developers is important to ensure ethical and equitable considerations of generative AI in educational environments [4].

### 1.2 Generative AI Assistant

A generative artificial intelligence assistant (GAIA) is a model trained to assist users through an interface that simulates human interaction, using information contained in a database. Its intention is to learn from such interaction and collect data and learning models through human feedback.

GAIA can learn to provide more accurate responses and avoid behaviours that could potentially be unsafe for the user [5].

### 1.3 DICI Workshops

The DICI Workshops (Design, Innovation and Industrial Creation) are a multifunctional space of the School of Architecture, Art and Design of the Tecnologico de Monterrey Campus Queretaro. Within its facilities of just over 1,500 m2, there are classrooms, laboratories, workshops, worktables, two painting areas and a warehouse for loan of tools and equipment. The High Technology Laboratory has rapid prototyping equipment for FDM and SLA technologies, Cricut equipment, dye sublimation equipment, a vinyl cutter, a mini thermoformer and a machining center. The workshops have machinery and equipment for the transformation of wood and its derivatives, metallic materials, and plastics (standardised presentation or recycled). There is also laser cutting equipment, a CNC router and water jet cutting equipment. The Ceramic Workshop, on its own, has lathes, a mixer, a pouring table and electric ovens. The new Object Art and Fashion Laboratory has industrial sewing machines, equipment for jewellery making and a product photography.

Under the framework of the Tec21 educational model, students learn through a self-managed learning process that allows them to progress through exercises where they solve design challenges linked to the industry [6]. Academic moments within the classroom aim to be more effective and enable students to discover much of the information they need to build a prototype directly in workshop spaces with the support of workshop technicians' experience.

In this process, it is common for some students not to obtain the required information since they need to be physically present in the DICI space to interact with the technicians, who have a defined schedule. Outside of this schedule, there is no remote technical assistance available, and if a student requires support, they will not be able to obtain it, at least not by the first source.

### **2 METHODOLOGIES**

In a pilot study conducted with a reduced group of Product Design students, constituting a minor segment of the overall student body within the Design program, they were asked to solve two challenges. The first one using traditional means through which they obtain information while on campus. For the second challenge, they were asked to use a prototype of a GAIA called Mr. DICI, to request and find the required information.

The study involved the participation sophomore and junior Product Design students who provided valuable information for the completion of this exercise and subsequent improvements in prototype versions.

The following outlines the features of the prototype utilised by the students during the study, along with the specifics of its construction and the platforms employed.

### 2.1 Mr DICI Prototype

Mr. DICI (It was named using the acronym from the DICI workshops) is an artificial intelligence generative assistant based on OpenAI technology. It is programmed to provide technical support to Product Design students and offer useful information to resolve doubts during the prototype creation phase of the product design process.

This initiative is promoted by the school's Design department with the intention of having a full-time assistant capable of providing information regarding the creation of manufacturing projects.

The premise is that having a tool that clarifies doubts about any part of the prototype fabrication process and is oriented towards focusing on information linked to the reality of the laboratories is essential.

With the advancement of AI integration in the product design process, various aspects have been revolutionised during object creation. For the purpose of this prototype, the following services were used to ensure the functionality and access of students to the assistant: OpenAI, Chipp and Notion. **OpenAI** 

OpenAI is one of the most influential AI technology providers, including powerful language models such as Generative Pre-trained Transformers (GPT). In the development of the Mr. DICI prototype, the utilisation of the Application Programming Interface (API) offered by OpenAI was explored to create an academic assistant designed to support Product Design students.

The capabilities of GPT models allowed Mr. DICI's design to provide consistent support for students during the information search process for their projects. The API serves as a backbone for generating responses to academic inquiries, offering guidance on various topics such as material selection, workshop tools and equipment usage, as well as information on workshop operation, its laboratories, and the personnel operating it [7].

The GAIA Mr. DICI's engineering is planned to meet all the needs that students have during the prototype creation process, providing assistance tailored to their learning. The assistant features a personality crafted to incorporate traits of friendliness, expertise, and empathy, reflecting the qualities of an experienced academic advisor who encourages students' autonomous learning and further information seeking. There is always an invitation and emphasis on ensuring that design practices are within a framework of responsibility and sustainability. The assistant advises students to consider the environmental impact of their proposals and offers suggestions to minimise carbon footprint through responsible design decisions.

These instructions were loaded from the assistant's design manager, and various files with specific information, such as databases, were uploaded.

In Figure 1 you can see the architecture of GAIA Mr. DICI and its informatic structure, with the elements considered for the prototype.



Figure 1. GAIA Mr DICI's Architecture

# Chipp

To ensure students' accessibility to the assistant, Mr. DICI can be visualised on the Chipp interface through an API Key that allows integrating both platforms, enabling assistant customisation and embedding for seamless interaction.

Chipp is a platform that enables building and integrating GPTs, characterised by being fully customisable, integrated with other platforms, and monetisable. The platform does not require deep programming knowledge or code generation [8].

### Notion

Additionally, the assistant is accessible through Notion, generating a microsite that provides users with a user-friendly interface within a simple platform and gives them full access to the functionalities that Mr. DICI offers.

Notion is a note-taking application that has the ability to integrate embedded applications into microsites that can be published for users to access. The platform allows for asynchronous communication with teams of indefinite size, standardising processes and collecting information, integrating external tools, and expanding information networks [9].

For the research activity, there were two challenges presented to the students for resolution. In both instances, they were allotted 15 minutes to address them.

### Challenge 1

Your professors request you to develop a prototype of a shower rack that must contain containers for shampoo, conditioner, soap, fibres, and other personal hygiene utensils. The main requirement is that it be constructed with metal and wood, and you must build it entirely in the DICI.

Do not use your computer; write down your project requirements. You can refer to the DICI or your professors for information.

### Challenge 2

Your professors of Modularity and Optimisation request you to develop a prototype of a desk made from standardised laminated materials that must be cut on the CNC Router of the DICI. The main requirement is that it be constructed with wood and/or its derivatives and a second material that is also laminated and cut on CNC. You must build it entirely in the DICI.

Use the Mr. DICI AI assistant to solve the challenge; assemble your project requirements on your computer.

In both challenges, it was requested to the students that they must consider the following requirements:
Type of material according to the environment and context

- Type of joints
- Fastening
- Machinery and equipment to be used
- The person who can help you build it

# **3 RESULTS AND DISCUSSION**

After resolving both challenges, the students were asked to answer a questionnaire containing the following questions. For some questions, the following scale was used:

- Easy
- Moderately complex
- Complex
- Very complex

At the beginning of the study, students were asked how important the use of DICI was for their professional education as Product Design students, requesting them to respond on a scale from 1 to 5, with 1 being "Not Important at All" and 5 being "Extremely Important". Unanimously, all of them answered "Extremely Important".

Despite emphasising the crucial importance of workshop usage, their perceived experience for obtaining information is considered by 22.2% as "Complex" and by 77.8% as "Moderately complex". Below we can see the results on Figure 2.



Figure 2. Student's perception during the obtaining information process before challenges

For the resolution of Challenge 1, there was a change in the perception of complexity in information searching: 33.3% considered it "Easy" as they found someone who could assist them without difficulty; 33.3% considered it "Moderately complex" as they struggled to organise themselves to find someone to consult the information, although they were ultimately able to obtain the required data. 33.3% answered "Complex" because they felt anxious about not knowing the materials required for the challenge and were unsure about manufacturing processes and joining elements to assemble the final pieces, as we can see on Figure 3.



Figure 3. Student's perception during the obtaining information after Challenge 1

For Challenge 2, 88.9% of students considered that obtaining information through the GAIA Mr. DICI was "Easy" and allowed them to find the information in a simpler way than they have traditionally done. Additionally, they mentioned that having an information assistant at their fingertips gave them peace of mind. They expressed that they obtained additional information about the advantages and disadvantages of materials, as well as recommendations to improve their project. Only 11.1% of students answered that solving the challenge was "Moderately complex" because the platform failed on some occasions, the results are represented on Figure 4.



Figure 4. Student's perception during the obtaining information after Challenge 2

After completing both challenges, it can be concluded that the use of a GAIA in the product design and development process, particularly during the prototype creation phase, is of great relevance for obtaining relevant information that will allow the student to take the first step in decision-making and continue with the management and manufacturing process. Implementing this type of tools in academia will make the process more efficient and provide autonomy to students and teachers, having an ally during the teaching-learning process.

# **4 FUTURE WORK**

With the intention of developing the generative artificial intelligence assistant, it will be applied to the Novus Fund for Educational Innovation, of the Institute for the Future of Education, of the Tecnologico de Monterrey. This fund supports the implementation of educational innovation projects that contemplate the use of new technologies. If supported by this fund, the development and implementation of this GAIA would take place during 2025.

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# LCA AND DESIGN THINKING: HOW TO INTEGRATE LIFE CYCLE ASSESSMENT IN EARLY-STAGE PRODUCT DEVELOPMENT?

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# ABSTRACT

Life Cycle Assessment (LCA) is a comprehensive tool that supports sustainability by assessing products' environmental impacts. It is both analytical and systemic. However, its integration in the early phases of product development remains challenging for industrial designers. How do industrial designers make sense of it? How do you move from LCA into the early stages of design? Particularly, the clash between the analytical, deductive, delimiting, and multi-criteria parameters of LCA with the divergent abductive reasoning of the fuzzy front end of concept development.

In the paper, we present an example of an LCA design course, which was structured to meet the challenge of how to redesign a product. The course serves as an experimental example of integration and conversion from deductive, quantitative, and analytical LCA to an abductive, qualitative, design thinking process of reconceptualisation. In this context, we identify patterns in the disparity across the level of design work. Two approaches, in particular, made a difference: 1) when SWOT factors were categorised according to life cycle stages, circular economy stages and/or circular product design methods, then it qualified the transition to mind mapping, 2) when the mind-map unfolded complexity in 4 or more levels, it enabled deeper insights on factors itself, implementation, relationships and trade-offs to other life stages, specific strategies and circular value propositions. In the case of both, the mind map served as a dynamic tool, used throughout concept development, to bridge the problem/solution space, as well as facilitate framing, rather than pre-stage guiding concept development.

Keywords: Life cycle assessment, product development, pedagogy, industrial design, sustainability

# **1** INTRODUCTION

Designers must synthesize several types of data when conceptualising a new design. Considerations about usability, materials, production, form, strategic positioning, and other dimensions must drive decision-making into actionable steps in the product development process. Life Cycle Assessment (LCA) is a comprehensive tool that supports sustainability by assessing products' environmental impacts. It is both analytical and systemic. However, its integration in the early phases of product development remains challenging for industrial designers. Particularly, the clash between the analytical nature and multi-criteria parameters of LCA with the divergent abductive reasoning which characterises the fuzzy front end of concept development.

This paper reports the structure and results of a BSc in Industrial Design course where students learn about LCA and use it to develop product concepts. To overcome the identified challenge of LCA usage, the course adapts a framework defined by da Luz et al. [1] and simplifies it into three phases for pedagogical purposes. The goal is that students learn how to use LCA, while understanding patterns in product categories; and how to identify hotspots and creatively act upon them.

In the *first phase*, students select a reference product to perform a LCA in the following categories: home appliances, small appliances or consumer electronics. LCA is used to assess impact categories and identify hotspots that will guide the planning of the second phase. The *second phase* correlates hotspots with new product design. Its development is based on a SWOT analysis of the life cycle stages and mental models of solutions which define new approaches for strategic environmental goals based on the restimation of benefits on the identified hotspots. Finally, the *third phase* concerns the redesign of the product. The results show how students ideated on one or more areas defined in the previous phase, depending on the selected reference products. The reflection and comparison of new solutions against

the reference product supported students in understanding the value of LCA as a support tool that elevates the debate around sustainable product development. The discussions of sustainability became more tangible regarding specific parameters on which to ideate and identified areas that could be addressed by traditional product-focused perspectives or product-service systems perspectives.

The novelty of the research is threefold. First by presenting a pedagogical approach to using LCA in the fuzzy front end of industrial design. Second, by integrating LCA information to guide early-stage decision-making in product development. Lastly, reducing the complexity of LCA usage by identifying hotspots where concept development can focus on tackling environmental impacts across the full life cycle of a product.

# 2 INTEGRATING LCA WITHIN DESIGN THINKING

Table 1. LCA and Design Thinking

	LCA	Design(erly) Thinking
Aim	LCA's main aim and focus is on quantifying	The primary focus of design thinking is to
	the potential environmental impacts [2].	create new qualified artefacts, that make sense
		in the context for which they were intended [3].
Problem	Definable system problems	Undefinable wicked problems
conception	In LCA, defining the goal and scope are	In designers' conceptions of reality, problems
	critical for modelling the boundaries of the	are understood as complex, indeterminate and
	reality conception. Thus, to evaluate the merit	ill-defined. They are wicked problems in the
	of a LCA all choices of the assessment should be clearly defined including: problem	sense they can never fully be understood, nor
	definition intended applications study	defined ([5, 6, 7].
	recipients, system boundaries, assigned	"Design problems are 'indeterminate' and
	function, functional unit assigned to quantify	"wicked" because design has no special subject
	the system and inventory data [2].	matter of its own apart from what a designer
		conceives it to be. The subject matter of design
	"Life Cycle Assessment (LCA) is structured	is potentially universal in scope because design
	according to ISO14040 standards (ISO	thinking may be applied to any area of human
	14040, 2000; ISO 14044, 2000) with the	experience. But in the process of application the
	environmental impacts of a product a	designer must discover or invent a particular
	service, or a system, including all its related	subject out of the problems and issues of
	activities." [4]	specific circumstances. [6, p.10]
Mode of	<b>Deduction</b> is described as the logic of	Abduction is described as the logic of
reasoning	necessity. It starts with a set of premises or	possibilities. It starts with a set of propositions
6	statements, and then applies logical rules to	or qualified guesses, that needs subsequently to
	derive a conclusion. This process ensures that	be empirically tested to arrive at 'better'
	the conclusion is necessarily true, but only if	propositions. It forms a conclusion from the
	the premises are true [9].	information that is known [10, 11].
Process	Defining and delimiting to quantify	Framing propositions to qualify
	According to the standards LCA is conducted	As problems are characterized by incomplete,
	through tour steps: 1) goal and scope	changing, contradictory and interdependent
	definition, 2) life cycle inventory, 3) life	information, designers tend to abductive
	All entails systematic definition delimitation	potential futures are created through framing to
	and quantification of information	be qualified empirically [8]
	and quantification of information.	be qualified empirically [8].

In the paper, we present an example of an LCA design course which was structured to meet the challenge of how to do a redesign of a product, based on an LCA. The course studied is titled "Strategic Material Choices" for industrial design-engineers. The course covers 5-ECTS on the last semester on the Industrial Design bachelor's program Aalborg University in Denmark based on a Problem-Based Learning (PBL) model. The learning objectives determined that students must develop competencies regarding the sustainability consequences of product materials choices, allowing them to conduct LCA in project scenarios. These sustainability considerations are deemed significant both during concept development, influencing solution direction and strategy, and during product detailing, where specifications for manufacturing, materials and finishing are determined.

We position the course as an experimental example of integration and conversion from deductive analytical LCA to an abductive design thinking process of reconceptualisation. In this context, the course represents a field experiment where we are particularly interested in the transition from LCA, as an analytical, quantitative, and deductive approach, to design thinking as a creative, qualitative and abductive approach. Table 1 summarises the framework used to clarify the aims, problem conception, mode of reasoning and process of both LCA and design thinking.

# **3 METHODOLOGIES: THE STUDY SETTING**

The course spanned over three weeks and included lectures, supervision sessions and two milestones. The course was coordinated by two faculty members with a background in industrial design, and lectures on LCA in week 1 including the first milestone were delivered by two faculty members with a background in environmental management. Students worked in teams of four members to perform the LCA of the reference product during week 1, and then individually. The academic evaluation included the individual submission of a report based on a given template of three summary sheets plus an appendix.

The summary sheets aim at emulating the three main phases of using LCA in early concept development and were mapped onto the three weeks of the course. Each summary sheet template is designed to work as a spread of two A4 pages, serving as a toolkit that synthesise information and support decisionmaking in the design process (Fig 1). In the educational setting they facilitate comparison of student work and peer learning. The goals and steps described to students are detailed on Table 2.



Figure 1. Example of template of summary sheet 1

Week	Activity	Goals/Instructions	Information structure of
			the summary sheets
	Highlights of the LCA of a reference product	<ul> <li>Summarise the LCA of the reference product to serve as an actionable tool for the design process.</li> <li>System boundaries: fill in the critical aspects to understand the scope of your analysis. Identify the most significant issues.</li> <li>Explain the assumptions and limitations behind the values and the sources of information.</li> <li>Identify the life cycle stages with the highest environmental impact (hotspots).</li> <li>Understand the systemic relationships in life cycle stages.</li> <li>Identify potential hotspots for industrial design improvement.</li> </ul>	<ol> <li><u>Identification</u>: a) Product class; b) Product category.</li> <li><u>Overview</u>: a) Product image; b) System boundaries.</li> <li><u>Product Life Cycle</u>: a) Bar chart with product life cycle impact; b) Table with life cycle stage, Value, Unit, Assumptions/Limits, Source.</li> <li><u>Identification of hotspot</u> <u>relevant for industrial</u> design: a) Life cycle stage;</li> </ol>

			b) Justification of its
2	Correlate the identified hotspots in the previous LCA with new concept design	<ul> <li>Define new approaches for strategic environmental goals.</li> <li>Define a SWOT (strengths, weaknesses, opportunities, and threats) analysis on the LCA, with a particular focus on the identified hotspot(s). Begin by asking critical questions to the reference product to understand internal and external factors affecting the product. The goal is to analyse the current situation.</li> <li>Create a mind map of your reasoning in brainstorming potential solutions. The mind map is the visual summary of your brainstorming sessions in envisioning a solution space. The goal is to improve the situation.</li> <li>Show ideation sketches visualising possible solutions on one or more areas (from the SWOT analysis and mind map)</li> </ul>	<ol> <li><u>Identification</u>: a) Product class; b) Product category.</li> <li><u>SWOT</u>: a) SWOT diagram; b) Summary of potential improvement areas.</li> <li><u>Mind Map</u>: a) Mind Map diagram; b) Brief explanation of the reasoning behind the most promising solutions.</li> <li><u>Ideation on Configurations and Materials</u>: Annotated sketches.</li> <li><u>Selection of viable concept</u> reflection: a) Life cycle stage; b) Justification of its relevance.</li> </ol>
3	Compare the new proposed solution with the reference product	<ul> <li>After performing an LCA of the concept developed, compare it with the reference product by creating a bar chart showing both the values of your solution and the reference product. The goal is to provide a straightforward illustration of the improvement you propose.</li> <li>Describe the system boundaries.</li> <li>Calculate the improvement rate of your solution. Also explain assumptions and limitations behind each value.</li> <li>Reflect on the overall process of designing with LCA in the forefront of design problems.</li> <li>Consider the challenges encountered in understanding the systemic dimension of the complete life cycle of a product. Discuss the complexities and insights gained in the process.</li> <li>Provide recommendations to improve the process (if you had additional time and resources).</li> </ul>	<ol> <li><u>Identification</u>: a) Product class; b) Product category.</li> <li><u>Overview</u>: a) Concept rendering; b) System boundaries.</li> <li><u>Product Life Cycle</u> <u>Comparison</u>: a) Bar chart with reference product and new concept life cycle impact; b) Table with Life Cycle Stage, Value of reference product and new concept, Unit, Improvement rate, Assumptions/Limits.</li> <li><u>Reflection on the use of</u> <u>LCA in industrial design</u></li> </ol>

# **4 RESULTS**

Students were able to successfully apply LCA and develop concepts of products aiming at improving the identified hotspots whilst reflecting on each step and the overall process. This section unfolds this claim by providing examples taken from positive submissions and reflecting on observed pitfalls.

Regarding the *summary sheet #1 (LCA of reference product)*, the example illustrated in Figure 1 demonstrates the student's ability to reflect on the metric used in the LCA, by considering that using the ReCiPe method [12] would account for factors beyond just global warming potential. In the identification of relevant hotspots to be addressed by industrial design, the student reflects on potential approaches to raw material selection and nudge of user behaviour to improve the use phase. This transition signifies a shift from deductive reasoning, starting with the identification of hotspots, to breaking down the problem into manageable segments (e.g., nudge user behaviour to minimise resources in the use phase) that can be addressed through new product development. Some students who had multiple potential hotspots, further detailed specific product life cycle stages. An example can be the search for additional granularity of information regarding raw materials to clarify which material or component contributes most to the global warming potential.

*Summary sheet #2 supported bridging from analytical approach to abduction*. We observed that it was the part of the process that accounted for more disparity across the level of student work. Regarding the SWOT analysis, students were instructed on how to perform it, to map life cycle stages as strong or weak and map external opportunities and threats related specifically to those identified life cycle stages. Students who categorised the SWOT factors onto life cycle stages, circular economy stages and/or

circular product design methods [13] had a more proficient transition to mind mapping. In these cases, these categories provided the framework to structure the mind map, thereby facilitating an assessment of trade-offs to select preferable perspectives for concept development. Regarding the mind map, some students stated factors as a one-liner and others who developed further the factors. Students who developed further the factors (unfolding complexity in 4 or more levels) were able to reflect on them, gaining insights on both the factor itself (e.g. reuse water) to its implementation in product development, its relationships to other product life cycle stages, specific strategies and their circular value proposition (e.g. disassembly for repairability vs disassembly for recycling), or other industrial design factors (e.g. envisioning different user scenarios, defining working principles). In such cases, such as the one illustrated in Fig. 2, the mind map served as a dynamic tool used throughout concept development that supported bridging problem and solution space and facilitated framing, rather than merely guiding concept development at a preliminary stage.



Figure 2. Example of a mind map in summary sheet 2

In the overall reflection on the use of LCA as an important driver for concept development, students' reflections on *summary sheet #3* provided insights on the awareness of using LCA as an analytical tool to inform abductive reasoning in design. Students acknowledged that LCA allowed for a focus on hotspots. A few students stated that its use reduces intuition from design as problems and systems complexity (such as number of parameters and interrelationships) are at the forefront of reasoning. Nonetheless, students also reflected on the need for integrating LCA results with other critical factors, including cost, quality, simplicity, or functionality. Furthermore, they reflected on the uncertainties of using approximate data to estimate global warming potential, highlighting the need to critically consider the trade-offs in decision making rather than solely optimising LCA hotspots.

### **5 DISCUSSIONS**

The framework presented in this paper allowed students to use LCA to drive concept development. Most students found the process effective in supporting engagement in both analytical mode and abductive reasoning. Also, they were able to create concepts not only for incremental optimisation of identified hotspots but thinking beyond such a framework of thought. Despite this, some students reported that shifting from deductive reasoning, quantification and systems thinking into designerly thinking is difficult. One student defines this as "a never-ending wicked problem."

Based on evidence from best examples, we recommend improvements to activities in planning and concept development stage (summary sheet #2). The interdependence of the SWOT analysis and the mind map should be higher. Categorising SWOT factors and following those categories in mind

mapping provides better support from deductive to abductive reasoning. Furthermore, mind maps should branch out into at least four levels. As an example, the *first level* should identify *product life cycle stages*, the *second* could define different *scenarios of improvement based on circular economy stages*, the *third design methods* (e.g., modularity, disassembly), the *fourth*, what *working principles* (or product architectures, or functional requirements) could be established. From then on, potential features or concepts that embody the *working principles* can be defined, and user interaction envisioned. To conclude the mind map, the most promising concepts should end with a brief *clarification of trade-offs* that could be connected back to the identified factors on the SWOT analysis and the hotspots to consolidate the decision-making for further development.

Based on the assessments of the reports we conclude that pedagogically, the selection of mid-range products facilitates learning. Students who either selected very cost-effective products or environmental efficient products faced challenges in improvement: the former because of trying to address the same cost, while the latter due to limited relevant criteria to improve hotspots.

### **6** CONCLUSIONS

This study highlights the potential of methods that facilitate the shift from deductive to abductive reasoning within an existing framework [1] for sustainable product development. This approach may support professional designers in navigating the complex landscape of sustainability by synthesising knowledge as a set of tangible factors. The knowledge generated at the early stages of product development provides practical insights, empowering decision-making at both strategic and product levels. Moreover, it may enable multidisciplinary teams to maintain a nuanced understanding of the dynamic interplay of factors influencing sustainability goals and supports discipline-based developments to be pursued. Ultimately, such proposed methods foster a holistic approach to addressing real-world sustainability challenges within design-driven processes.

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# DESIGN AND IMPLEMENTATION OF A SKILL DEVELOPMENT PROGRAM IN AI DRIVEN GENERATIVE ENGINEERING

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# ABSTRACT

The application of Artificial Intelligence opens up completely new opportunities for the development of innovative products and systems. Computational design synthesis techniques such as generative design can be used to explore a design space with many potential solutions optimised for different objectives. By using CAD tools that deploy these techniques, designers no longer must limit themselves to the variation and simulation of a few parameters. Engineering designers using these tools can focus on evaluating and selecting the solution(s). The impact on the product development process, the handling of new techniques, methods, and the implementation for future product development and innovation activities results in an enormous need for training and further education of engineers.

This paper presents a comprehensive skill development programme for professionals and engineering students to provide the necessary skills (methodology and tools) in terms of Generative Engineering, design automation, and design optimisation. It includes an introduction to Generative Engineering as well as its foundations and software applications. The concept of the skill development programme is predominantly organised as eLearning divided into learning nuggets but is complemented by an additional practical part. The paper describes the approach employed in developing this program and highlights its outcomes. The teaching methodology and concept along with the focal teaching points are introduced. Subsequent optimisation measures and requirements are determined, which are based on the evaluation of the learning paths and nuggets carried by industry participants and their feedback. Finally, the potential of the suggestions for improvement and the resulting changes are discussed.

Keywords: Generative engineering education, skill development programme, generative design

# **1** INTRODUCTION

Progress in digital engineering tools has continuously changed the engineering design process. The shift from sketching on paper to CAD tools can be compared to the application of Artificial Intelligence (AI) in engineering design software tools (i.e. CAD) [1]. This shift for tools in terms of Generative Engineering, design automation, and design optimisation opens completely new opportunities for the development of innovative products and systems and changes the engineering design process. Even though Generative AI has been around for several years, it is still ahead of the plateau in the Gartner Hype Cycle for AI [2]. Especially Generative Design AI as an emerging technology is still in the Innovation Trigger area and indicates a steady increase in demand in the coming years. For the new emerging generation of CAD/CAE/Simulation toolsets a CAGR grow of greater than 15% during the forecast period 2024 – 2029 is expected [3, 4]. Their machine learning capabilities suit the growing demand for advanced manufacturing with complex designs and the need to reduce size and mass of products while improving the performance. On the other hand, these tools impose a paradigm shift in product development like the shift from sketching over 2D-CAD drafting to 3D-CAD product modelling. Since this technology is quite newly introduced in CAD tools, engineering professionals have to be upskilled to leverage the potential impact on future product development and innovation activities in companies [5, 6]. The market for professional education in Generative Engineering and Design (GE&D) is primarily driven by software vendors, who a high focus on their own software capacity and capability. Comprehensive training programs that are more focused on methodical aspects than on specific software tools or features can be found at universities, if at all, and are only occasionally available for professionals. Therefore, a curriculum comprising different educational paths and learning nuggets on these topics will be developed and integrated into skill development courses focused on professionals of different skill levels and technical specialisations but not excluding students on master level with background in engineering design. The results, the evaluation and the resulting changes are discussed in this paper.

# **2 STATE OF THE ART**

# 2.1 Generative Engineering and Generative Design

For this paper Generative Engineering (GE) is the generic term for a number of concepts related to the change in product development, including e.g. generative design, design automation and design space exploration. Generative design is the most widely used term and is an algorithm-driven approach to automate the develop of products and finding solutions by not explicit create the geometry. Instead, the definition of constraints, boundary conditions, rules and procedures allow the computation of multiple feasible solutions (design space exploration) including the implicit generation of geometric models. The aim is to consciously create the opportunity to break down ingrained thought patterns so that solutions do not just emerge as a gradual development of existing patterns. In contrast to topology optimisation, the geometry does not have to be explicitly specified and further boundary conditions can be considered [6]. Therefore, the engineers and designers need to shift their skills from modelling the shape to define the boundary conditions and be educated to evaluate multiple solutions [7]. This leads to a shift in the way of thinking for generative designers and engineers [6, 8]. In traditional education this and the exploration of as well as dealing with the larger solution space are not part of the education [9]. Therefore, Li et al. (2021) [10] propose an Evolving Design Thinking Model to integrate the new 'Generative Design Thinking'. They highlight the need to ingrate the required design technologies (e.g. Parametric Design Tools, Topology Optimisation, Machine Learning, ...) as well as the cognitive side in education to improve the education of generative designers.

### 2.2 Existing Learning Environments for Generative Engineering and Design

As the Gartner curve for emerging technologies already indicate the concept of Generative Design AI is quite new. Therefore, the landscape of training and education in this area is small to non-existing. Nonetheless a snapshot of the market situation and available skill development programs emphasises this. For this purpose, an "Internet Search Index Analysis (ISIA)" was conducted. There was a continuous increase in search phrases such as "Generative AI", "Generative Engineering" or "Design Automation" in purely numerical terms, at the same time these search queries were mostly related to the search for a definition or delimitation of the topics or were driven by other generative innovations, such as ChatGPT. Thus, they have little or no connection to the semantic field of "training and education" especially in engineering or CAD. While further training in classic CAD is offered by both software vendors and external companies, further training in generative design is primarily driven by software vendors. In the German-speaking area, very few training providers (around 13) were found that are dedicated to the topic of GE or related topics. Consideration the fact that the technology is in Phase 1 of the Gartner Hype Cycle underlines the results for the low number of available trainings.

# **3 CONCEPTS**

An analysis of the existing learning environments for GE&D has shown that due to the relatively recent development of this approach in engineering, comprehensive training documentation is scarce or nonexistent. In particular, the difference is that training is compared to CAD in general e.g., is provided primarily by the software vendors themselves. But since teaching of GE&D requires a change in mindset in addition to the pure software application, the need for independent curriculums is given. Therefore, the concept for this program does not specialise in a particular type of software, but rather focuses on methodology independent of software. The target groups come from different areas and develop different products with correspondingly different requirements in terms of knowledge. The concept of the skill development program is predominantly organised as eLearning divided into learning nuggets but is complemented by an additional hybrid practical part.

### 3.1 Teaching methods and framework

The eLearning teaching method are learning nuggets and paths. Learning nuggets are self-contained learning units that deal with a specific topic to improve certain skills (skill driven). These learning nuggets have a duration of 10 to 20 minutes and can contain text-based, video, or interactive content

(e.g. H5P). Each learning nugget is based on learning outcomes. The definition of Learning Outcomes is according to Bloom Taxonomy [11] for the learning nuggets as well as for the learning path. Several learning nuggets make up a learning path (competences driven). Each learning nugget and path end with an assessment. These online assessments are primarily based on multiple choice and other automatically graded Moodle question types like true/false, matching, a list of given answers as well as drag and drop to enable an automatic grading. Compared to free-text answers, the use of automatic evaluable questions poses a challenge to the evaluation of correspondingly higher competence. This is offset by the variety of question types to allow learners to continuously monitor their progress in asynchronous learning. The scope for the experience of this program is to provide factual and theoretical knowledge in broad contexts to reach a range of cognitive and practical skills, including value judgement and sustainability. The framework for this concept includes the goal to achieve different overarching learning outcomes.in terms of innovation, technology and creativity skills and competencies as well as the competencies to make value and sustainability judgements. The overall achievement is to enable the learner to define and analyse a problem space, generate new solutions and assess their validity and to create solutions.

### 3.2 Implementation

The curriculum comprises different educational paths and focused on a mixture of theory and practice, which is specialised to the learner. The combination of theoretical knowledge and software-independent examples lead to develop the understanding of Generative Design CAD tools, their methodology and application for GE. The focus is not on master the available tools but acquire the required methodologies and mindset shifts that will leverage the full potential of GE&D and other AI driven engineering design tools and techniques. A special focus is on the comparison of classic engineering design approach with GE and the interaction between GE and classic modelling. All learning paths contain nuggets with practical content using state of the art design tools. In this context new processes-oriented tools using the visual and low code programming interface are also part of the practical application. The given learning nuggets in each category enable design engineers to understand, to validate, to apply and to integrated AI driven GE and Design Automation in product development process.

To reach this scope, the approach of the skill development program is divided into three different learning paths with individual focal points and a hybrid the workshop (Figure 1). The individual focal points are close related to awareness as a general overview of this topic, GE&D, simulation, and business aspect of GE. The first path is focus on the GE approach in general, with all necessary core principles, key competences, and streams like topology optimisation, design automation and design space exploration, machine learning and artificial intelligence. The learners learn how GE improves and changes the product development process, expand the solution space, explore and evaluate new ideas. The second path is about GE in terms of optimisation of products close to simulation and lightweight design. The path covers the basic of simulation and algorithms behind the optimisation, based on Artificial Intelligence. The learners learn steps to avoid errors and acquire the knowledge and skills to apply initial approaches. Possibilities for automation are shown and new possibilities are opened up through so called "field driven design" for lightweight design. The third path is about GE from a business perspective as part of the innovation process. The basics of GE, as well as innovation and product development processes are presented. Subsequently, both theoretical elements are linked. This learning path also gives examples of how and where GE can aid design and development decisions in view of more innovative solutions. The hybrid workshop is close related to the first learning path and covers the different streams and transfers these into practical application examples. Discussions rounds and interactive hands-on complete the workshop. The final assessment will be accomplished in a projectbased case study to ensure that interactive elements are in the foreground of the education activity and that engaging each participant on an individual basis is ensured. The learning paths are independent and do not necessarily have to be consumed in combination with the others. Only the workshop primarily focuses on the first learning path to strengthen the learner's understanding of CAD tools, methodology and application of GE and is based on that. The target audience addressed by the content are engineers, product developers & designers, CAD designers, team and department management (development and production) as well as students (e.g. mechanical engineering)

1. Generative Engineering & Design	2. Topology Optimization & Lightweight Design	3. Generative Engineering & Innovation
Topics: Basics of Generative Engineering and the underlying principles like Machine Learning, Tools for GE&D, Low-Code Environments, Topology Optimization, Design Space Exploration and Design Automation	Topics: Basics of Generative Engineering and the underlying principles like working with Finite Elemente Analysis, Topology Optimization, Design Automation and Field Driven Design	Topics: Basics of Generative Engineering and Innovation, Introduction into Innovation, Design & Development processes and the combination of both
Additional Generative Engineering & Design Workshop	Topics: different topics (topology optimiza automation) are applied to simple case stud	ition, design space exploration, design dies

Figure 1. Structure of the learning paths

# **4 EVALUATIONS OF THE E-LEARNING**

To gather feedback and insights from the participants of the pilots workshops a voluntary survey was administered. This survey saw participation from 12 individuals, all based in Italy, working in the electronical manufacturing field, to evaluate the eLearning content. The majority of the respondents were engineering professionals from different areas. This range of backgrounds provided a broad spectrum of perspectives and experiences, contributing to a comprehensive understanding of the workshop's impact and areas for improvement. The following figure 2 shows an extract of the results from the survey to six from fourteen questions. Each question, in the figure shown in different colours, could be answered by the participants on a scale from 1 (low approval) to 10 (high approval).

The participants syndicated their current knowledge of GE&D. Prior to the workshop, the general experience with GE&D among participants was predominantly low, indicating limited prior exposure to the technology and methodology. However, there were still several participants who had a moderate to substantial level of experience before participating in the workshop (red). The participants gave a positive assessment of both the consistency of their expectations of the content (orange) and the depth of the content (grey). These responses indicate that the workshop has had an impact on the perception and anticipated content, suggesting an expansion of practical understanding and acceptance of GE&D while also containing an intermediate level. The knowledge, skills and concepts are only moderately to well evaluated for the explained content (yellow). Based on the textual additions and in connection with the following aspects (blue), it can be concluded that the type of learning (e-Learning) is primarily the cause of the non-adequate explanation. This is also made clear by some comments calling for an even greater focus on examples. Based on what participants learned in the workshop, there is a notable belief in the relevance of GE&D topics for their own work (green).

The workshops' content, structure, and the incorporation of hands-on GE&D experiences were particularly well-received, highlighting the effectiveness of the practical and interactive approach employed. The quality and relevance of the online learning content provided prior to the in-person session received mixed reviews, though the majority still rated it positively, suggesting that while satisfactory, there is space for improvement in aligning pre-workshop materials with the participants' needs.

The additional text evaluations received provide additional potential for improvements. The remarks received suggestions to implement more real industry examples, notes on the content of individual nuggets and especially of less text based and more video-based content. The assessments at the end of the nuggets and paths were also rated as positive. It was also emphasised that the learning form as learning nugget is well suited for time-spread learning, but not for learning in one go.



Figure 2. Feedback evaluation

### 4.1 Adjustments of eLearning content

As a result of this survey, the structure of the e-learning courses was adapted for future training courses (Figure 3). The basic division into three learning paths with the option of a practical workshop remains unchanged. The content and scope have been adapted. Instead of the very comprehensive first learning path, the content in this one has been reduced to make it an "awareness" workshop. This still covers all subject areas, but with less depth of content. The second learning path continues to cover topology optimisation and lightweight construction, but with a reduced focus and also includes the content of the first learning path in advance. As a result, these are no longer sequential but parallel. This learning path is therefore also a prerequisite for the practical workshop. The third learning path with GE and innovation remains unchanged. Overall, the focus on application examples was stressed out by reducing the text and implementing more videos and interactive examples. Furthermore, the content will be made available to the learners with enough time to complete it before the actual workshop in case of the hybrid approach.



Figure 3. Adjusted structure of learning paths

# **5 CONCLUSIONS**

The integration of artificial intelligence into the engineering design process through GE&D shows possibilities for sustainable change in the process. This change makes it essential to offer both students and professionals an opportunity for software-independent further training. To meet this new need for education, a skill development program for teaching GE&D with its related technological foundations and current streams for different fields of specialisation was introduced. The learning content aims to convey the subject matter in a fundamental and comprehensive manner, but do not address particular tasks or software tools. The content forms the foundation for mastering the necessary transfer to the participants' own problems. However, practical examples and various CAD tools are shown to convey

these. The results show the enthusiasm for the potential of GE&D in the product development process. The feedback from industrial professionals indicates that content relevance, presentation and depth are critical factors that need to be addressed to facilitate wider adoption and knowledge transfer. The presentation of real, industry-related examples is one important aspect of this. The evaluation also showed that the presentation of content must be primarily supported interactively through videos and other options in order to generate widespread interest. At the same time, it was determined that the current focus is primarily on technology awareness instead of certificate courses for special interests. This initiative's successful execution demonstrates a strong foundation for future training programs and shows the effective integration of emerging technologies in education and training.

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# INVITE THE ELEPHANT INTO THE ROOM: AN ANALYSIS OF DESIGN STUDENTS' CHATGPT USE IN A SCIENTIFIC ARTICLE WRITING COURSE

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### ABSTRACT

The rise of ChatGPT poses challenges for teaching courses in which the final assignment is a written essay. This paper shares experiences with such a course, by analysing review articles written by students in which they were requested to include statements on how they used AI tools. The analysis shows that they use this as language checker, as discussion partner, as information simplifier, as translator and as search engine, and reflections are shared about pros and cons of doing so, both from a student and a course organisation perspective. The analysis of students' articles suggests that the majority of students either use ChatGPT responsibly or not at all, but that there is also suspicion of students cutting corners. One interesting effect of using ChatGPT is that time spent in the course seems to move from spending time on finding sources and writing approaches, to selecting the most meaningful sources to read and considering which approach to choose.

Keywords: Design education, artificial intelligence, research ethics, ChatGPT

# **1** INTRODUCTION

Artificial intelligence has the potential to substantially transform education. With students being able to generate unique texts within a short time frame based on a few prompts, there is considerable debate online about the pedagogical consequences of this new situation. Some authors are positive, and highlight immediate, interactive, flexible, and personalized learning and feedback, flexible learning [1-3], improved explicit reasoning, knowledge retention, and improved student engagement in general [2]. At the same time, the emergence of AI tools like ChatGPT challenges traditional assessment methods that would be prone to cheating [4,5]. Some even state that there is room for written essays in higher education anymore [6] and that the 'essay assignment is dead, really' [7]. It has also been stated that pedagogy will change from the present dominance of constructivism (obtaining a good personal understanding of a subject) to constructionism (to be able play and tinker with a subject, to learn how to iteratively take apart and put together again) [1].

At the Norwegian University of Science and Technology (NTNU) there was no formal basis for regulating the use of AI when ChatGPT became available online in November 2022, other than quite general guidelines which mostly address plagiarism, and a comment that 'potential challenges and opportunities that would result from using chatbots vary from discipline to discipline and course to course'. Later that semester, NTNU made available some material that is aimed to help teachers to discuss AI with students [8], which can be considered quite useful although it remains the teacher's responsibility to evaluate the relevance for courses being taught.

As course descriptions for the 2023/2024 academic year were already finalised before ChatGPT was launched, teachers had to address the use of AI in courses based on their own ideas of what was appropriate use of chatbots and the like. One such course is TPD4505 Design Theory, in which students are required to write a scientific review article, in the last year of master programs in Industrial Design Engineering and Interaction Design. In the autumn 2023 edition of this course, which has continuously run since 2001, 75 students were tasked to write a 10-page review article on a topic of their personal interest, in conjunction with a design course where students are tasked to do a design project founded on state-of-the-art theoretical understanding in a relevant field. Instead of ignoring the issue and hoping that students would not misuse AI tools in their assignments, the elephant was invited in the room by organising a workshop at the beginning of the course, to address specifically the use of AI when writing

a review article, and to provide clear guidelines for students on how to approach this issue. Subsequently, all students were requested to include, either in the methodology section of their review article or in an appendix, to explain how and why they did (or did not) use AI-based tools in doing the research for their article and during the writing process.

The method used to analyse the students' responses is explained in section 2. Section 3 and 4 explain the pedagogical philosophy for the course and the content of the workshop at the start of the semester which challenged students to navigate the landscape of appropriate, undesirable, inappropriate and unacceptable use of AI tools like ChatGPT towards the preparation of their review article. Sections 5 and 6 analyse the students' responses and discuss lessons drawn from them.

# 2 METHOD

The Design Theory course was taken by approximately 58 students from the 5-year integrated Industrial Design Engineering and 2-year international Industrial Design master program at NTNU, located at Gløshaugen campus in Trondheim, in addition to 17 students from the 2-year master program in Interaction Design, which are located at the NTNU Gjøvik campus. The empirical data which is analysed in this paper, and which is the main basis for discussion was collected from the 58 papers written by students in Trondheim, by extracting those sections (ranging from one sentence to ca. a half A4) in which explained how students had, or had not, used AI in the preparation of their article. Data was extracted from the other 15 assignments; due to administrative reasons it was not possible to the use of AI during preparation of the article; most likely because students either forgot or did not perceive the explicit request to do so as a compulsory item (which was essentially correct) and chose not to address it. This resulted in 36 articles with useful data for the analysis provided in section 5 of this paper.

The excerpts were in their entirety put in a database. They were thoroughly read and subsequently sorted in categories, which developed during the process; initially, detailed categories were made for each individual purpose AI was said to be used for, but gradually, categories were merged to some extent since students used different phrasing to essentially say the same. This process resulted in five categories: Using AI as discussion partner, language checker, information simplifier, search engine and translator. Statements and reflections from assignments that were considered particularly interesting were highlighted and pre-sorted for easy tracking during the writing process of this article.

It is acknowledged that interpretation of students' explanations is subject to bias, which is another reason why further granulation of the categorisation is not considered as meaningful. For example, students used ChatGPT for 'brainstorming', 'discussion', to suggest 'structure', 'topics to include', 'headings' et cetera, this was all compiled under the same heading 'ChatGPT as discussion partner', regardless of what the discussion was exactly about.

It should be noted that no AI was used whatsoever in the writing process of this E&PDE 2024 article.

# **3 COURSE BACKGROUND AND PEDAGOGICAL PHILOSOPHY**

The formal learning goals of the TPD4505 design theory course is to challenge students to extend their knowledge about scientific and theoretical approaches used in design research, in particular related to a topic which has their special interest, and to obtain skills for scientifically reporting such knowledge by writing a scientific review article in English. Key abilities that students should practice are: 1) choosing, defining and refine a research topic for further scientific study, 2) using scientific research methodologies related to design research, 3) selecting, reviewing, and interpreting relevant literature, and deriving implications for future research. In addition, the course aims to help the students to see the value of doing research, and making them experience how obtaining a theoretical background can inform and complement the decisions they make in design process, in addition to using design tools and methods, talent, intuition, gut feeling, etc. A third aspect of the chosen pedagogy and examination form is to prepare students for the practicalities and challenges which they will meet when doing their master thesis project (usually the next semester). For most students, writing a review article is something highly outside their comfort zone, as so far in the study program, they have been mostly working in groups, using familiar tools methods, giving them the possibility to excel in areas in which they already comfortable with. In practice, for many students this means that they experience uncertainty, frustration, and decision refusal during the course, and hesitate to ask for feedback (they need to organise tutoring sessions with their supervisor themselves). But they also experience the joy of overcoming an obstacle,

and pride of accomplishing something they were dreading; all very useful preparation and experience before starting their master project, and for becoming an independent and critical thinker who is prepared for a professional career. With all three learning goals in mind, the key element of the course has always been to search, gather, and sort scientific literature, to gnaw through and chew on articles during the analysis process, before considering the best ways to categorise and present insights. With the rise of AI tools such as ChatGPT, much of the searching, sorting, gnawing and chewing can be outsourced, which potentially severely undermines the aforementioned learning goals. This is why the autumn 2023 edition of the course was complemented with a workshop on how to address the use of AI in the course.

# 4 PRE-ASSIGNMENT WORKSHOP

The workshop was organised in a way that the teacher first introduced the topic and laid out a proposal for the ground rules, which were then discussed with the students, and to form the basis for the ground rules in the course. Table 1 shows how appropriate and inappropriate (meaning: unacceptable) use of AI was formulated, but also what was considered to be 'in the grey zone': use of AI which is not forbidden but potentially compromising the students' learning.

Table 1. Appropriate and inappropriate use of	AI
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Appropriate use	Inappropriate/unacceptable use	
<ul> <li>Brainstorming for ideas</li> </ul>	Present AI-generated text as own text	
<ul> <li>As discussing partner</li> </ul>	• Copy and paste AI-generated text in an article without proper	
<ul> <li>Improvement of English text)</li> </ul>	citation (including letting AI paraphrase text)	
• Let AI suggest sources, with are then of	• Relying on AI-generated text to replace critical analysis of the	
course checked by the students	sources used for that text	
Grey zone		
· Let AI generate research questions and rev	iew approach without a good own understanding of the literature.	
• Let AI generate drafts of text based on a just a limited input from your side.		
• Let AI summarise of large amount of text	(like articles)	

During the workshop also benefits and drawbacks of using AI when doing research for and writing a scientific research article were discussed, as shown in Table 2.

Table 2.	Benefits and	drawbacks	of using AI
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Benefits	Drawbacks
• With AI a student can perhaps cover	<ul> <li>AI cannot replace original and critical thinking.</li> </ul>
more ground and/or work faster	• It may compromise motivation for original and critical thinking.
• Using AI a student may feel less alone	• Reading and chewing on what they read instead of letting AI do it
and have a discussion partner.	for them makes students think and be creative. They may miss out
• AI can provide suggestions for things	on that when they let AI do this for them.
to read (although search engines can	• Using AI may make students confuse someone else's opinion and
do that as well)	values related to a topic for their own (they may become a robot
• Probably most importantly: Using AI	themselves)
will provide students with a first-hand	• The temptation of using shortcuts may hinder academic growth
experience to reflect over its potential	and even compromise ethical values.
and its dangers	<ul> <li>Students may feel less proud of their article after completion</li> </ul>

In the workshop it was also discussed how in particular ChatGPT-generated text may be recognized by those who grade the final articles, such as:

- Lack of a clear link to literature sources and/or use of unexpected, niche and/or obscure sources
- When text is very formal and consistent in tone and style and lacks 'human' variation, (excessive or lack of) nuance, argumentation style.
- Repetition, verbosity, unnecessary sentences with empty meaning
- Political correctness, an overly balanced tone (when ChatGPT sounds like a politician)
- Unnecessary value-based comments, like that something is important or rewarding or necessary for the survival of humanity.
- Text produced by a student in a suspiciously short time.
- Text which simply does not feel like something an inexperienced student could have written.

The workshop resulted in establishing a contract between students and responsible teachers, intended to provide a clear set of rules and frame of reference for students to navigate in. The workshop also provided a stage to share fears, both from the side of the students and the teachers, for example about how to take up possible accusations or being unjustly accused of unacceptable AI use.

# 5 ANALYSES OF ASSIGNMENTS

This section analyses the extracted sections reviewed for this paper. Students almost exclusively stated to have used the OpenAI chatbot ChatGPT, which is why 'using AI' and 'using ChatGPT' is interchangeably in this paper. Table 3 shows the percentage of articles in which it was stated how ChatGPT was used for different purposes. No significant differences were observed between gender.

Purpose	Number of students using ChatGPT for this purpose	Percentage of 36 articles in which ChatGPT was used for this purpose
ChatGPT as language checker	20	56 %
ChatGPT as discussion partner	18	50 %
ChatGPT as information simplifier	13	36 %
ChatGPT as translator	7	19 %
ChatGPT as search engine	5	14 %

Table 3. Purposes of ChatGPT

# 5.1 ChatGPT as language checker

The most common use for ChatGPT was as language checker; 56% of all students indicated that they had used it for this purpose. Phrases that students used for indicated this use include 'enhancing language', 'rectifying writing errors', 'improve sentence structure', 'proofreading', 'improve readability and clarity', 'making subtle adjustments', 'changing some words', and 'to convey the message more effectively'. A few students also used Grammarly and/or DeepL. One student explained in detail how ChatGPT was used to refine language, by providing examples of alternatives for words or phrases that easily become repetitive, like 'however' or 'a big challenge'. They stated to prefer using ChatGPT because it was an effective way to get suggestions without having to use a manual dictionary. Another student explained how they experienced that using ChatGPT for language improvement leads to restructuring of sentences that no longer convey the intended meaning, and that using it implies the need to carefully review and check each word afterwords. What several students do not seem to understand that using ChatGPT in many cases resulted in somewhat 'over the top' language, such as writing 'I *leveraged the capabilities of ChatGPT for the purpose of* (...)' instead of 'I used ChatGPT for (...)'.

# 5.2 ChatGPT as discussion partner

Half of the students indicated that they had used ChatGPT as discussion or brainstorm partner, in some way. This included 'for suggesting and refining research questions', 'as writing assistant', 'to shorten paragraphs', 'for general advice for composing and structuring a literature review', 'to shed light on specific aspects to consider', 'to find topics and ideas to include', 'to suggest headings for paragraphs', 'for framing, choosing and sharpening scope and focus', and 'to find perspectives that might have been overlooked'. Most students stated that they found this very useful, in particular at times when they felt stuck in the process. One student compared using AI with teaming up with a smart student and achieving better results collectively, instead of stealing the homework from that brainy classmate, and that way 'let it contribute to making you a better and more effective version of yourself'. However, there was also some criticism of students who stated that ChatGPT offered only superficial suggestions that did not contribute substantial value to the article'.

# 5.3 ChatGPT as information simplifier

In 36% of all review articles, students indicated that they had used ChatGPT as a tool to process information, such as for simplifying original texts for better understanding, synthesizing, or summarizing findings from literature, explaining difficult terminologies and themes, or getting input on whether potentially relevant articles said something about a specific topic before reading the whole article. One student explained how ChatGPT was used to create a timeline of events of when companies had introduced new products and features.

### 5.4 ChatGPT as translator

Next, in 19% of the articles it was indicated that students had used ChatGPT as a tool for translation, mostly for translating Norwegian into English for better understanding of English texts, or for translating their own Norwegian draft texts into English. It is not clear why students preferred to use ChatGPT for this purpose instead of regular translating services (although it can be assumed that services such as Google Translate were used by some), but it can be assumed that once ChatGPT is used for other purposes already, it is convenient to use it also as a translator.

### 5.5 ChatGPT as search engine

Finally, ChatGPT was used in 14% of the articles as a search engine, for example to identify relevant literature, or to identify good search teams. It should be noted that the course also includes a lecture on tools and techniques to search for relevant literature, as well as a library course specifically targeted for design students, where students are taught when and how to use tools such as Scopus, Google Scholar and Oria (a Norwegian service for digitally searching Norwegian academic research libraries). Students are also recommended to search the repositories of the Design Society and Delft University of Technology (since this university houses one of the largest Industrial Design Engineering study programs and as such includes many master theses which are not necessarily accessible using other databases). In the method sections of their articles, students normally also indicate that they have use one or more of these services, and there is therefore no indication that they have used ChatGPT to replace them. As one student put it, 'ChatGPT was used to identify some key literature in speculative design, but the suggestions were mostly literature I already had identified'. One way of smart use of ChatGPT was by a student who indicated that ChatGPT was used to suggest examples of companies which had introduced application of certain technologies (so not scientific sources), and who had asked why certain companies had done so, which provided sources that were then cross checked, by looking for original sources which were then included and properly cited in the article.

# 5.6 Not using ChatGPT at all

Only two of the 36 students explicitly stated that they did refrain completely from using ChatGPT, to 'prevent using data that can be affected by algorithmic bias', and because 'it had value (...) to experience how easy or difficult it was to find literature with high quality through more traditional search methods'. Seven students explicitly stated that they did not use it for reasons to improve content but only for language improvement, and that they meant that doing 'manual work' provided invaluable insights and learning even though it was time consuming. As one student put it: 'If AI was used to find sources, insights gotten during the search for relevant articles could have been missed out on.'

# 5.7 Broader reflections from students

Some students expressed explicitly fear that becoming comfortable with the use of AI may compromise their own ability to be creative and to draw independent conclusions. At the same time this posed a dilemma for them, considering that AI is here to stay, and refraining from using may have negative consequences as well. One student wrote that it was used very initially in the writing process, but that it only contributed with confusion, and that they therefore discontinued using it from the first draft of the article. Several wrote that they have only used the tool after a complete draft was finalised, before using the tool to improve the text. Another interesting comment was that the ChatGPT 'was especially interesting for having feedback and suggestions in between tutoring sessions and allowed for a more varied exploration of the topic. It has made that I used a more iterative approach that what I would have gone through without the use of the tool'.

# 6 **DISCUSSIONS**

Experiences with the workshop and the analysis of students' self-reported use of AI in their review articles pose no immediate grounds for concern. Most students seem to have reflected well over opportunities and challenges that come with using ChatGPT. An important point to consider is whether students have reported the truth instead of socially desirable reflections. There have in some instances been concerns with students who seemingly (or even rather obviously in two single cases) had used ChatGPT without mentioning this. For example, a student who sent an article draft which looked very mature at first sight, but with a comment that they had 'no clue whatsoever about writing an article'. It has also occurred that students, when confronted with a suspicion about inappropriate ChatGPT use,

first denied this, before admitting that they may had crossed into a grey zone. At one instance, a teacher expressed that it is challenging to devote considerable time to reviewing an early article draft which is obviously 'heavily inspired' by brainstorming with ChatGPT.

Overall, results suggest that ChatGPT makes diligent students consider a wider a range of literature and suggestions, and that students actually follow up checking out these suggestions: time use shifts from looking for sources, to reading those sources. This may be considered a good thing. However, ChatGPT may make lazier students choose articles and theories which are far from obvious or even obscure. Revealing this is simple when graders are familiar with the topic of the article, but less so if they are not. This is a concern. Also, the course is rather time-consuming for students which makes ChatGPT attractive for cutting corners. On the other hand, several students indicated that using ChatGPT as tool was more time-consuming than they thought, given the many directions and suggestions potentially worth exploring, but that it was generally worth it. This may lead to unnecessary time spent, and even to decision refusal. For example, spending time looking for and choosing between 10 or 15 suggestions for synonyms for a phrase like '*it was a challenge to*...' is essentially unnecessary, as the level of written English is expected to be that of an average pre-AI-era student. And when students end up choosing with '*it became a profoundly arduous undertaking to*...', it is not necessarily an improvement either.

# 7 CONCLUSIONS

Based on this evaluation, students' use of ChatGPT turned out to be less problematic than feared, even though some students most likely have taken shortcuts. As such, there is no immediate reason to do away with the current course format, nor to accept that that there is room for written essays in higher education anymore [6]. However, it is currently under consideration to redesign future runs of the course in a way that grading is based on an oral exam, testing students on their familiarity with a partially prescribed, and partially self-chosen reading list, and/or evaluating them based on a mini lecture that they need to prepare on a theoretical subject. This may take care of some concerns related to AI. Another reason is that it would likely reduce the time required for supervision, which as increased considerably after student numbers increased from 25 to 80 in only a few years. The insights reported in this paper will contribute to fine-tuning this course and will hopefully also inform and possibly inspire those who are responsible for courses with similar assignments that explicitly or implicitly invite to use ChatGPT.

# ACKNOWLEDGEMENTS

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# CONCEPT TO PRODUCTION WITH A GEN AI DESIGN ASSISTANT: AIDA

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# ABSTRACT

In design research there is a deep interest in how designers solve complex problems using design methods and heuristic shortcuts and in particular how this might relate to Machine Language (ML) to simulate the design process. With the introduction of Large Language Model (LLMs) such as Chat GPT we can appreciate how software with the remarkable capability of Generative AI (Gen AI) and generative design can be used to assist designers in the three-dimensional design of their products. In this paper, we will focus on how AI will impact designing in computing, identify what is relevant and suggest a new development opportunity. Our interest is in examining the potential for better and novel software solutions, making them easier to use during the design synthesis process and capable of adjustment throughout the 3D CAD development stage. The specific problem we aim to resolve is how to optimise a designer's time spent from concept to production using Gen AI & 3D CAD software without affecting the quality of design thinking, methodology and practical process. Gen AI as an evolving platform has the potential to create a design to production productivity shift that industry and academic groups have long predicted. Designing will remain creative and inventive, individualistic or team based and using what we have termed an AI design assistant, AIDA.

*Keywords: Product design, engineering design, artificial intelligence (AI), 3D CAD, human computer interaction (HCI), design automation, large language models (LLMs), generative design, machine language (ML)* 

# **1** INTRODUCTION

Since the arrival of Chat GPT and the development of Gen AI in creative design there has been a proliferation of new businesses, exploring new services and ways of working to advance the design process such as Generative Biomimicry, Topology Optimisation, 3D Image creation and Text to 3D CAD. Designers using or experimenting with Gen AI programs are discovering services and features which can produce convincing design options in seconds. With an extensive research background Cross N [1] studied both human and computer in relation to design ontology; and he suggested that AI and computational processes can lead to insight about human cognition. And so, we can expect many unexpected opportunities in linking (LLMs), Gen AI with 3D CAD to help explore conceptual territory and give designers the working tools to think differently.

This study concerns itself with recommending the creation or evolution of an AI Design Assistant (AIDA) to increase the performance of designers and engineers. As with any new technology this will come with its learning and training issues, although enthusiastic users and early adopters should play a positive role in development, testing and feedback. It is not always about speed, and designers know the importance of standing back and having some thinking time to apply their creative knowledge and avoid problematic consequences, this will not be the job of our new AI design tools. Being able to create well considered sustainable products will rely on the skills of our best designers, and these new AI tools will permit them to design far more quickly than they can at present. In the field of product design, we are experiencing rapid progress with AI led generative software because it offers novel and efficient ways of designing. There may be a broader impact on design jobs, but just as likely designers will become more productive and some of the time intensive work becomes easier to do with the help of AIDA, freeing time to work on other projects.
#### **2 LITERATURE REVIEW**

Since the introduction of Chat GTP using Gen AI capability, the potential for getting questions or detailed research options has proliferated, albeit with some known limitations, nevertheless a technological revolution is occurring, and the design process will be profoundly affected. Developers and designers are launching new products which provide clues as to these changes such as (LLMs) to create both 2D and 3D representations of reality. A team from Autodesk [2] integrated DALL-E a plugin that that generates 2D image inspiration for 3D design and allows users to construct text and image prompts based on what they are modelling. A team from Autodesk and academia [3] have demonstrated that natural language can be used to generate and edit 3D shapes and they have discovered an approach which can produce high-fidelity models. This approach can help augment 3D design workflows rather than replace them. A team from France [4] propose to integrate design rules and CAD software into a data model which would help engineering teams by allowing access to information specific to their professional domain which is generally hidden in unstructured technical manuals using a context aware cognitive design assistant. In a review of Deep Generative Models in engineering design [5], it is proposed that the role of Automated Design Synthesis has the potential to revolutionise the modern engineering design process using Machine Learning and Deep Generative Models relating to a knowledge resource encoded in the vast expanse of existing designs.

Yang Q et al. [6] explain how Human Computer Interaction (HCI) designers struggle to envision and prototype AI systems because the scale and complexity of the project algorithms makes it virtually impossible to predict all outcomes and HCI designers use both complex, resource-intensive technologies and simple inexpensive artifacts such as paper prototypes and Wizard of Oz systems to help visualise and explain their concepts. De-Peuter S et al. [7], Propose AI assisted design (AIAD) a framework for developing collaborative assistance for design problems is defined 'AI should aim to cooperate, not automate, by supporting and leveraging the creativity and problem-solving capabilities of designers'.

Generative design is popular in Product and Engineering design and using the chair as an exemplar [8], the authors question the relationship between man and machine finding that the designers' professional experience to be the most important factor in a good outcome and that design plugins are currently insufficient to design a whole product. A team from Strathclyde University [9] have reviewed the field of AI in Product Design and Smart Manufacturing and note how AI is impacting on the design process and how better historical data will improve designs, reconstruction times and development of material selection. Wang X et al (2023) [10] highlight the potential for human machine collaboration, knowledge management, design innovation and engineering skills education. In [11], Brem A et al. discuss the immense transformative potential of AI and specifically how this is transforming innovation. They discuss the potential of AI in new product development at the early stages of creating novel and innovative designs using images or audio data. In [12], a design process using 3D Generative design is explored conceptually so the human designer can iterate and design faster.

The examples in Figure 1 provides a broad selection of what is significant and completed recently. It should be noted that the designer would remain in control of the development of the final product by evolving the organic potential of existing generative and topological software. Examples in the field of generative design usually involve single-part products, using a single production technology such as injection moulding or 3D printing.



Figure 1. Generative Design Examples

In Figure 1a adjustable automotive car seat, Toyota wanted to simplify the complexity of the car seat and make the seat frame thinner, lighter and more sustainable. They worked with Autodesk, and they would not have imagined that it could be improved so significantly other than using the generative design process. Moreover, Figure 1b the Phillipe Stark AI chair was developed with Kartell & Autodesk using a generative process and the minimum amount of material which the designer described as being 'better than anything he could have done', perhaps this is indicative of some unexpected or future potential.

Additionally, Figure 1c, 3D metal printed brackets developed by Autodesk for the aerospace market using generative design and using topology optimization, which involves changing the internal structure of a solid to make it lighter in this case with a cellular latticework providing it with far more strength.

In Figure 1d The Patrick Jouin folding chair was created using Dassault systems 3D Experience software and he realised organic processes using machine algorithms. The platform was created to make it easier to achieve 3D printed products and the chair was presented at Milan Design Week.

## **3 RESEARCH THINKING**

This work reflects our interest in getting the design process to be easier and more efficient as an evolved alternative to industry standard manual 3D software and encourage Gen AI as a means of efficiently creating 3D design concepts which are co-evolved by human and machine, with decision making firmly in the control of the designer.

AIDA will inevitably become easier and familiar to the designer and 3D CAD modelling will become quicker and more efficient. The quality of design thinking and experience remains just as crucial as it is now, with experienced designers exercising judgement and vision achieving the most productive outcome. Any design process which integrates CAD and automated AI process can still fail on a commercial level, so it will require intervention stages for humans to guide or re-direct the process.



Figure 2. Artificial intelligence Design Assistant (AIDA)

The interface for designer interaction will vary through the stages of the design process; early brief and specification stages are most readily served by current text based LLMs, tools for subsequent stages will be developed with visual select / reject then CAD-like interfaces. The following stages explain how this might work on a practical level and we can deal with the how in future research:

• Stage 1. The designer starts with writing a brief entered into text based LLMs such as Chat GPT and it provides a detailed document with potential options so all aspects such as product descriptions, technical requirements and broad categories are included for consideration; the brief is evolved and changed as required.

- Stage 2. A request for market research information can be made to comprehensively identify what exists in a field and using a select/reject visual prompt, iterate towards the preferred design direction such as an office chair design and the designer creates a broad market presentation for design manager or client, listing market and category types with bulleted style, feature and material observations.
- Stage 3. Edit and reduce the large number AI options to a recommended few to pursue and develop. At this point the designer runs a 3D model generative concept creator while sketching and thinking about personal ideas. The AI concept generator options are narrowed by select/reject, but the designer has the option to add in a concept which is described in text and adjusted numerically via the prompt screen and added to the AI options. The designer then adjusts some of the other AI concepts in the prompt screen again with text and numbers until the client presentation is accepted.
- Stage 4. A preferred design starts the detailed design stage, and the designer starts to work on a 3D model adjusting forms in text and numerical prompt stages. Additionally access to 3D component databases with text and numerical prompt changes and full components are added to the model. AI is then asked to create 3 generative options via the Prompt screen and the designer decides one of these AI options is better than the original but once again they make plenty of adjustments in the Prompt screen until a client presentation is complete.
- Stage 5. The Optimise stage has the designer doing far more traditional 3D CAD adjustments but the Prompt screen is still available for text and numerical adjustment as is the option for AI to create 3 or more further optimised generative options.

As mentioned above, several research initiatives in industry and academia have been working in LLMs to generate 2D & 3D CAD but not a destination point on how Gen AI can help make designing easier throughout the complete process. We have observed profound change in the design industry and aim to define a realisable and adaptable version of how product designers can design differently and arguably better.

## 3.1 Research practical

To validate the proposed approach AIDA, four prompts were written to design four different chairs without using traditional 3D CAD software such as Solidworks or Autodesk Fusion 360. The aim is to prove what could be done in both text to 3D image creation (as seen in Figure 3) and text to 3D CAD (as seen in Figure 4). To do so we used online service providers to test our hypothesis that designing of a product will eventually become a co-creation process for designers and engineers with an AI design assistant such as AIDA.

Technology to explore the potential of the AIDA concept was available via internet service providers of AI to image & AI to 3D CAD, as a service sector it is in its infancy, but is nonetheless using very clever LLMs technology indicating a direction of travel when considering how design tools will change.

In a search for an AI-3D model generator Fotor.com was utilised with its potential for design concept creation of a chair. It proved useful as a research tool for this project and can help relieve aspects of design fixation, create alternative concepts and high-quality photorealistic presentations. With its Prompt text commands we requested, Plywood dining chair & Plywood dining chair with arms. The complete learning and practice process with Fotor.com including creating 4 designs was two hours. A variety of results were achieved, symmetric and asymmetric and a second design option appeared in two of the image generator attempts.



Figure 3. Text to 3D image

Then the potential of text to 3D CAD model was explored via Zoo.dev to create chair options from a text and prompt window and download step file products which was relatively easily. The images in Figure 4 may seem basic but this is a new technology allowing the creation of a 3D CAD model and downloadable file solely from text input. We requested: Chair; Dining chair; Dining chair with arms and a height adjustable office chair. The LLMs algorithm conducted a search and loaded some basic geometric forms to represent the product requested. We don't know the algorithm functional routine, but it seems to search for product types online then mimic objects by reducing them to basic 3D block forms. It works best for single item objects but showed potential for multiple component products too. Once this technology can access a much bigger dataset then it should start to return some more useable options for design development. This is an Alpha software development version, though it helped us to envision an integrated design tool to link early conceptual work to detailed CAD development using primarily a text prompt.



Figure 4. Text to 3D CAD

## 4 **DISCUSSIONS**

We gained a positive impression of text based (LLMs) & prompt screens to continuously tune the design brief and conduct research. We see development potential for using Text to 3D CAD code blended with traditional 3D CAD so that Gen AI 3D models can be produced at concept, concept development and product detailing stage. This allows generative design options to be explored at the concept and detailed design stage in fact all stages of the design process, concepts will be efficient to prepare and present, and later used for generative design options or modified and detailed at any stage in the design process. This means we lose the need to fix designs at 3D CAD stage and designers have a single tool from concept to production. This is the basis of a long-term proposal to create a single design platform start to finish AIDA without any limitations on concept and product generation.

The design process using this suggested AIDA allows text, graphical menu selection or numerical adjustment to 3D objects via a prompt screen, a relatively blunt tool at concept stage which can also function as a 3D parametric CAD tool when required. At any stage it can produce generative options such as design concepts, although it uniquely works also at the product detailing stage. Options are usually narrowing towards the production stage, but dramatic change can sometimes be required because an unexpected change can arrive later than planned. AIDA help would mean a significant change is less stressful and costly. Generative design solutions in this proposal relate to design morphology and topology. Biomimicry is currently a very popular in design led production and particularly in 3D printing, however fashions and needs change so we will require an integrated design method of achieving more complex and better 3D products.

## **5 OPEN RESEARCH QUESTIONS FOR AIDA**

Product designers are witnessing an increase of activity in AI related projects which require evaluation and good questions before we decide what help is needed to assist in the practice of designing. Our proposal for an AIDA approach will eventually integrate with industry CAD/CAM products with seamless functionality and therefore, the following questions require further research before progress can be made:

- When can we access the right quality of 3D object and component datasets?
- What type of algorithms and expertise are required to implement AIDA?
- How do we make AIDA intuitive and efficient to use?

- How do we implement a user-friendly prompt menu?
- How do we achieve incremental (imprecise) concept change then fine tuning (precise) product development within AIDA?
- Can we integrate Morphology & Topology with aesthetic options not just biomimicry?
- How are generative and parametric characteristics combined?

The design process using an AIDA will not change design stages or decision making it just means that an AIDA will do some of the heavy lifting by answering research questions and providing computer generated design options, both earlier and later in the design process than previously possible and it requires experienced designers to achieve a high-quality outcome. There are no AI shortcuts for design expertise, just time saving efficiency for those that know how to use this new technology. Additionally, the next generation software needs to facilitate the design of complex multi-component products which is not yet a practical service offering of Gen AI product development.

## **6** CONCLUSIONS

The integration of heuristic shortcuts to Machine Learning and the advent of Large Language Models like Chat GPT, highlights the potential of Gen AI in revolutionising the design process. This paper focuses on how AI, particularly Gen AI and 3D CAD integrated software, can optimise designers' efficiency from concept to production without compromising the quality of design thinking. Keeping a multiple component product well managed is of great interest to designers who work with a multitude of 3D CAD software providers with numerous optional bolt-on products. We believe that our AIDA proposal helps define a destination for a co-creation tool which lets humans do the creative thinking and AI the big processing tasks. We recognise this will require vast development input and ultimately some very clever and intuitive prompting tools. The evolving nature of Gen AI holds the promise of a significant productivity shift in design to production, offering exciting prospects for both industry and academia.

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# ASSESSING THE EMOTIONAL, PHYSICAL, AND COGNITIVE IMPACT OF MULTISENSORY DESIGN EXHIBITS AT DUTCH DESIGN WEEK

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#### ABSTRACT

Design students face the challenge of presenting their work at university events with little training in designing exhibits. To help design students successfully communicate their projects, they would benefit from studying design exhibits that enhance viewer engagement. Human-centred design is often multisensory and appeals to human emotions, thought patterns, and relatable behaviours. However, "the "lower" senses of smell, taste, and touch are rarely taught in school curricula. This research combines multisensory engagement of six human senses, sight, smell, taste, sound, touch, and spatial awareness, with facets of emotional, cognitive, and physical (ECP) behaviour to explore how sensory stimuli impact a visitor's experience with exhibits. Fourteen undergraduate design students and one design instructor collected sensory and ECP data on 41 exhibits while attending the 2023 Dutch Design Week. Emotionally, the senses of taste and smell had the highest impact on the visitor. Cognitively, the senses of taste and touch scored highest. Physically, the sound, spatial, and smell senses had the most impact. Sight had the lowest variance in ECP scores, while taste had the greatest. Results verify that as the number of senses increases, so does the exhibit impact. Studying exhibit design engagement caused two student researchers to redesign their end-of-year presentations to include more senses. Design exhibitions engage visitors visually, limiting audience proximity and engagement with display content. Exhibits designed to incorporate smell, taste, touch, sound, spatial awareness, and sight, in that order, can transform casually observing visitors into engaged participants consuming an exhibit's content rather than merely viewing it.

*Keywords: Design student exhibits, exhibit education, design presentation methods, Dutch Design Week exhibits* 

## **1** INTRODUCTION

Design students often face the challenge of presenting their work at university or public events with little training in designing project exhibits. Exhibits are an effective, experiential way to communicate ideas, connect with visitors, and teach concepts. However, some exhibits accomplish this goal more significantly than others. To help design students successfully communicate their work to visitors, they would benefit from studying human-centred design methods to enhance visitor impact in contemporary exhibitions.

Human-centred design is often multisensory and appeals to human emotions, thought patterns, and relatable behaviours [1]. However, Classen teaches us that "the "lower" senses of smell, taste, and touch are rarely engaged by the school curriculum, for these senses are not generally considered to provide "ways to wisdom" but rather, only channels for pleasure or displeasure". Cultures that try to educate all the senses are stereotyped as sensualist and decadent" [2]. Obrist et al. explain that exhibits engaging multiple senses encourage visitors to experience and interpret content with increasing impact [3]. Contemporary museum education has also embraced the principles of multisensory exhibits [4]. Engaging exhibits convey essential information to the visitor and strive to garner visitor investment toward this content. Liang & Nan report that "good" exhibits involve, at their core, interactivity to express their purpose [5]. Thus, this study embraces multisensory design principles and incorporates six human senses, sight, smell, taste, sound, touch, and spatial awareness, or the relationship between oneself and other entities within a space, as one of two components to assess exhibit impact. The second

component assesses emotional, cognitive, and physical (ECP) behaviour as outlined in Kahn's study measuring employee engagement or disengagement through ECP behaviours [6] along with Packer and Ballantyne's exhibition study using ECP behaviours "to characterise the content and intensity of visitor experiences at different sites or for different groups" [7].

Exhibition "engagement" defines a visitor who is emotionally (E) or empathically connected with the work exhibited; they are cognitively (C) vigilant regarding the content and become physically (P) involved with the exhibit. Engaged visitors freely express their thoughts and feelings, their creativity is triggered, and their beliefs and values connect with the work. Conversely, disengaged visitors withdraw, are emotionally absent, cognitively passive, and lack physical connection with the work.

To explore how sensory stimuli impacts a visitor's ECP experience with an exhibit, design students attending the 2023 Dutch Design Week (DDW) in Eindhoven, Netherlands, enlisted their fellow travellers to collect data by photographing and recording their sensory and ECP experiences with selected exhibits. Researchers hypothesised that study participants who reported multiple sensory engagement with an exhibit would also report higher emotional, cognitive, and physical connections with the exhibit. They also believed that students who studied the different components of design exhibits would gain new insights and thus impact their end-of-year exhibit design plans. Additionally, they surmised that the methods used and their experiences in gathering and sorting the data, combined with the study findings, would be a helpful model for future students and educators striving to enhance a design program's end-of-year exhibit impact and engagement.

## 2 METHOD

## 2.1 Participants

Fourteen undergraduate design students, seven females and seven males, from illustration, graphic, industrial, and user experience design, and one design instructor from Brigham Young University collected data on 41 exhibits.

## 2.2 Data Collection

The students collected qualitative written and visual data on their mobile phones using Google Forms. Responses were recorded instantaneously in a spreadsheet, and photos were uploaded into shared folders. Three surveys were created. The first survey contained six questions describing an exhibit and how many of the six senses, touch, sound, smell, sight, taste, and spatial perception, were experienced. Participants also recorded the exhibit's perceived emotional, cognitive, and physical impact. The second survey contained three questions exploring the exhibit designer's sensory experience intentions. The third survey combined the two surveys and was collected from students who were slow to write and post results. Students collected data in pairs, one collecting visitor impressions and the other gathering exhibitor insights. Exhibits were selected based on personal appeal.

#### 2.3 Data Analysis

Exhibit photos were printed, assigned a number, and sorted on three large mobile whiteboards. Each exhibit was tagged with notes identifying which of the six senses were engaged by that exhibit along with its ECP score based on a five-point Likert scale, anchored with "very poor" at the low end and "very well" at the high end. The scores were recorded on colour-coded notes and adhered to the respective exhibit photo, allowing researchers to quickly view, sort, and evaluate the data.

#### **3 RESULTS**

The scores compare the number of senses engaged by an exhibit and how emotionally, cognitively, and physically impactful a student participant considered it to be. Figures 3-5 below report all 41 exhibit responses using 20% transparent circles. The darker the circle, the higher the number of exhibits reported at that score. The lighter the circle the fewer number of exhibits at that score. None of the exhibits reported engaging five or six senses.

#### 3.1 Average ECP scores for individual senses.

All ECP scores were averaged and categorised by sense. For example, in Figure 1, the leftmost medium green bar represents the average of all emotional scores reported for all exhibits engaging the sense of sight.

Emotionally, taste and smell senses had the highest impact on participants, with a score of 5.0. Cognitively, the taste and touch senses scored highest at 4.50 and 4.45.

Physically, the sound, spatial, and smell senses scored the highest at 4.52, 4.52, and 4.50.

Sight had the least variance in scores, with a high of 4.36 and a low of 4.28. Taste had the greatest score variance, with a high of 5.00 and a low of 4.00; it also had the lowest score recorded.



Figure 1. The average ECP scores for all six senses

#### 3.2 Number of senses and total ECP score

An exhibit's "combined ECP score" sums all emotional, cognitive, and physical scores received in relation to the number of senses the exhibit engaged. The lowest possible score is 3.0, and the highest is 15.0, see Figure 2. As the number of senses engaged increases, the variance between scores decreases. One sense has a total of three scores, the least number of scores, a seven-point spread between scores, the broadest score difference, the two lowest scores, and one score at 15, or 33% of one sense scores. Four senses report a total of 13 scores, a three-point spread between scores, the narrowest score difference, and seven scores at 15, or 54% of four sense scores, significantly outnumbering the high scores of the other three senses.



Figure 2. Combined ECP scores for all exhibits by the number of senses

#### 3.3 Number of senses

Figures 3-5 show individual emotional, cognitive, and physical scores, ranging from 1.0, very poor, to 5.0, very strong, and grouped by the number of senses.

#### 3.3.1 Emotional scores by number of senses

Figure 3 compares the emotional impact score with the number of senses an exhibit engaged. This graph demonstrates the clearest trend between an increasing impact score and the number of senses engaged. Ten exhibits, the most of any intersection on the graph, scored a 5.0 with four senses engaged. None of the exhibits scored below 3.0.



Figure 3. Emotional scores by the number of senses engaged

#### 3.3.2 Cognitive scores by number of senses

Figure 4 compares the cognitive impact score with the number of senses an exhibit engaged. The highest concentration of responses falls on exhibits that engage three and four senses. This result still leans towards positive visitor engagement with increasingly multisensory exhibits.



Figure 4. Cognitive engagement scores by the number of senses engaged

#### 3.3.3 Physical scores by number of senses

Figure 5 compares the physical impact score with the number of senses an exhibit engaged.



Figure 5. Physical engagement scores by the number of senses engaged

This graph shows the lowest score for an exhibit, 2.0, in the one sense column. The highest concentration of responses falls on exhibits that engage three and four senses, with scores of 4.0 and 5.0, respectively, reinforcing that exhibits with three and four senses have a higher potential for visitor engagement.

## 4 **DISCUSSIONS**

#### 4.1 Average ECP Score for all Six Senses

Figure One indicates that exhibits that engaged either the sense of taste or smell had a perfect emotional impact score of 5, suggesting a correlation between taste, smell, and emotional engagement. This high emotional response reflects research reporting that strong chemical and emotional responses triggered by taste and smell have evolved to safeguard humans against potentially harmful substances [8]. Other research suggests that increasing the number of senses within an exhibit allows visitors to experience exhibit content in a natural, understandable way–a way in which they are accustomed to experiencing their surrounding world [9]. Alternatively, exhibits engaging taste and smell were less common at DDW, and their novelty may have amplified their ratings.

High average ECP scores for all senses indicate the impact exhibits had upon the students collecting the data. As students experienced and evaluated different exhibits, they also critically examined various exhibit design components and informed their own design sensibilities.

#### 4.2 Combined ECP Scores of Exhibits Correlated with Number of Senses Engaged

Figure Two indicates a positive correlation between the number of senses engaged in an exhibit and its impact on the visitor. Thirteen exhibits engaged one and two senses and had lower ECP scores than the 28 exhibits engaging three and four senses with higher ECP scores.

Table One records averaged combined ECP scores according to the sense involved and ordered from high to low.

Sense	Smell	Taste	Touch	Sound	Spatial	Sight
Ave. ECP score	4.58	4.50	4.39	4.39	4.37	4.32

Table 1. Sense vs. Average ECP Score

These results indicate that exhibits engaging the sense of smell received the highest ECP impact score. Conversely, exhibits engaging the sense of sight scored the lowest. Notably, sight is the most frequently engaged sense (present in all 41 evaluated exhibits) yet received the lowest average impact score.

#### 4.3 Average ECP and Combined Score per Sense

Figure Six combines data from Figures 4, 5, and 6 and averages ECP scores by the number of senses engaged. The darkest green or rightmost bar in each sense grouping combines all ECP scores per number of senses. These combined ECP scores, starting at 3.88 for one sense, 4.17 for two senses, 4.24 for three senses, and 4.60 for four senses, verify that as the number of senses increases, so does the exhibit impact.



Figure 6. Average and combined ECP scores per sense

When observing individual E, C, and P scores, the three senses/cognitive score is the lone result diverging from the increasing pattern. This could be explained by visitors' resonating with exhibit content regardless of sensory engagement, or it could be errors in data collection. Further exploration into this anomaly uncovered research indicating the brain's ability to link knowledge and memories to sensory experiences, which increases cognitive activity [10]. Results on this graph affirm the researcher's initial hypothesis that a positive correlation exists between the number of senses engaged in an exhibit and the exhibit's impact on the visitor.

## **5 CONCLUSIONS**

This study aimed to expand perspectives on how sensory engagement impacts visitor's emotional, cognitive, and physical engagement with an exhibit. This study caused another immediate outcome: two of the student researchers to redesign their end-of-year exhibit. One student stated:

I once considered the senses of taste and smell irrelevant to my senior thesis project; this paper's findings have pushed me to find ways to engage those senses with my audience to increase exhibit engagement.

The data collection experience and findings outlined in this study could also be a helpful model for students and educators striving to enhance the impact and engagement of end-of-year exhibitions. Traditionally, design exhibits limit audience proximity and interaction by taking a vision-only approach to their content. Exhibits designed to incorporate smell, taste, touch, sound, spatial awareness, and sight, in that order, can transform casually observing visitors into engaged participants consuming an exhibit's content rather than merely viewing it.

#### ACKNOWLEDGEMENTS

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# BINDING AI AND XR IN DESIGN EDUCATION: CHALLENGES AND OPPORTUNITIES WITH EMERGING TECHNOLOGIES

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#### ABSTRACT

Our Design Program at Tec de Monterrey is progressively incorporating Artificial Intelligence (AI) tools, further enhanced by Extended Realities (XR), into our pedagogical practice. This innovative consolidation primarily improves the conceptualization stage of the design process. As students mature in their design intelligence, they harness AI to iterate and visualize alternatives, enriching their decisionmaking discussions with various project stakeholders. This led to the swift creation of physical prototypes across three distinct categories, each with their unique briefs. Vizcom AI emerges as the most utilized tool, a 2D-rendering platform that refines outputs based on initial sketches and user prompts. Complementary tools aid in navigating the convergence of design and technology education, including VR modelling, AR, and electronic systems simulation. Collectively, these technologies accelerate the design process. However, it is worth noting a consequent limitation in the development of basic analog design abilities, especially affecting the understanding of space and spatial intelligence. Students reported their learning experience with these technologies, along with their expectations and concerns. As we continue integrating these technologies into design education, we have identified the opportunity of leveraging VR to enhance spatial intelligence comprehension, while preserving AI's benefits. This study acts a base to develop new teaching and learning practices that support our students' professional future in an evolving design landscape with these transformative technologies.

Keywords: Extended reality, design, virtual reality, higher education, educational innovation

## **1** INTRODUCTION

#### 1.1 Current interest in virtuality and artificial intelligence

Over the last 10 years digital technologies have been evolving to adapt to the rapidly changing manifestation of virtual worlds. On this realm education plays a vital role in providing students with tools that can help them to solve projects by conceptualizing and prototyping. The arts and the sciences have been exploring the use of virtual reality (VR) making it more accessible [1] not only in academia but also in commercial and social contexts. Another aspect is the emerging use of artificial intelligence (AI) in everyday life. The increasing systemic connectivity of data, coding, and sophisticated devices to visualize and process images have created an improvement in learning environments [2]. Design disciplines are taking advantage of these technologies consolidating the profession.

#### 1.2 Design for XR y VR technologies

The design process for XR experiences introduces a range of unique considerations and challenges compared to the traditional design process, requiring specialized tools, testing methods, and a focus on creating immersive, spatially aware experiences for users. Table 1 compares several aspects of the design process in traditional and XR environments.

Aspect	Typical Design Process	XR Experience Design Process			
User Interaction	Primarily 2D interfaces	3D and spatial interaction			
Environment	Limited to physical or digital interfaces	Immersive and interactive environments			

Table 1. Comparison of the design process in traditional and XR environments

Tools	Traditional design software	Specialized tools for XR development				
Testing	Screen-based testing and feedback	Real-time user testing in XR environments				
User Experience Focus	Visual and functional aspects	Immersive experience and spatial awareness				
Iterations	2D mock-ups and prototypes	3D prototypes and immersive simulations				
Motion and Interaction	Limited to mouse, keyboard, or touch input	Gestures, gaze, and spatial tracking				
User Perspective	Observer perspective	User's own perspective within the XR space				
User Comfort Consideration	Limited to screen size and clarity	Consideration of motion sickness and comfort in immersive environments				

#### 1.2.1 Considerations for the design process

The use of XR is highly used in teaching design, but it also can be used in the design process in phases like virtual prototyping, immersive design reviews, interactive exploration, training, simulations, and client presentations. On the other hand, AI is even more used as part of the design process, like generative design, predictive modeling, writing with NLP assistance, image and style recognition, customization, prototyping, testing and the most used: image generation for exploration and iteration [3], as part of the design process.

#### 1.2.2 Platforms

Gravity Sketch is a 3D modeling software that revolutionizes the design process by enabling users to create immersive, three-dimensional experiences in virtual reality (VR). This innovative platform allows designers and creators to craft intricate models and concepts using natural hand gestures and spatial understanding, breaking free from the constraints of traditional 2D interfaces. With its intuitive and collaborative features, Gravity Sketch allows users to ideate, iterate, and visualize their designs in a truly immersive environment, redefining the boundaries of digital creation and opening up new possibilities for spatial design and prototyping.

Meta Spark Studio is a platform for crafting XR experiences, offering a seamless and intuitive environment for creators to build immersive content. It empowers designers and developers to bring their ideas to life in virtual and augmented reality. The platform's robust features enable the creation of spatially aware experiences, interactive environments, and lifelike simulations, fostering a new era of storytelling and user engagement. By providing access to advanced capabilities for spatial computing and sensor integration, Meta Spark Studio has become a tool for innovators looking to push the boundaries of XR design and deliver captivating experiences across a variety of industries.

FrameVR enables creators to craft immersive 3D environments with ease. The platform's emphasis on collaboration allows multiple users to simultaneously design and interact within the virtual space, fostering real-time creative exchange and reducing the barriers to teamwork. By providing a range of customizable assets, spatial design elements, and interactive features, FrameVR empowers users to bring their vision to life in a truly immersive environment, making it an invaluable tool for designers and creative teams seeking to create compelling virtual experiences.

Tinkercad offers, among its suit of functions, an accessible and user-friendly platform for simulating electronic circuits. Its intuitive interface allows users to seamlessly drag and drop components, connect them with virtual wires, and experiment with various circuit configurations without the need for physical components. Tinkercad's extensive library of electronic components enables users to simulate a wide range of circuits, from simple LED circuits to complex microcontroller-based designs. Additionally, its simulation feature provides real-time feedback on circuit behavior, allowing users to visualize electric properties and component interactions, providing a valuable learning experience for those looking to understand and experiment with electronics in a virtual environment.

#### 1.2.3 Generative AI for (product) design

Though numerous generative AI tools and services primarily concentrate on delivering enhancements and alterations to visually created content by humans, they frequently generate variations in visual style

rather than the concepts depicted in the image. Effectively exploring the design realm demands innovative thinking, originating from the exploration of significantly unique ideas. Nevertheless, these ideas are vulnerable to, and frequently shaped by, the designers' intuition, expertise, and predispositions regarding the subject [4] providing room for innovation.

Systems for translating text into images empower designers to swiftly convert imagined ideas into lifelike design representations within seconds. Yet, incorporating prompt engineering-driven design into business operations poses challenges due to the mentally demanding process of transforming designers' visual concepts into textual expressions. This transformation requires expressing intended meanings with clarity and recalling the specific design ontology acknowledged by the generative model. Consequently, this issue gives rise to text prompts that produce image depictions incongruent with the designer's envisioned visual concept, or vice versa, thereby necessitating considerable time for iterative prompt refinement until the desired outcome is attained Ben Hutchinson et al [5], seen as a new type of competences for design and engineering students.

## **2 LEARNING CONTEXT**

The experimentation with emerging technologies occurred in three different use cases with different briefs presented to Design students. All briefs led to the creation of physical prototypes, underlining the connection between the creating with and within digital tools for the physical world.

#### 2.1 Digital communication for products

The aim of this intermediate design course is for students to know and use digital representation and communication media in the different product design phases. General concepts of 2D and 3D digital representation and communication, and digital manufacturing of the product are included. No prior knowledge is required. The expected learning outcome is for students to execute the digital representation of a specific product in the different design phases for its integral communication. The challenge for the student was to create a toy model of herself, like the Funko Pop toys. The process took them across sketching, 3D modelling, 3D printing their toys, and packaging it. One condition was that they had to use AI during the ideation design process and for the rendering visuals.

#### 2.2 Technological integration

The aim of this advanced design course is for students to develop high added-value, technology-based innovation solutions. Prior knowledge is required of composition and representation, basic ergonomics, digital modeling software management, selection and use of materials, and basic graphic production and design processes. The learning outcome is for students to integrate viable technological design projects that are committed to client expectations. The challenge for students was to create new tools to connect the physical world with a VR environment used for industrial training. Students used AI to quickly ideate alternatives for an industrial partner to quickly make decisions that guided the design process to better fulfil the expectations.

#### 2.3 Emerging technologies and digital transformation

The aim of this advanced design course is for students to formulate competitive design proposals and management models for innovation. Prior knowledge is required of composition and representation, basic ergonomics, digital modeling software management, selection and use of materials, and basic graphic production and design processes. The learning outcome is for students to develop solutions by integrating Industry 4.0 technologies that generate industrial property. The challenge was to create AR experiences for children's stories. Along the process, students co-created with different AI tools and used AR tools to build and distribute the experiences.

#### 2.4 Intelligent materials

The aim of this advanced design course is for students to learn about intelligent materials, metamaterials, and biomaterials to visualize new product design opportunities. Prior knowledge is required of 3D printing and laser cutting, and the associated software. Learning outcome: Students conceive products by taking advantage of the responsive characteristics of intelligent materials so that they can be activated in specific circumstances to solve real-life problems. Students worked in the MAZDA Automotive Design Challenge, where they had to design smart cars using smart materials. One condition was that they had to use AI during the ideation design process.

## **3 EXPERIMENTATION, APPLICATION, AND EXECUTION FOR AI AND XR**

#### 3.1 Using Vizcom

Within the realm of creative ideation, students traditionally engaged in the generation of a series of manual sketches to delve into ideas, colours, volumes, and other design elements. This undertaking consumed approximately 8 hours, necessitating meticulous efforts to attain high-fidelity sketches and comprehend each facet of the diverse ideas or iterations they developed. In formulating a hypothesis, the proposition was made that the incorporation of artificial intelligence could enhance efficiency and expedite the completion time of this process. To test this hypothesis, students employed a generative AI framework. They integrated their preliminary sketches with a well-crafted prompt, and the AI took charge of rendering detailed images swiftly, thereby facilitating a more expeditious progression through the ideation process.

In the experience of working together with industrial partners, their expectation is to see the concepts and digital representations of potential solutions after 3 or 4 weeks of guided student work. For one of the educational experiences presented, students were able to present their first digital representations in just 4 days, aided by AI tools. This provided the industrial partner with greater visibility of the process which resulted in much better feedback for students. This impacted in greater satisfaction of both students and the industrial partner.

#### 3.2 3D Modeling to generate ideas

We use the software Fusion 360 for 3D modeling teaching. Here we apply AI for generative design, where students try different shapes to reduce material from the object aided with the AI. Younger students use AI to make renders from their 3D models, being able to change colour and materials faster.

## 4 CONCLUSIONS

The current advancements in Design Education emphasize the integration of new technologies, particularly artificial intelligence (AI), in various design courses. Students are now engaging in creating digital representations of products using 2D and 3D design concepts, digital manufacturing, and AI-driven ideation processes. This integration is exemplified in projects where students design personalized products, incorporating AI during the creative process. This integration extends to advanced design courses, highlighting the importance of technological assimilation and the application of industry 4.0 technologies, leading to high-value, technology-based solutions.

In addition to digital design and AI, Design Education is evolving to include the exploration of innovative materials. Students delve into the field of intelligent materials, meta-materials, and biomaterials, which necessitates a solid expertise in 3D printing and laser cutting. AI's role extends beyond ideation to 3D modeling, where software like Fusion 360 is used for generative design. Younger students are leveraging AI to streamline rendering processes, facilitating quicker experimentation with colour and materials.

Despite the significant strides in integrating digital technologies and AI in Design Education, a key challenge lies in maintaining the development of basic analog design skills. These skills, such as understanding space and spatial intelligence, are fundamental to design. Therefore, while the incorporation of AI and digital technologies is substantially enhancing efficiency, accelerating design processes, and fostering innovation, it is crucial to address this potential limitation to ensure a well-rounded development of students in the field. In summary, Design Education is rapidly evolving, driven by AI and digital technologies, but it is essential to maintain a balance with traditional analog design skills for holistic student development.

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# ASSESSING THE EYE GAZE BEHAVIOURS OF ILLUSTRATORS SKETCHING FACIAL EXPRESSIONS FROM OBSERVATION

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#### ABSTRACT

Sketching is a historical means of sharing knowledge and remains vital for communication across disciplines. Drawing translates mental images and experiences into visual knowledge and expression. Sketching education is steeped in tradition, but emerging digital technologies like eve-tracking glasses allow researchers to, for the first time, see through the eyes of illustrators as they work. This exploratory study uses eye-tracking glasses to measure head and eye kinematics, eye gaze quantity and duration, and production script order of novice and expert illustrators. It introduces terminology, high-fidelity measurement tools, assessment methods, and insights that could influence future drawing pedagogy. Eleven illustration undergraduate students and three instructors wore eye-tracking glasses as they drew facial expressions while referencing live models. Results uncovered four categories of head pitch and eye saccade kinematics and expert and novice gaze differences referencing the model and drawing paper. Experts rapidly gaze at the reference 3.5 times more than the novice who gaze longer and 3.0 times more often than the expert. Novices gaze at their paper for 59% of their drawing time, compared to the experts at 40%. Experts had 18 rapid (less than 1.0 s.) paper gazes, while novices had 8. All participants followed a similar product script, beginning with light construction lines for the head, face, nose, eyes, and mouth in varying orders, then adding darker contour lines, adding detail from the centre outwards. Participants returned to refine eye and mouth facial details 25 - 35 times. This study uncovers previously unseen bio-mechanical movements and observational drawing methods.

*Keywords: Eye tracking, drawing pedagogy, sketching research, head and eye kinematics, drawing gaze quantity and duration* 

#### **1** INTRODUCTION

Sketching is a historical means of sharing knowledge and remains vital for communication across disciplines. It facilitates the translation of mental images and experiences into visual knowledge, extending into diverse domains like design research and business strategies. In the digital age, sketching education continues to evolve, prompting discussions on purposes and processes [1], [2]. Emerging digital platforms for sketching have introduced a new means of generating and assessing visual experiences, consequently impacting teaching and learning. Traditionally, drawing pedagogy tends to assess outcomes rather than processes. However, instructors have begun to explore the benefits of evaluating and teaching through emerging technologies, such as eye-tracking [3], [4]. Eye-tracking has already been used to assess and improve performance in automobile driving and architectural CADD drawing [5], [6]. Our previous eye-gaze research studied pen, hand, and eye motions between novice and expert sketchers while drawing geometric forms from memory [7]. This exploratory study continues the research by assessing the drawing behaviours of novice and expert illustrators while drawing organic forms, or facial expressions, from observation. Traditionally, figure drawing is a core component of art and design training and incorporates observing live models. To avoid recording the models with eyetracking glasses, this facial expression exercise was selected. The study also introduces kinematic measurements of head and eye motion by quantity and duration and explores scripting order. We expect to define terminology, investigate high-fidelity measurement tools and assessment methods, and

uncover appropriate topics to explore. Comparisons between expert and novice illustrators should uncover pattern differences that could influence drawing pedagogy.

## 2 METHOD

Eleven undergraduate illustration students, the novices, and three illustration instructors, the experts, participated in the study. Ten students were female, and one was male, between 19 and 25 years old, with a mean age of 23. Two instructors were male and one female, between 35 and 43, with a mean age of 40. Tobii 3 eye-tracking glasses and software were used with Adobe Premier Pro to gather and assess data. Prescription eyewear is incompatible with the Tobii glasses and removed for the task. In the drawing task, a student modelled an exaggerated facial expression for a partner student to draw for three to five minutes, and then they reversed roles. Students selected their facial expressions and used their personal sketching tools and paper to draw. The study was conducted in a typical classroom, and all the participants remained in the room during the recording, which took about 1.5 hours. After researchers reviewed the recordings multiple times, metrics were determined through consensus and data was collected through manual observation and with software.

## **3 RESULTS**

## 3.1 Head & Eye Kinematics

The human head's six-dimensional motion and spatial orientation yield essential sensory information [5] to illustrators during observational drawing tasks. Head motions are classified as Pitch, or nodding up and down; Yaw, turning the head left to right; and Roll, or tilting or. rolling the head around at angles [6]. The human eye has four types of movements. This study only studies saccade movements, rapid eye movements that abruptly change the point of fixation between the reference face and the drawing paper. Saccades range in amplitude from small reading-like movements to large room-scanning movements [7]. Unmanipulated screen captures from the recordings provide visual examples of four different head/eye movement behaviours observed in this study.

#### 3.1.1 Fixed Pitch & Long Saccades (FPLS)

Kinematically, this participant (Figure 1) had a fixed head pitch with no yaw or roll movement; he rarely moved his head, and his eyes did all the movement while drawing.



Figure 1. Reveals a fixed head pitch and long eye saccades

His saccade amplitude between the reference model and the paper was some of the longest in the study. In Figure 1, the ceiling lights remain in the exact location in both images, while the red fixation circle, indicating pupil gaze, changes location significantly (long saccade movement).

#### 3.1.2 Short Pitch & Long Saccades (SPLP)

Kinematically, this participant displayed a short head pitch movement with long eye saccades; her head nodded some, but her eyes moved the most. Figure 2 shows a small change in the location of the background door top in relation to the image's top border. The location of the red fixation circle significantly changes (long saccade movement).



Figure 2. Reveals a short pitch head motion and long eye saccades

## 3.1.3 Long Pitch & Short Saccades (LPSS)

Kinematically, this participant displayed a long-pitch head movement with short eye saccades; her head nodding is amplified, and her eye movement is reduced.



Figure 3. Reveals a long pitch head motion and short eye saccades

Figure 3 shows the reference model cropped out of the second image and the gaze fixation trailing lines (thin red lines) start (the end without the red circle) in locations unrelated to the face or the paper.

## 3.1.4 Long Roll & Short Saccades (LRSS)

Kinematically, this participant displayed a long roll-pitch head movement with short saccades. This motion is like LPSS but angled and tilted. Figure 4 shows the reference model significantly cropped out of the second image and the distinct angle change of the drawing page and table.



Figure 4. Reveals long roll head motion and short eye saccades

# 3.2 Gaze Duration and Quantity

## 3.2.1 Gaze Duration of Reference Model

Novices (blue dots) spent between 23.71% and 35.41% of their time gazing at the reference model. The experts (red) spent between 27.52% and 35.96%, as shown in Figure 5. Indicating little difference between novice and expert behaviour.



Figure 5. Duration of novice and expert gaze at the reference model

#### 3.2.2 Gaze Quantity and Gaze Duration of both Reference and Paper

The total number of gazes and gaze durations on the reference and the drawing paper were graphed using the recordings from two experts and two novices. Figure 6 shows two of them.



Figure 6. Duration of novice and expert gazes at the reference model and drawing paper

The horizontal axis reports the number of gazes, and the vertical axis reports the duration. The blue area represents reference model gazes, and the red area represents drawing paper gazes. To assess performance differences between experts and novices, five different time segmentations were identified. The first and shortest segment spans 0.0 to 0.25 seconds (s), the second spans 0.26 - 1.0 s., the third spans 1.01 - 2.0 s., the fourth spans 2.01 - 3.0 s., and the fifth is 3.01 s. and longer. These segments are delineated by the four darker black lines crossing the width of the graph.

Figure 7 explores gaze performance within each time segmentation. The vertical axis shows the number of times participants gazed at the reference model and the drawing paper. The colour blocks represent the five different time segmentations.



Figure 7. Total assessed number and duration of gazes on the reference and paper

Figure 8 combines the expert and novice gazes at the reference model and drawing paper into averages. Experts had 21 reference gazes at durations less than 0.25 s (blue), while novices had 6, indicating that experts rapidly gaze at the reference model 3.5 times more than the novice. Novices had 23 reference gazes at durations greater than 1.01 s (yellow, green, and orange), while experts had 7, indicating that novices gaze longer at the reference model 3.0 times more than the expert.

Novices gazed at their paper 69 times for longer than 2.01 s. (green and orange colours) or 59% of their drawing time. In comparison, experts gazed at their paper 40 times for the same duration or 40% of their drawing time. Experts had 18 rapid, less than 1.0 s. (blue and red) paper gazes, while novices had 8, a difference of 2.25.



Figure 8. Total average gaze number and duration of reference and paper

Experts have more rapid gazes, less than 1.0 s., referencing the model and drawing than novices. Novices have significantly longer gazes, more than 2.01 s., referencing the model and drawing than experts.

#### 3.3 Production Scripts

Video assessments of three novices and two experts found they lightly drew construction lines for the head, face, nose, eyes, and mouth in varying orders. Then, they added darker lines to the eyes, nose, and mouth contours before addressing the outer face and hair contours. Details were made from the centre outwards. Participants typically paired features together symmetrically and returned often to refine facial details. Differences in construction order between novices and experts were not observed. Data indicates participants returned to refine the eye and mouth areas more than smile lines, cheeks, and ears, as shown in Figure 9.



Figure 9. The average number of times participants revisited portrait details

#### **4 DISCUSSION & CONCLUSION**

This study was experimental, exploring what and how to measure an illustrator's eye gaze during observational drawing. Observing an illustrator's gaze while they draw is an intimate glimpse inside their head that has not been researched. More data is needed to identify meaningful patterns, but terminology and methods to measure head and eye kinematics and assess gaze duration and count with high fidelity were defined. Exploring script construction exposed that illustrators frequently retouch the mouth and eyes while the nose is drawn early and not revisited, suggesting it is a utilitarian aid in building relationships between facial features.

This study indicates that gaze quantity and duration, when measured in seconds, differ between experts and novices, but it did not teach us why. Do gaze differences, head and eye kinematics, and scripting patterns make a difference in sketching performance? The study has laid a foundation that future studies can exploit. As more meaningful gaze behaviours are identified and defined, they should impact future classroom instruction.

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# UNDERSTANDING HOW UNDERGRADUATE STUDENTS PERCEIVE BIASES IN AI-GENERATED IMAGES, A RESEARCH-THROUGH-DESIGN PROBE

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## ABSTRACT

The speed and proficiency of generative Artificial Intelligence (AI) systems have proliferated in recent years, enabling more people, including design students, to use AI-generated images for their projects. However, it has been well documented that the Large Language Models supporting AI generators have incorporated troublesome gender, cultural and race biases during training. Undergraduate students, whose visual culture and critical skills are still in development, often lack the capacity to identify such biases in the images they obtain when using AI generators. This can lead to visual outputs that perpetuate prejudiced representations of people. To better understand the nature of this problem and potential ways to mitigate it, we conducted a design probe study on a group of first-semester undergraduate design students in Lisbon, Portugal. The results of this study can be used by teachers to guide their students better and researchers to develop methodologies to help younger generations identify biases in AI generative systems. The impact of this research extends beyond the classroom and can benefit other educators and designers of future AI generative systems. Most importantly, it can contribute to curtailing the perpetuation of race, cultural and gender biases in today's society.

*Keywords: AI-Generated images, bias in AI, undergraduate design students, design probes, research through design* 

## **1** INTRODUCTION

In the rapidly evolving landscape of AI techniques, the acceleration of ease and quality of automated media generation raises important concerns about the cultural biases we might perpetuate with these systems. The incorporation of AI-powered systems into a growing number of aspects of our lives requires a thoughtful examination of the ethical consequences that the automation of cultural tropes can have. The presence of potentially harmful biases concerning gender, race, age, and cultural background in AI-generated images has been well documented (Naik et al., 2023). These biases perpetuate harmful stereotypes, reinforce societal inequalities, and negatively impact marginalised communities. For instance, AI technology in the justice system demonstrates a clear bias towards black individuals when it comes to detecting and predicting criminals. (Angwin et al., 2016; Malik, 2023). The implications of bias in AI systems can reach beyond the digital interfaces, affecting real-world decisions and perpetuating social injustices.

The field of AI, specifically Generative Machine Learning methods, has undergone considerable progress in recent years, leading to systems with the capacity to produce a broad range of imagery, including hyper realistic images, that can be indistinguishable from photographs. It could be argued that this represents a progression from post-photography, as it challenges conventional photography by exploring the modern image environment filled with abundant images and information (Moreiras, 2023). However, several studies have raised concerns about the unintentional perpetuation of biases often found in AI-generated media. According to Feng et al. (2022), gender biases in image search results significantly influence people's perceptions and reinforce existing biases. In our study, we chose to investigate the views of college students at the undergraduate level, as they are consumers and possible participants in this changing technological environment.

While the creation, reproduction, and perpetuation of cultural bias in imagery have long been subjects of investigation in Sociology, Psychology, and Communication and Media Studies, they remain less explored in the context of AI-aided design education. Accordingly, our research starts with a comprehensive strategy, integrating qualitative and quantitative techniques to investigate how undergraduate students interpret negative stereotypes in AI-generated images. Integrating design probes into the research process enables us to connect theoretical discussions on AI biases with a practical understanding of how young users experience these biases (Gaver, 1999). Many individuals argue that young students may lack the maturity to comprehend and recognise biases, prompting a need to assess the validity of this claim. The results of this research contribute to scholarly discussions and real-world initiatives in the continuous effort toward ethical AI advancement.

# 2 BACKGROUNDS: BIAS IN GENERATIVE AI

Generative AI, especially deep learning models, has made impressive progress in producing content, particularly images. These mechanisms, powered by extensive datasets, are trained to imitate patterns and styles found within the data used for training. This learning procedure gives rise to concerns regarding the possible perpetuation of biases that exist within the data. Researchers have uncovered a complex connection between culture and gender bias in LLMs, revealing how training in diverse cultural settings may result in varying forms and degrees of biases (Zhou et al., 2023a). Generative AI image models can generate highly detailed and lifelike images but are still susceptible to reproducing and perpetuating societal biases.

AI biases can appear in various ways, such as gender, race, ethnicity, and cultural stereotypes. The most prevalent issue is gender bias, as shown in the research by Gorska et al. (2023), where 76% of images from nine popular text-to-image generators portrayed men. While some may contend that this simply reflects societal gender bias, research has demonstrated the prevalence of gender stereotyping in AI-generated images, as compared to human perceptions, particularly showing a greater degree of gender stereotyping within work-related settings (García-Ull et al., 2023). In general, two main kinds of gender bias have been studied. Representational bias pertains to the unequal portrayal of men and women in different media contexts, especially the over-representation of women in stereotypical feminine positions. Presentational bias involves reinforcing biases in a gender-stereotypical manner, such as women being more inclined to exhibit smiling, calmness, or pitch downward in female-dominated professions (Sun et al., 2023). As AI plays a growing role in shaping decision-making processes and moulding our digital interactions, it is crucial to understand and address these biases.

Nonetheless, there are other forms of biases that demand our attention. Recent studies have shown the existence of age bias in AI systems, indicating the need to also consider the viewpoints of older individuals (Chu et al., 2023). Cave et al. (2020) have also identified the predominance of whiteness in the racialisation of AI and its implications within critical race theory. The creators of these tools already recognise the issue, but resorting to a hasty fix, such as generating random images of people from various ethnic backgrounds, is also not an appropriate solution. Google's Gemini, for instance, was designed to display a variety of individuals but overlooked instances where such diversity should not have been shown, such as women holding the position of pope or black soldiers serving in the German army during WWII (Raghavan, 2024). While altering the databases and historical data used to train AI models may pose challenges, researchers, developers, and policymakers must take proactive measures to tackle these problems.

## **3 METHODOLOGIES**

The study centred on first-semester undergraduate students enrolled in a design program. As newcomers in the industry, these students bring a distinct viewpoint that is not influenced by extensive familiarity with design conventions. This may lead to more genuine responses to AI-generated images. Salminen et al. (2020) state that artificially generated facial images have numerous potential applications, such as creating data-driven personas, advertising, virtual avatars, and fashion. Therefore, students need to understand the biases that may be present in these types of AI-generated images. To maintain the students' interest in the research and gather optimal data, we opted for a design probe study. This approach provides an innovative method to involve young people in immersive environments by using inquiries (Matos et al., 2022). This approach also embraces unpredictability and vagueness, offering a technique for studying specific audience groups during the initial phases of research (Černevičiūtė et al., 2022). Given the potentially sensitive nature of the study's content on biases, it was crucial to

prioritise ethical considerations. Steps were taken to ensure participant anonymity and confidentiality at every stage of the research.

Participants in this research were shown a collection of AI-generated images specifically chosen to demonstrate different types of bias, including gender, race, and cultural stereotypes. In addition, every student was given a Design Probe task package containing a compact journal, cards featuring thought-provoking terms (such as impoverished individuals, substance abusers, migrants, etc.), a paper for composing a letter to the AI tool of their choice, and a set of guidelines. The diary was the central element of the collection, requiring participants to contemplate the four images that Midjourney creates when given a prompt each day for seven days and articulate their emotional response. Prompts were given to assist them in reflecting on and analysing the images, with participants being allowed to express themselves through writing or drawing while ensuring complete anonymity of their responses. This multimodal method sought to capture both overt and covert responses, revealing participants' conscious reactions and potential unconscious perceptions of bias in the AI-generated images.

A significant volume of data was collected through reflections recorded in personal diaries in reaction to biased AI-generated images, written responses on cards to provocative terms, and self-reflections following an attempt at creating a self-portrait with AI. Furthermore, the instructor conducted group discussions with the students to gather their perspectives as well as additional insights that might have yet to be included in their reports. After collecting data, thematic analysis and qualitative coding were used to identify recurring patterns, themes, and variations in the responses from participants. Due to the nature of the topic under investigation, we combined digital and analog materials. Digital probing methods allow for a more exploratory approach to uncovering contextual information and can provide subjective in situ perspectives that are frequently absent in broader studies (Koch et al., 2018; Megarry et al., 2023). This method enabled a comprehensive investigation into how first-semester design undergraduate students perceived, interpreted, and contextualised biases in AI-generated images.

# 4 INSIGHTS INTO BIAS PERCEPTION AMONG UNDERGRADUATE STUDENTS

The results of the investigation employing design probes with first-semester undergraduate students in design provide fascinating observations into the intricate realm of bias perception in images generated by AI. Contrary to initial assumptions, an important finding revolves around the students' capacity to recognise biases in the images they were shown. These students not only recognised the biases present in the images but also demonstrated an awareness of their own biases or those prevalent in society, aligning closely with Perry et al.'s (2015) proposal. The students who had no awareness of biases in the images also exhibited immature behaviour throughout the semester. It is possible that their limited experience directly impairs their ability to recognise both their own biases and those of others.

We gathered information from 25 students, seven male and 18 female, between the ages of 18 and 20. In analysing the data collected from the students' reactions to bias in AI-generated images (Table 1), several notable patterns emerged. The dataset contains the reactions of the students within a span of seven days, during which they evaluated one set of images generated with Midjourney per day. The first column indicates their gender, feminine or masculine, and each daily evaluation includes a binary indicator of whether the student perceived bias (left column) and a coded summary of their comments (right column). The final column aggregates the number of instances out of seven where each student identified bias. Notably, the data reveals that a third of the students-highlighted in red-either did not perceive any bias or identified it in only one instance, whilst more than a third perceived bias in 5 or more of the images. This suggests a varying degree of sensitivity to bias among the students, with some potentially lacking the critical awareness or tools needed to recognize biases in AI-generated images. While this consideration is significant for design students, it is imperative to cultivate a comprehensive understanding of how students, in general, respond to bias. This knowledge is essential for educating future generations with heightened awareness, ultimately contributing to the reduction of bias in society. Upon coding the responses to the AI-generated images, we identified nine distinct types of reactions to perceived biases. These codes are as follows: Feminism (F), Racism (R), Stereotype (S), Underrepresentation (U), Pity (Y), Image Quality (IQ), Props (P), Looks (L) and Other (O). Notably, students who perceived bias frequently commented on gender (F) and racial (R) biases, highlighting issues of stereotypes (S) and underrepresentation (U). In contrast, those who did not perceive biases tended to focus on the aesthetics of the images, discussing aspects such as image quality (IQ), the props used in the background (P), and the physical appearance or looks (L) of the AI-generated humans. This

differentiation in focus underlines the varied perspectives among students and suggests that those who are more attuned to bias are inclined to critique the underlying social implications, while others concentrate on superficial or technical elements of the images.

Gender	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Total
F	Yes	S	No	IQ	Yes	F	Yes	R, S	Yes	F, R	Yes	F	No	0	5/7
м	No	0	No	L	No	0	No	Y	No	L	No	L	Yes	0	1/7
F	Yes	F, R	Yes	U	Yes	F, R	Yes	R	Yes	F, R	Yes	F	No	Р	6/7
F	Yes	F	Yes	U	Yes	F	Yes	R, S	Yes	L.	No	L	No	S	5/7
F	Yes	F	No	Y	Yes	F	No	Y	Yes	F, R	Yes	R	Yes	R	5/7
м	N/A														N/A
F	Yes	F	Yes	S	Yes	F	Yes	R, S	Yes	L	Yes	F	Yes	R	7/7
F	No	IQ	No	IQ	No	IQ	0								
F	Yes	F, R	No	Y	Yes	F, R	Yes	R, S	Yes	S	No	L	No	Р	4/7
М	No	IQ	No	IQ	No	IQ	No	0	No	IQ	No	IQ	Yes	0	1/7
м	Yes	F, R	Yes	S	Yes	F, S	Yes	R	Yes	F, R	Yes	U	Yes	R	7/7
F	Yes	F, R	Yes	S	Yes	F, R	Yes	R, S	Yes	F	Yes	U	Yes	R, S	7/7
F	Yes	F	Yes	S	Yes	F	Yes	S	Yes	S	Yes	S	Yes	S	7/7
м	No	0	No	IQ	No	IQ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	No	IQ	No	Y	No	Р	No	0	No	L	No	IQ	Yes	R, S	1/7
м	Yes	F	No	IQ	Yes	F	Yes	R, S	Yes	F, R	Yes	R	No	IQ	5/7
F	Yes	F	Yes	S	No	Р	No	IQ	No	IQ	No	IQ	No	Р	2/7
F	Yes	F	Yes	R	Yes	S	Yes	R	No	0	Yes	F	No	P	5/7
F	No	IQ	No	IQ	Yes	F	No	IQ	Yes	F, R	No	IQ	Yes	R, S	3/7
F	No	IQ	No	Y	No	IQ	No	Y	Yes	F	Yes	F	Yes	R, S	3/7
F	No	IQ	No	IQ	No	IQ	No	L	No	IQ	No	IQ	N/A	IQ	0
F	No	IQ	No	Y	No	IQ	No	Y	No	L	N/A	N/A	No	IQ	0
F	Yes	F, R	Yes	R, S	Yes	F, S	Yes	R, S	Yes	F, R	Yes	R	Yes	R	7/7
F	N/A														N/A
м	No	IQ	No	Y	Yes	Р	No	L	No	L	No	L	No	Р	1/7

Table 1. Data that shows students' reactions to bias in AI-generated images

In general, the images that students found to be most biased were those depicting gender representation, according to Figures 1 and 2. This perception was predominantly observed by female students, while male students exhibited the lowest level of awareness towards biases present in the study. However, this idea is familiar, as fMRI research has demonstrated that individuals process information from members of their own group and those outside it in distinct ways, impacting how they perceive and interact with ingroup and outgroup members (Molenberghs et al., 2018). It is natural for students to encounter challenges when recognising biases from social groups that are different from their own to some degree. Moreover, some students who expressed negative views towards at-risk communities, such as immigrants, remained oblivious to any prejudices in the images presented to them, thereby confirming the assertion made earlier.

A notable discovery was that students are reluctant to use AI to generate images. We received feedback such as "You can perceive that AI has a lot of stereotypes," "Everyone looks the same," etc. They argue that the images contain numerous imperfections, fail to depict reality accurately, are presented without proper context, and perpetuate stereotypes and preconceptions. Once more, this appears to be a prevalent response observed in individuals, as they often exhibit heightened sensitivity towards AI's inconsistent performance and tend to make harsher judgments regarding the fairness of AI decisions compared to their assessments of human experts (Jones-Jang et al., 20220), as well as a general preference for human-made art or images than AI-generated (Zhou et al., 2023b). However, they will encounter AI-generated images, so it is crucial for them to grasp the prejudices that may be present in such images.



Figures 1. and 2. Images created with Midjourney on December 2023. Prompts: A doctor (left), CEO (right)

## **5 CONCLUSIONS**

The results from a study using design probes showed that new undergraduate students in a design course were able to identify biases in the AI-generated images they were shown. Contrary to the initial expectations, most students not only recognised biases but also demonstrated an understanding of their own biases and those that are common in society. Female students, especially, were noted to be more sensitive to gender representation biases in comparison with their male classmates. The study emphasised the significance of taking into account some students' limited exposure and potential lack of maturity in identifying biases, underscoring the necessity for enhanced support in educational environments. The research also revealed that students were hesitant to utilise AI for producing images due to worries about flaws, absence of context, and reinforcement of stereotypes. Overall, the study provides significant findings that can assist educators in supporting students and shaping the design of approaches to increase understanding of biases in AI-generated content.

In the future, we aim to replicate this study with students from various classes. This will allow us to gather a greater volume of data and enhance the quality of the study. As anticipated, some students did not fully complete the exercise, resulting in our analysis being based only on complete data. This study is part of a PhD research on AI bias. The data collected in this experiment will serve as the foundation for developing a model to instruct present and future designers about bias in AI-generated media. By fostering a new wave of designers with advanced technical skills and deep ethical awareness, we can lay the groundwork for a future in which AI technologies are created, analysed, and employed with an increased emphasis on accountability and diversity.

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# ENHANCING RETENTION IN MECHANICS THROUGH THE IMPLEMENTATION OF PRODUCTIVE FAILURE DIDACTICS

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#### ABSTRACT

With the introduction of the new bachelor in 2021 all courses underwent a revision to promote, amongst other, an autonomous learning attitude. The conventional approach of teaching engineering relied on direct instructions and problem-based learning and proved to be inadequate, as students struggled to apply their engineering knowledge in capstone design projects.

To align with the new approach and to increase the application of engineering in capstone design projects, "productive failure" was introduced as a new didactical approach within our first-year course, Understanding Product Engineering. The approach engages students in active problem-solving, with the goal to increase the retention time of the theoretical concepts.

To evaluate the retention time of engineering knowledge, we developed a test to measure students' retention time over the different cohorts after one year of the first-year engineering course. During the second-year engineering course we started with an in-class formative entrance-test. An online multiple-choice test was created using questions mirroring those from the first-year final exam. 245 students performed this test, of which 16% were repeaters, and 11% transitioned from the previous bachelor programme.

The retention of knowledge reduces with each cohort, but some knowledge more than other. Especially questions with a lower Bloom's level seem to stick more. When going to higher level questions we see a decrease in retention over all cohorts. We also notice that students from newer cohorts seem to be more confident in answering higher-level questions while making as much mistakes as the other cohorts. This could be an indication that students are more confident to try even knowing that they might fail.

*Keywords: Autonomous learning, productive failure, direct instruction, retention, product engineering, engineering mechanics* 

## **1** INTRODUCTION

With the introduction of the new Industrial Design Engineering (IDE) bachelor in 2021 all courses underwent a revision to promote, amongst other, an autonomous learning attitude [1]. The conventional approach of teaching engineering relied on direct instructions and problem-based learning and proved to be inadequate, as students struggled to apply their engineering knowledge in capstone design projects. To have an insight of the application of our taught engineering topics we send out a questionnaire to the coaches from the bachelor capstone project (Design Project 5, IOB6-1). We had 8 responses from the coaches which reflect the work of about 80 to 90 bachelor students. Based on the results from this questionnaire, none of the student's showed any reference to mathematics, and few to mechanics, materials, and manufacturing processes in their final report (figure 1). The cause of the low referencing of engineering knowledge in student's capstone projects is diverse and depends amongst others on the student's interest in engineering and the background of the coach who guides the student. Other causes could be the lack of confidence of the student in applying engineering knowledge, or the retention of this knowledge over time.

To align with the new bachelor's approach in autonomous learning and to increase the application of engineering in capstone design projects, "productive failure" [2,3] was introduced as a new didactical approach within our first-year course, Understanding Product Engineering (UPE, IOB1-2) [4]. Productive failure flips the traditional learning process and starts with an explorative problem which students cannot solve without the right knowledge. This is followed by an instruction explaining the

missing concept. The approach engages students in active problem-solving, with the goal to increase the retention time of the theoretical concepts. We have developed our education around this using our inhouse developed framework [5] which includes lectures, workshops, and instruction videos facilitating the seamless integration of this approach into our own courses and to disseminate it among our academic peers. As an example of our approach, students are given a problem involving a system of equations without prior instruction on how to solve it. They brainstorm solutions using their existing knowledge for 10 minutes, where they most likely will fail. After this, the tutor reviews their ideas and teaches the necessary mathematical methods (like the substitution method or using row operations in an augmented matrix). Then, students solve a similar problem to apply their newly acquired knowledge. This process activates their thinking, creates a need to learn, and builds confidence. The initial struggle helps retaining the concepts.



Figure 1. Overview of different engineering topics applied in capstone projects (n=8 coaches, who coach around 80 to 90 students)

Based on different literature [6-9] productive failure seems to increase the retention time but is not tested in the context of a whole engineering design course. We aim to see how well and what the second-year students remember what they learned in engineering during the previous year. For this we developed a formative Retention Time test (RT test) which is commenced during the first lecture at the follow-up course on Product Engineering, one year later. This paper will present our first formative retention-time test, the test results, and our conclusion which can be drawn on the possible retention time of our approach.

#### 2 METHOD

During the kick-off lecture of the second-year follow-up course of Product Engineering (PE, IOB3-5) we started with a half-hour in-class formative entrance-test. This RT test was based on the final three-hour summative exam of the first-year course UPE, which took place the week before on November 8, 2023. 6 out of 10 exam questions were transformed from open questions to an online multiple-choice test, and the test was created in Microsoft Forms.

Before commencing the RT test, students were instructed to approach it with utmost care. All students in the course were seated in a large lecture hall. They were advised to maintain silence throughout the test and to complete it seriously, avoiding speculative answers. Before the start of the test students were informed about the research and asked whether they anonymously want to contribute to the research. Because the test was administered anonymously, we started with general questions which gives us insight in the year they started the first-year engineering course UPE and how well they did on its exam. After these general demographic questions students were given 6 questions mirroring those from the first-year final exam. Figure 2 shows one of the exam questions and the mirrored RT test question. Besides answering the questions students always had the opportunity to tick off the "I don't know" (in Dutch: "ik weet het niet") box without consequences.

The RT test consisted of 6 multiple-choice questions concerning subjects about:

- 1. Memorising manufacturing processes: consisting of 5 true or false statement on Shape Rolling and Die Forging.
- 2. Understanding of free body diagrams: consisting of nine optional Free Body Diagrams related to a stepladder against a wall.
- 3. Applying of mechanics of materials: where students had the choice between three beams with different cross-sections (rectangular, square, and round) made from three different materials (softwood, PVC, and low-carbon steel), and choose the option with the smallest elongation.
- 4. Understanding internal forces: consisting of four potential shear force diagrams related to a beam under load.
- 5. Understanding internal stressed caused by external forces and moments: where students had to calculate the internal shear stress and choose between 5 optional ranges (see figure 2).
- 6. Analysing materials: where students had to determine which material (HDPE, PP, PLA, or ABS) a product is made of based on the results of two experiments (buoyancy test and the tensile test).



Figure 2: Comparison of the exam question (left) mirrored in the multiple-choice RT test (right)

## **3 RESULTS**

The RT test was executed with 282 students, of which 245 indicated they were willing to contribute to the research. 73% (178) of these students were second-year students who have started their IDE bachelor the year before in 2022, 16% (39) were repeaters and started in 2021, and 11% (28) were students which transitioned from the previous bachelor programme and started before 2021. This latter group has never taken the first year UPE course and serve as a control group. They followed three separate courses on materials, mechanics, and manufacturing, not using the productive-failure didactical approach.

Figures 3 and 4 show the results of the RT test. The numbers are given as a percentage of the different cohorts, to make them more comparable. Figure 3 shows the grade for the students' last UPE exam or last Statics exam. For all cohorts it shows a similar distribution, where for every cohort approximately 40% has received a sufficient grade between 5.5 and 6.9. Figure 4 shows the results of the RT test, which shows a decrease in retention of the taught knowledge over the years. Most of the "before UPE" cohort finished the test with 1 out of 6, while most of the students from cohort 2021-2022 received one point

more and that of cohort 2022-2023 even two points more. This might be an indication of loss of retention over time but does not say there is causal relation between the didactical model and the retention of knowledge.



UPE or Statics exam for the different cohorts

Figure 4. The results from the RT test for the different cohorts

On average the score for the test was low, with an average of 2.6 out of 6.0 points. Most points were scored on questions concerning single-concepts like manufacturing (Q1) and free-body-diagrams (Q2), see figure 5. Questions which need more procedural thinking steps like the questions on mechanics of materials (Q3) and analysing materials (Q6), or those who need more abstract and conceptual understanding like the questions on internal forces (Q4), internal stresses (Q5) are more difficult for students to retain or recall the approach.



Figure 5. Results per questions for all cohorts

Figure 6 shows the results per question grouped per cohort. The difference per cohort for question 1 is not apparent. For question 2 we notice a decrease in wrong answers, where the newer cohorts scores better than the older ones. For both questions 3 and 4 the cohort 2022-2023 scores better than the other two. Less students ticked of the "I don't know" box, which might indicate they still recall parts of this concept but do not know how to approach it. Question 5 seems to be the most difficult question noticing the high number of "I don't know" ticked off. From the group who did answer this question, the students from cohort 2022-2023 shows the highest percentage of correct answers, again possible indication for recollection but not knowing how to approach it. For question 6 the number of wrong answers is the same, but most of the newer cohorts scored better on this question.



Figure 6. The results grouped per cohort for all six questions

## 4 **DISCUSSIONS**

Our research has limitations due to the educational setting. It is not possible to have a control group of students in the same cohort without the productive failure approach. All students follow the exact same UPE course and there is no identical UPE course at another university for comparison. Students volunteer to participate and do so anonymously to protect their personal data. Therefor we were unable to use data from the university grading system. We did have a unique situation because of the cohort mix entering the PE course. Cohort 2020 did not follow UPE-productive failure course and cohort 2021 and 2022 did have UPE-productive failure course. Which means we can compare these different cohorts where the "before UPE" cohort could serve as control group.

Our research also has limitations on contextual factors. The test was conducted in a lecture hall instead of an exam hall which could result in cheating, not everyone brought literature or had software available to consult during the test, the questions used in the test are a conversion from open questions to multiple choice questions, and the test was formative which could result in less serious participation or choosing the "I don't know" option.

During the UPE course of 2021-2022, several student groups were instructed by teaching assistants instead of teachers. Although teachings assistants and teachers received the same briefing, it could result in a different knowledge transfer. During the course run of 2022-2023, the direct instructions of knowledge by teachers and teaching assistants were replaced with prerecorded video's, to provide all students with equal instruction. In addition, coaches were better instructed in the productive failure didactic approach. The cohort 2023-2024 received a comparable course as the cohort 2022-2023.

## **5 CONCLUSIONS**

We see on average no difference between the cohorts on their exam grade, but the decrease of retention overall is present. Some knowledge retains longer than other. Lower levels of learning in the Bloom's taxonomy [10] seems to stick for longer, than higher up levels. The question concerning manufacturing is on the lowest Bloom's level Memory which seems to be the most constant over the years. When going higher up in the Bloom's level we see a decrease in retention, especially on questions concerning Bloom's level of *Understanding* (question 4 and 5), and on the level of *Analysis* (question 6). We notice that the newer cohort students are more confident to answer these questions but make as much mistakes as the other cohorts. This might be a possible indication for recollection but not knowing how to

approach it. This could also be an indication that students are more confident to try even knowing that they might fail.

#### **6 RECOMMENDATIONS**

The results from this test are not significantly valid to draw thorough conclusions, therefore we need more information and longer-term tests to see if there is a trend towards longer retention over the different future cohorts. We propose to do a longitudinal test to see whether students recall knowledge and skills. We therefor propose to repeat the RT test annually serving as longitudinal study of our engineering education to continuously assess and improve our didactical approach within the course, and possibly the engineering learning line in our bachelor. For this, we will devise one yearly online test which will be used in the first year and second year engineering course. The first-year test will be introduced as a formative pre-exam test in week 9 of the UPE course, where the second-year test will be introduced as formative entrance-test. With this we will be able to make a better comparison of the results on the retention, leaving out the quality of questions as a variable.

To research the application of engineering in the capstone project more thoroughly we propose to do qualitative research on the final reports of bachelor graduate students over the past 3 years and the upcoming year, including students who did not follow the new bachelor.

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# EXPLORING FIRST YEAR INDUSTRIAL DESIGN STUDENTS' UNDERSTANDING OF SUB-TOPICS IN DESIGN THINKING

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# ABSTRACT

This study reports on what tool and methods design major students use to discover, define and solve design problems. The site of this study is Design Thinking and Methods, a compulsory course for first-year Chinese design majors. The teaching goal of this course is to cultivate students' design thinking practice and innovation ability. Firstly, this paper reviews the definitions of design problems and design thinking through literature. Secondly, it outlines students' understanding of design thinking and design problem solving. Then these concepts are analysed to explore similarities and differences among 220 students. Finally, students design project are classified in relation to students' attention in different stages of design activities. The study found that most students can find design problems, but often they are unable to identify the nature of the design problems, which then leads to inappropriate design solution.

Keywords: Creativity, ill-structure problem, design thinking, design method

# **1** INTRODUCTION

## 1.1 Research background

Although, it is argued that creativity is an important element to achieve a successful design solution, Youmans [1] suggests that designers' mindset may prevent them from realizing their innovative potential. This is in line with Wu's [2] argument that the design major freshmen might be confused and have cognitive difficulties when facing complex design projects. As the phenomenon of students' cognitive difficulties is not unique, it does require teachers to continuously reflect on how students complete design activities in the learning process. According to Ye [3], most teachers in China ignore developing abilities such as curiosity and dealing with a confusion which are important elements of the design thinking mindset. This study aims to better understand what elements of design thinking design students use to find, define and solve design problems.

## 1.2 Research objectives and methods

In order to understand students' understanding of design knowledge and their ability to solve practical design projects, the empirical research explored first year design students use of design tools and methods during a design studio project in the course of Design Thinking and Methods taught by one of the authors. The course is set in the second semester of the freshman year. This is the first design course that combines theoretical teaching with task-driven design.

This study is informed by data collected over the three years from September 2021 to November 2023. The curriculum and teaching content stated the same over this three-year period. A total of 220 students were surveyed. During the course the students were allocated to 12 design student teams comprising of 5 to 6 members. Prior to this course, the students completed basic design courses, and thus were familiar with basic professional design skills.

# 2 UNDERSTANDING DESIGN THINKING

## 2.1 Design process model guided by design problem

Bravo and Bohemia [4] used the design process model as a teaching tool, defines the learning objectives and activities at each stage, contributes to the generation of design professional culture, and helps teachers and students to form common values and promote the solution of design problems. The Double-Diamond proposed by the UK Design Council [5] suggests these four design stages: i) Discover (diverge), ii) Define (converge), iii) Develop (diverge) and iv) Deliver (converge). Brown et al. [6] mentioned that divergent thinking and convergent thinking overlap in the three stages of Inspiration, Ideation and Implementation in the design process, which is reflected in the different design methods and tools used in the design process. These two design thinking models embody the integration and innovation of design thinking and design cognition. As mentioned by Wynn and Clarkson [7], the motivation for studying design process models is that they "represent" how design practice is conceived. Therefore, combined with the focus of the two thinking models, this paper puts forward a design mode dominated by design thinking, as shown in Figure 1, which takes design problems as the core in the course and carries out design practice with real project design. Focus on exploring students' concerns at different stages of design activities.



Figure 1. Design thinking model guided by design process

## 2.2 Students' understanding of design thinking

In the face of ill-structured problems, students need to use different design tools and methods, systematically evaluate and discuss proposed ideas, cross-experiment divergent thinking and convergent thinking, and repeat iterations to come up with creative ideas, so as to solve the design dilemma. To provide formative and summative feedback to students, it is essential that lectures understand how students understand design thinking and its application.

Over the three years, a total of 220 students responded to the question "What is design thinking?". However, 16 students' responses were excluded as they described information which was unrelated to the problem. Therefore, 204 valid text responses related to the problem were evaluation. The responses were pre-processed by LDA (Latent Dirichlet Allocation), a topic model of text semantic analysis, and sorted by frequency, as shown in Figure 2.

According to the collected data, the students mentioned a total of 18 terms. The data indicate that students associated solving problem, creativity, and defining problem and meeting the human needs with the Design Thinking. In the class, students were encouraged to exercise divergent thinking and convergent thinking through the use of different design tools, such as mind mapping, brainstorming, etc., so as to use methodology and innovative methods to promote creative thinking to solve complex problems. In this process, students demonstrated that they were able to establish empathy with users, conduct user-centred interviews with users, sketch users' journeys, understand users' needs, and pay attention to users' feelings. This would suggest that students should have developed some understanding of design thinking, but students paid a little attention to the final testing phase of the design process, as illustrated by Figure 1 (stage 4 Deliver). The stage is important to verify that the design is feasible and reasonable.


Figure 2. Keyword frequency distribution table

#### **3 CURRICULUM DESIGN PRACTICE**

Bohemia et al. [8] mentioned that learning assessment can provide a useful conceptual framework for more general teaching practice and students' learning experience. When students assume the dual design roles of client and designer, they can complete self-evaluation and improve their learning ability. Therefore, in the practical stage of the course, over the three years, 36 design teams were required to complete the final design project of the course on the theme of "Looking for Design Problems existing on Campus'.

During the practical phase of the design project, students assume the dual roles of clients and designers. The practical design component of the course lasted for 3-weeks and it incorporated these four dimensions of: problem finding, problem definition, problem solving and investigation methods. Figure 1 shows inspiration throughout the process of identifying and defining problems. Crilly [9] pointed out that designers often get stuck in design fixation in the process of finding and defining problems. In order to understand how students discover and define problems, it is necessary to clarify how students choose and use design tools, which is also the reason to investigate what tools helps students with deploying use divergent thinking, as shown in Figure 3.



Figure 3. Design tools used by students

The data collected over the three years indicate that 21 design teams used mind mapping, 8 design teams used brainstorming, 3 design teams used both mind mapping and brainstorming tools, and the remaining 6 design teams did not use any of the specified design tools (e.g., card sorting, story boards, etc.). In addition, when investigating the willingness of students to participate in team cooperation in design practice, data from interviews with students showed that most students prefer to think from an individual perspective rather than explore the issues together with the team members, which is not conducive to promote the collaboration between design team members. As different students have different abilities and enthusiasm to participate in design practice, the division of labour in teams varies greatly. It was difficult for the students to delve into whether the design problems the team found needed to be addressed.

Data collected from the 36 design teams indicate that they have manage to identify design problems which could be allowed to 7 topics (see Figure 4), among which the most concerned problems for the students were the old campus public service facilities, unreasonable layout and hidden safety risks of campus roads, all these problems represent an imbalance in the interactive relationship between "people" and "products", indicating that students paid more attention to the perception of people in the space. Although these identified problems cannot represent the attitudes of all teams studying, living and

working on campus, students have not fully verified whether the problems of seven different themes are real and need to be solved, but nevertheless it demonstrates that students have the ability to find problems. During the course a few students tried to shift their focus from "products" to "people". For example, some roads on campus cannot meet the needs of disabled people. Thus, they tried to create a sustainable social relationship on campus in a new way while meeting the needs of some teams on campus.



Figure 4. Design problem topics

Sarkar and Chakrabarti [10] mentioned that in the field of design, it is crucial to generate creative ideas and perspectives based on a common understanding. Therefore, the design process requires scientific research methods. Figure 5 summarizes the survey methods used by different design teams in the process of defining problems and proposing design schemes. Although the students belong to one of the target user groups, it was surprising that majority of the students, design teams (n=33) chose internal discussion, and only 2 design teams used questionnaire, and only 1 group used interview as to gather users' data to inform their design solutions. This indicate that most students have difficulties in choosing suitable research methods. The 3 design teams which either used interview or questionnaires to complete the field investigation, however, did not give comprehensive consideration to the determination of research objects, question setting, data collection and other contents, which indicates that students need systematic learning of the research methods.



Figure 5. Research methods used by students

During the next design project stage, 16 design teams drew design sketches and proposed detailed solutions to the problems raised. However, due to the differences in communication and investigation methods of the design teams in the early stage, the completeness of the works presented by different design teams varied greatly. For example, 3 design teams focused on the needs of people with disabilities on campus and proposed optimization suggestions for related issues, but they did not conduct research on the target groups. Instead, they chose to discuss within the team and try to meet the needs of disabled groups through association. This approach contradicts the concept of " Meet the human needs " and "building empathy with users", which is the core of design thinking repeatedly mentioned by students (Figure 2). Poggenpohl and Sato [11] believed that reflective activities urge designers not only to improve the making of things, but also to improve the impact of things on the larger context (the audience, environment, materials or social culture), as it forces designers to think not just about how an object looks, but how it is experienced. As we move from design as merely a material activity to design as an experiential activity, it is crucial to focus on the design object itself. In this study, the 16 design teams submitted sketches which unfortunately have not indicated that students engaged sufficiently in reflective practice. Although students used different design tools and research methods to define the design problem, they still chose to change the shape, location, material, height or colour of the original item to optimize the product, or to create a new product in an attempt to alleviate the existing design problem, as shown in Figure 6. One of the design teams identified a problem of students using drawing tools which made their hands dirty, and thus the students were unable to open doors with clean hands. In consultation with the design team, they designed a doorknob that uses an arm to open the door with the help of the handle. However, the students did not consider whether the product design is reasonable

in the given environment setting, and whether they could have solved such problems in ways, such as continuous reflection: Why can't we use our hands to open the door? What kind of method can help us use our hands to open the door? Do all the students in the classroom have this problem? Whether students need a new tool to open the door, etc., students have not demonstrated a deep understanding of the target users' needs, and they were unable to reflect on the problems found in a deeper level, so that they were unable to realize the idea in more creative ways.



Figure 6. Door accessories

Designers have to start thinking about the usability of design by reconstructing the experience to get more alternative design approaches. Just like designing an environmentally friendly coffee cup, in the market, a large area of plastic and paper made of cup body and cup holder, when discussing how to optimize the product, designers often shift the focus of the design problem to the plastic itself has harmful, non-degradable defects, so as to choose other materials with environmental protection properties to replace the plastic, and rarely pay attention to whether the material itself has environmental significance. From another perspective, most plastic is made of petroleum, although it can't be degraded, but it can be compressed and recycled into other products that can be used in life (such as hangers, umbrellas, clothes, etc.), Paper is made of natural materials such as wood and bamboo. However, due to the composition of paper and other material used to make the cup waterproof, beverage paper cups cannot be recycled for reuse, The high cost of use will inevitably lead to large-scale waste of natural resources. In this way, "plastic cups" seem to be more environmentally friendly than "paper cups". Students often lack such critical reflection to explore these sort of design problems.

#### 4 **DISCUSSIONS**

In summary, the performance of the 36 design teams in different stages of the design project is shown in Table 1.

Stages	Performance
Discover problem	Design tools were used in 33 of the 36 groups
Define problem	36 groups came up with 7 different design themes
Solve problem	16 out of 36 groups presented design sketches and schemes
Research methods	All 36 design teams used research methods, but students had cognitive difficulties in choosing the right research method

Table 1. Performance of 36 design teams at different stages of design activities

Saunders et al. [12] mentioned that selecting appropriate research methods is important for understanding and expanding knowledge in the research field, and research methods can reflect researchers' views on the relationship between knowledge development process and acquired knowledge. Although all the 36 design teams used different research methods to solve design problems (Table 1), from the information shown in Figures 4 and 5, it can be seen that students demonstrated a poor awareness of research methods. For example, only a limited number of design teams tried to use different research methods to understand the needs of users. However, even teams which attempted to engage with design research struggle to identify the target users and then to collect the information meant that the data results were not ideal, which indirectly led to the failure of the design process to identify the suitable solutions.

Secondly, when solving design problems, students needed to accurately locate the audience of design problems. While establishing empathy with target users, they also need to actively promote the stakeholders of design projects to participate in the research, so as to deeply understand the common needs of different stakeholders. Team members need to evaluate and plan different stages of the design, reflect on and criticize the internal logic of things through divergent and convergent thinking, and realize creative ideas through continuous experiments and verification. Yang [13] pointed out that Chinese

students are generally less creative in solving specific problems. This study also confirmed the similar phenomenon, which may be related to students' lack of comprehensive application of knowledge and deep reflection on complex problems. Only relying on their own design experience or discussions among teams cannot completely solve the problems in design, which requires students to have a forward-looking vision and social responsibility and change the focus of design from producer-centred to user-centred, and the production mode to service mode.

Finally, when considering the design scheme to solve the problem, it is still necessary to reflect on the nature of the design problem, explore the potential opportunities of the problem, and evaluate whether the preset solution can produce positive social, environmental and economic effects, so as to better improve the experience of target users and the positive feedback of the society through innovative and critical thinking.

#### **5 CONCLUSIONS**

This study focus was on the ability performance of industrial design majors in the freshman year and could not represent the design ability of students in all course stages. The research results indicate that although the novice design teams struggle to complete design project, all the students have the ability to find problems. The data also indicate that the students struggle to make a good use of design knowledge when defining and solving problems. The collected data is limited to verifying the design of product optimization. This study points out different forms of confusion in the design process of novice design teams formed by students. Therefore, this study also suggests that more scholars should further explore whether design thinking and methods courses can help cultivate students' creative thinking, and at the same time provide new course reform directions and reference suggestions for design educators.

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### THE POTENTIAL OF DESIGN WORKSHOPS' ICEBREAKERS IN THE POST-COVID ERA

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#### ABSTRACT

Design workshops involve individuals from different backgrounds such as researchers, designers, government officials, students, and those with disabilities. Icebreaking is a method frequently employed by workshop organizers to foster rapid acquaintance among the diverse participants from the onset to the point of facilitating collaborative teamwork. This study delves into icebreaker techniques across three types of design workshops conducted domestically in Japan, and internationally. Icebreakers of face-to-face, online, and hybrid workshops are analysed by comparing their communication methods, proactive or cooperative engagements, and emotional perspectives. The objective is to explore icebreaking methodologies from past workshops and identify their impact in post-COVID design workshops. This research can also evoke students' concern for social issues and their sense of responsibility through online teaching even after the epidemic.

Keywords: Design workshop, icebreakers, design method, post-COVID

#### **1 BACKGROUND**

Design workshops are typically participatory workshops based on design thinking, where participants from diverse backgrounds take up a local issue and work in teams to propose a design solution over a period of two to five days. In these workshops, the participants are diverse, including researchers, designers, government officials, students, and people with disabilities. Icebreaking is a method often used to help participants get to know each other quickly from the initial meeting, until they start creating together as team members. Imamura states icebreakers consist of elements such as self-introduction, recognition of others, and collaborative work [1]. He describes icebreakers as playing the dual role of dynamite that breaks through the rigidity of a group, and as cement that binds people together [1]. Miura described icebreakers as "human relations" due to the degree of human connections made among participants [2]. Tanaka and Moribe state the need to deliberately create an atmosphere from the first meeting point that would instigate a desire get to know the other person, which in turn can create a better relationship [3]. Hori et al. talked about the effectiveness of icebreakers from the perspective of "team building," which is used to help members get to know each other, build relationships, and increase their willingness to work together [4].

After the COVID-19 outbreak, in-person design workshops changed to online meetings and, as a result, the icebreaking approach changed significantly. Face-to-face discussions were held online via ZOOM and Teams, sticky notes became the online whiteboard Miro, and icebreaking methods had to adapt. Zhang highlighted the effectiveness of icebreakers in enhancing communication during online workshops [5]. In the post-pandemic era, design workshop organizers enjoy greater flexibility in choosing operational methods, including face-to-face, online, or hybrid formats. However, research exploring the positive impact of icebreakers on design workshops in this new context is still limited.

#### **2 OBJECTIVES**

This study focuses on the use of icebreakers within design workshops across face-to-face, online, and hybrid formats. It aims to delineate the nuances and impacts of various icebreaking strategies—spanning communication methods, the spectrum from individual to collaborative efforts, and emotional

dynamics—to enhance design workshops in the post-COVID landscape. These findings can be implemented in future design workshops in the post-COVID era.

#### **3 METHODS**

As a design workshop practitioner, the author has conducted many design workshops in Japan and internationally with three formats: face-to-face, online, and hybrid. For each workshop type, recorded images and data were collected and analysed to measure the icebreaker's effectiveness. Based on Hori's previous research [4], the focus was on the participants' desire to collaborate and their emotion. Using the Participant Involvement map framework proposed by Manzini [8], each workshop's active involvement and collaborative involvement was measured. Specifically, media data of the three workshop types which contained ice-breaker methods, communication methods between participants (verbal or non-verbal communication), participants' participation attitudes (proactive or collaborative), as well as the level of participants' emotions, were visualised and analysed.

By extracting and integrating the characteristics of icebreakers in the three types of workshops, this study aims to explore the possibility of new, effective icebreakers that allow participants of design workshops to get to know each other to confidently to create together.

#### 4 DESIGN WORKSHOPS AND ICEBREAKERS

The purpose of a design workshop is to use design methods to bring together participants from diverse backgrounds to find creative solutions to social issues. Design workshops are divided into four processes: Explore It, Respond to It, Make It, and Share It [6]. This research, using two-day design workshops as case studies, organizes the icebreakers into process types. Icebreakers will be held according to a process of the three workshop types: face-to-face, online, and hybrid as seen in Figure 1.



Figure 1. Icebreaker activities of design workshops

In the figures that follow, using the labels: Physical (P), Digital (D), Hybrid (H), a description of the icebreakers: Who are you (1), Create together (2), Meditation (3), and Tai Chi/Dance (4) were provided. For face-to-face workshops, icebreaker activities are P-1, P-2, P-3, P-4; for online workshops, they are D-1, D-2, D-3, D-4; and for hybrid workshops, they are H-1, H-2, H-3, H-4. Digital records of two-day workshops from were analysed to discover each icebreaker's communication method, participant engagement type (e.g., proactive/cooperative), and emotional level (ranging from normal to very happy).

#### 4.1 Icebreakers in face-to-face workshops

Face-to-face workshops were held from 2015 to 2019, and 2023. At the beginning of the workshop, diverse participants meet for the first time and begin with the "Who are you" icebreaker. At that time, the following icebreakers (P-1—P-4) are conducted and described in Figure 2.

#### 4.2 Icebreakers in online workshops

The online workshops were conducted in 2020. All participants communicated via Zoom and used Miro to develop ideas. The descriptions of the icebreakers (D1—D4) are captured in Figure 3.

#### 4.3 Icebreakers in hybrid workshops

Hybrid workshops were conducted from 2021-2022; their icebreakers (H1—H4) described in Figure 4. While primarily conducted with in-person participation, some participants joined online. Therefore, preparations were made for both in-person and online participation, with Zoom and Miro being utilized.

Icebreaker Activity	Communication Method	Participant Engagement	Emotional Level
P-1: Who are you? (2017) Draw an image of yourself on a card, put it on your clothes, and introduce yourself. (Sharing your hobbies is crucial, as it quickly initiates communication with people who share similar interests.)	Verbal and nonverbal	QQO QQO QQO OQO Proactive	Normal
P-2: Creating together: Silent Machine Game (2016) This is a game to ease tension among team members who do not know each other, where they silently combine their badies to form a single machine. Then, they present it, and other teams guess what kind of machine it is. It involves using the brain, physical movement, and cooperation.	Verbal and nonverbal	By B B Cooperative	Very Happy
P-3: Meditation (2023) For 10 minutes, participants closed their eyes, either sitting or lying down, and followed the verbal guidance of the instructor while engaging in meditation.	Verbal and nonverbal	OOO © OOO Proactive	Slightly Happy
P-4: Dance (2017) A 3-minute SDGs dance. Participants watch a dance video and imitate it. Although it's an individual activity, dancers also observe the movements of those around them while dancing.	Verbal and nonverbal	Proactive-Cooperative	

Figure 2. Face to face workshop icebreaker observations



Figure 3. Online workshop icebreaker observations



Figure 4. Hybrid workshop icebreaker observations

#### 4.4 Findings

Tanaka and Mori found that conversations using online conference systems differ from face-to-face conversations in terms of the quality of interpersonal communication [7]. Face-to-face conversations involve both verbal and nonverbal communication, the physical presence, gaze, posture, and distance of between participants are important and are often accompanied by powerful emotional experiences. In online conversations, nonverbal cues take a back seat, leading to more direct exchanges where one person speaks and the other responds. This means that individuals online tend to verbally express themselves more explicitly, making it easier to share personal viewpoints and engage in meaningful discussions. Based on these characteristics, we analysed icebreakers based according to communication type, participant engagement type, and emotional level:

For introductory icebreakers, P-1 utilizes verbal and non-verbal communication, making it easier for participants to understand and express their emotions, thus facilitating empathy among participants. In D-1, verbal communication takes center stage; focusing on the content of speech without feeling a physical presence makes it difficult to establish empathy. In the case of H-1, communication bounces back and forth between in-person participants and those online. It was found that face-to-face participants understand each other best, followed by hybrid participants, then solely online participants. For collaborative icebreakers, P-2 fosters emotional contagion through physical and facial expressions, making participants' joyful expressions distinct. Although D-2 involves cooperative creative activities, enjoyment may decrease compared to face-to-face workshops due to the constraints of online applications. In H-2, there are no issues during the discussion stage, but online members cannot participate hands-on, leading all members to use Miro, mirroring D-2. It was found that face-to-face workshops are the easiest to facilitate team building, while hybrid formats are the most challenging. Regarding meditative icebreakers, while the environment of online participants may have a slight impact, there was not much of a difference among P-3, D-3, and H-3 in terms of activity content. Tai Chi and dance icebreakers are activities done individually under the guidance of a leader; it is easiest in face-to-face workshops (P-4). D-4 was difficult because it is hard to capture movement transmitted by a camera on a computer screen through Zoom. Hybrid workshops (H-4) are the most challenging; the recording device must follow the leader's movements, while being aware of the participants who are

#### **5 ICEBREAKERS DISTRIBUTED ON PARTICIPANT INVOLVEMENT MAPS**

The workshops conducted in this study aim to collaboratively generate solutions to social issues involving diverse individuals. Because of these characteristics, a framework called the Participant Involvement Map [8] (PI map) was applied for analysis. In creating a PI map, this study employed the principles of active involvement and collaborative participation. By using these two principles as axes and intersecting them, the PI map was generated in Figure 5. This map outlines methods through which participants can contribute towards achieving a desired outcome.

The degree of active involvement refers to what participants are tasked to do, ranging from passive to active participation. In passive participation, participants are categorized as passive users who are served by active providers. In contrast, active participation involves participants leveraging their personal resources such as time, energy, attention, and specific skills. In this scenario, the distinction between users and providers blurs, as users become co-producers alongside providers.



Figure 5. Participant involvement map adapted from Manzini

The degree of collaborative involvement signifies the extent to which participants engage in collaboration, varying from no collaboration to intense collaboration. In instances of no collaboration, participants work alone, either being served or being actively involved as individuals. Intense collaboration involves participants working with peers (horizontal collaboration) or with other social actors such as experts, institutions, associations, or businesses (vertical collaboration).

Quadrant A represents low participant involvement in both activities and collaborations. This aligns with traditional service models and some collaborative organizations where participants primarily play the user role. Quadrant B demonstrates low user involvement in practical activities but emphasizes collaboration in organization design and management. This is typical of traditional services and collaborative organizations co-managed by participants. Quadrant C indicates intense participant involvement in practical activities with others. Quadrant D reflects intense participant involvement in individually carried out activities. This mode is prevalent in do-it-yourself-based services and collaborative organizations that have adopted such approaches [8]. PI maps were then created by applying these concepts to the icebreakers of the three workshop types as seen in Figure 6.



Figure 6. Comparison of PI map for the three workshop types

The PI map of the face-to-face workshop generally shows a strong tendency towards active involvement. It is thought that it is easier to motivate participants because many communication methods are utilized, and emotions are easily contagious. In online workshops, everyone participates through a digital device, so there is a tendency for weak active involvement and weak collaborative involvement. In comparison to the other two types, hybrid workshops exhibit a broader spread of active involvement and collaborative involvement. According to Manzini's concept, the PI map does not label Quadrant C as the most favourable or Quadrant A as the least favourable. What is ideal is having a balance between all Quadrants that aligns with the end goal of a workshop or activity.

#### **6** CONCLUSIONS

When icebreakers are used as a self-introduction activity, the quality of communication can be ranked in the order of face-to-face workshops, hybrid workshops, and online workshops. For icebreakers that involve co-creation, it was found that those that are more challenging are more emotionally satisfying for the participants. Face-to-face workshops involve both verbal and non-verbal communication, making it easier for participants to understand and empathize. Additionally, it was found that the feedback from online collaboration can be received easily as the workshop progresses, making evaluation easier. Icebreakers that employ meditative practices have very little observable differences. For icebreakers that involve movement, face-to-face workshops were found to be the most effective, while hybrid workshops were found to be the most difficult.

Icebreakers in face-to-face workshops appear to be easiest to conduct and have the best emotional feedback. Online workshops focus on verbal communication and are more likely to promote the exchange of opinions that go well beyond personal views. Hybrid workshops pose the greatest challenge for organizers, requiring extensive preparation. However, according to the analysis of PI map, hybrid workshops show the widest range of active involvement and collaborative involvement, suggesting the positive potential for diverse participation. One limitation of this study is its perspective, which is primarily that of a workshop organizer. Future research will require data gathered from a broader participant base to enrich and deepen the findings. This study solely draws its conclusions from the above-mentioned processes and design method workshops; further research is needed for design workshops with different processes.

In the post-COVID era, a variety of workshops can be conducted even more successfully with the appropriate icebreaker in play. Icebreakers, where communication is crucial, excel in face-to-face workshops but appear to have a greater impact in hybrid workshops. The results of this research can assist workshop practitioners, educators interested in innovative teaching methods, and professionals responsible for human resource development, by showing ideal ways to spark participants' interest in one another, foster teamwork, and propose innovative solutions during workshop activities.

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### INTEGRATING AR INTO A GRAPHIC DESIGN PROGRAM FOR AN ENHANCED DESIGN CURRICULUM

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#### ABSTRACT

The continued interest in augmented reality (AR) applications in the business sector has precipitated a corresponding surge of design with AR in the design industry. In turn, the rise of AR in the design profession requires a proactive response from design education. Upon that foundation, this paper introduces a pioneering pedagogical approach integrating AR into a foundational 2D graphic design course, aiming to expand students' digital capacity, foster an understanding of design thinking, and cultivate problem-solving skills. This paper outlines the AR-enhanced project and assesses its pedagogical efficacy based on student surveys conducted at the end of the project, including the challenges encountered along the way and positive suggestions for the specific learning context. We aim to share insights from the teaching experience and provide educational institutions with a valuable reference for advancing their curricular approaches.

Keywords: Augmented reality, AR, graphic design

#### **1** INTRODUCTION

Augmented reality (AR) has recently transitioned from a mere technological fascination into a practical tool embraced by the business sector [1]. The shift indicates the ongoing integration of AR applications into the mainstream of the design industry, prompting a call for a corresponding curriculum in design education. Recent scholarly research on AR in design education has showcased early initiatives for the pedagogical use of AR [2] across design-related disciplines. This paper presents a comprehensive assessment of AR's potential as a pedagogical tool in graphic design foundation for achieving learning objectives, including enhancing students' technological competencies, deepening understanding design theory, and cultivating problem-solving skills through immersive design processes. We conducted course surveys to evaluate students' learning experiences in meeting the learning objectives. This paper validates and reaffirms AR's role as a pedagogical instrument, underscoring higher education's adaptability in responding to the demands of the digital age.

#### 2 AR AND ITS PRACTICE IN THE DESIGN INDUSTRY AND EDUCATION

The meaning of AR differs depending on the perspective taken [3]. For instance, Wellner et al. [4], in an action-oriented approach, defined AR as a system that overlays computer-generated information onto real-world environments. In another case, Azuma [5] described AR from an objectivist standpoint as a system in which "the virtual and real objects coexist in the same space" (5: 356). Pragmatic researchers such as Ghazwani and Smith [6], then regarded AR as a tool that enables users to observe virtual objects integrated into the real world in real time, placing particular emphasis on AR's potential usability. However, within the creative industry, AR has been viewed as a creative technology rich in various digital media in a virtual space [7]. A number of professional studios, such as *NEEEU Spaces* [1] and *Arcade*, the one spotlighted on the Zap Work showcase, have utilised AR to address real world design problems, indicating the rise of AR in professional design practice. Although AR remains relatively rare in mainstream design, the growing examples from the design profession have affirmed AR as a design medium endowed with considerable creative potential.

The growing practice of AR in the design industry calls for a response from design education [2]. However, unlike the professionals in the design industry, educators approached AR as a principle of augmentation rather than a mere innovative technology. Wu [3] argued that viewing AR as a concept is

more productive for educators, suggesting a focus on the idea of augmentation to pedagogically enhance students' learning experience. Abidin et al. [8], for example, experimented with AR to augment the presentations of student interior design projects. At Queensland University of Technology in Australia, Kerr and Lawson [9] developed an AR-featured project, "Master of Time," to help first-year students in landscape architecture "create new practices in digital storytelling" (9: 6). These examples in design education reflect Korani et al.'s [2] assertion that AR is not only a creative technology in the design industry but more about a pedagogical tool that facilitates design learning in education.

#### **3 AR TOOLS AND ACCESSIBILITY**

Coding requirements in AR tools have remained a major challenge for design students, as pointed out by Abidin [8]. However, the ubiquity of smartphones and high-speed internet connectivity has paved the way for mobile-based and web-based AR platforms, making AR increasingly accessible to a broader audience. Zap Works Designer, released in 2021, and Adobe Aero, introduced in 2019, are both mobile and web accessible. Both offer a designer-friendly approach to creating, viewing, and sharing interactive AR content on smartphones. Zap Works Designer, in particular, promises a "no apps, no downloads, and no coding" approach, serving as a gateway for embedding AR into design education, and asserts itself as a ready, approachable tool for design students in studio settings. For those reasons, we chose Zap Works Designer to facilitate the AR-enhanced project in this study.

#### 4 LEARNING OBJECTIVES

#### 4.1 Expanding digital capacity

The digital content overlaid on the real-world objects through an AR tool, such as Zap Works Designer, involves various media applications, including digital text, 2D images, audio, video, 3D models, and animation. When incorporated into a studio course, AR can become a conduit for students to explore diverse forms of digital media. Through a hands-on project featuring AR, students will explore specialised file formats, data exchange and transfer, and digital practices commonly utilised in AR applications and game design but less prevalent in traditional graphic design practices. Since the key to using multiple digital media is integration and adaptability [11], and for that reason, the approach involves collaborative endeavours exploring 2D, 3D, audio, video, and animation can develop and enhance students' technological knowledge and skills for interoperability workflows and expanded collaboration [12]. As the demand for print materials continues to decline and virtual interactivity is gaining prominence [2], such enhanced digital proficiency equips design students with the adaptability required to navigate the evolving landscape of the digital era.

#### 4.2 Fostering design thinking

As a technology and form of knowledge beyond the conventional boundaries of graphic design, AR supports students in comprehending design thinking as a boundary-pushing approach widely discussed in recent design literature. Design thinking is not merely a mindset but a structured method of seeking innovation outside conventional norms, akin to what Cross [13] has described as solving problems from a "completely different angle" (13: 11). This structured method features a strategic framework centred on boundary-pushing, seeking creative opportunities for problem-solving outside the given discipline [14]. Wang [15] noted that by engaging with a different subject or type of expertise, often from a distant field, designers gain fresh perspectives that enable them to scrutinise design problems from novel angles.

In design education, exploring AR beyond the constraints of the 2D grid in graphic design resonates with the design thinking framework. Such experimentation prompts students to explore AR as a creative medium beyond the traditional realm of graphic design. In turn, students can grasp design thinking as a boundary-breaking approach, examining graphic design problems from AR's perspective to address them innovatively. The learning experience helps students understand design thinking as a design method. However, in the long term, this approach serves as a stepping stone for shifting students' focus from formal aesthetics in the foundational study, as occurred in the past, to innovative problem-solving, which is highly valued in graphic design learning and practice.

#### 4.3 Enhancing problem-solving design skills

Integrating AR into a graphic design project immerses students in a collaborative design practice in which they constantly need to decide the reasons and methods for interoperating between various

platforms, utilising cross-media tools, and converting different digital files. This multidisciplinary or, more accurately, the transdisciplinary design process requires students to proceed with goals and purposes aimed at problem-solving. The design experience mirrors the concept of "design by immersion" as introduced by Hall et al. [16], in which designing within multiple disciplines is viewed as an immersive design process that "captures and supports transdisciplinary approaches to problem-driven visualisation" (16: 110), a method "well suited to problem-driven visualisation work" (16: 109), and "a way to transform and enrich knowledge and skills through a transdisciplinary experience" (16: 111).

Given that multidisciplinary practice has always been inherent in design and is increasingly recognised in the field [17], the AR-integrated multidisciplinary design process not only encourages students to focus on design problem-solving but also enhances their design knowledge and skills during their foundational training. Furthermore, it offers an early indication of the future direction of design, which involves a more collaborative, multidisciplinary approach. Indeed, this trend is evident in today's expanding design boundaries, the growth of user experience (UX) design, AR, and emerging design practices utilising generative artificial intelligence (AI). While the learning experience may pose challenges for entry-level students by requiring increased cognitive attention to multiple disciplines, it can foster an open, flexible, and creative mindset, mitigating the risk of students developing rigid preferences solely focused on print design during their early learning stages.

#### 5 METHODS

To explore AR's potential in graphic design, we conducted a pilot study by integrating AR into a poster design project in a foundational studio course comprised of two sections of second-year college students in the graphic and information design program at a state public university. Prior to the AR-integrated task, students in foundation studies often took on an aesthetic-centred approach, emphasising design principles and enthusiastically pursuing visual appeal. This AR-enhanced poster design project, however, asked students to incorporate AR (Zap Works Designer) in graphic design to add an interactive dimension to encourage a problem-solving driven design strategy.

The course, spanning six weeks with two-hour sessions held twice weekly, featured a fully guided teaching approach given its foundational nature. It included three phases: Phase 1, lasting two weeks, focused on introducing graphic design principles and the poster project alongside lectures on Augmented Reality (AR) applications. Phase 2, a one-week segment, introduced design thinking methodologies through studio seminars. Lastly, Phase 3, spanning three weeks, centred on digital workflow, tutorials on Zap Works Designer, and studio critiques, immersing students in a multidisciplinary design process (Figure 1).



Figure 1. Students experimenting with AR using Zap Works Designer in a design lab

Upon the conclusion of the project, a survey utilising Likert scale, true-and-false, and open-text responses was administered to students to evaluate the learning objectives based on their experience, including the challenges encountered in the study. Class observations were included to complement the assessment, shedding light on the learning experience. The survey additionally incorporated questions aligned with the CT-PAF evaluation framework to assess the pedagogical effectiveness of Zap Works Designer as an educational multimedia tool in this practice. CT-PAF is a framework that aims to help educators assess technological learning tools regarding their pedagogical impact and outcomes [18].

#### 6 **DISCUSSIONS**

#### 6.1 Success

Twenty-three students in the class responded to the survey. All students except for one reported having an enhanced understanding of digital file formats, data transformation, and cross-platform interoperability following the completion of the project. Such an improved understanding empowered students with a broader digital skill set, for it encouraged students to explore various techniques, styles, and mediums and thus prepared them to be more productive and efficient as they took continuously advanced design courses. Moreover, knowing diverse digital media resources beyond the confines of Adobe 2D tools such as Illustrator and Photoshop prevented students from confining themselves in a print-only design comfort zone. It opened more creative opportunities and expanded students' perception of design via a collaborative approach that leverages various digital platforms and types of technology. Such a holistic approach equipped students with the versatility and agility needed to step into their future careers and thrive in an increasingly digital-centric professional landscape.

For a foundational design course, design thinking is undoubtedly an advanced theory. Thus, negative feedback from students was anticipated when the theory was introduced alongside the AR-integrated project. However, the survey results were nearly unanimous in both course sections positively regarding their enhanced understanding of design thinking and its role in driving creativity. By incorporating AR into a graphic design project, students were able to experiment with design thinking as a methodological approach, thereby expanding the boundaries of graphic design from traditional 2D formats to include AR technology to solve the assigned design problem: engaging visitors in a museum event by providing an immersive experience. Despite the perception that introducing design theory was premature and diverged from conventions of advanced studies in design theory, understanding design thinking benefited students in the study by instilling in them an open mindset characterised by inclusivity, curiosity, risk-taking, and flexibility, all of which are valuable within the very realm of design education. We proposed that an immersive design experience would cultivate students a problem-solving mindset and skills, as discussed in Section 4.3. However, the survey showed that four students disagreed for various reasons; one expressed the need for more AR practice, and another commented on a lack of connection between AR and problem-solving in design. Nevertheless, most students (n=19) agreed that the project helped them develop problem-solving skills. For instance, one student commented, "I believe the [AR] design experience helped me with my problem-solving skills because it challenged me to find a solution." Exploring AR alongside graphic design involved collaboration across platforms, software, and tools, making the AR-enhanced project a transdisciplinary design process. That transdisciplinary approach was driven by design reasoning, for students continually needed to justify the use of multiple tools and platforms with goals for solving problems in poster design, thereby preventing them from focusing solely on the visual appeal of the poster. After all, problem-solving through design is integral to modern design and will continue to be emphasised in design education, especially in increasingly tech-driven climates. In that sense, the project transcended mere aesthetic practices as was once common in the course by serving as a catalyst for developing a proactive vision within graphic design studies. As one student remarked in the survey, "It helped us to get a heads-up on assignments in the future," the study facilitated a shift from focusing solely on visual appeal or "eye candy" to a problem-solvingcentred design strategy much valued in design education and the design industry.

#### 6.2 Challenges

The survey revealed two primary challenges encountered by students during the AR-integrated practice: significant cognitive attention required for the task and the short time frame, which intensified these challenges. Although all students in the study agreed that Zap Works Designer was user-friendly, a significant number of them found the learning experience in this project to be somewhat overwhelming. Some reported experiencing considerable cognitive challenges, and only a minority of students expressed feelings of ease and comfort during the learning. Several students described that this practice involves not only a novel tool to learn but also a new hybrid design process never experienced before. Beyond that, some students voiced concerns that the six-week time frame for the AR-integrated project was insufficient, despite recognising AR's potential benefits in pedagogy.

Upon reflection after the completion of the project, we acknowledged the disadvantages of the approach. Learning to use a new AR tool while mastering design principles indeed required students to navigate multiple tools simultaneously, leading to increased cognitive demand. Extending the project's time frame, depending on the course schedule, and providing additional guided workshop hours could

alleviate some of the learning pressures and mitigate the intensity of the learning experience during the learning process.

#### 6.3 Evaluating Zap Works Designer based on the CT-PAF evaluation framework.

An evaluation method explicitly tailored for assessing technology adopted in visual design is rare in the design literature. To evaluate the AR tool utilised in the project, we developed an evaluation rubric based on the CT-PAF framework. CT-PAF is an assessment system devised by Oyelere et al. [18] to gauge the pedagogical effectiveness of computer thinking tools. We adapted part of its evaluation indicators to evaluate the AR tool used in the project (see table 1). On the student survey, questions were thus tailored according to those indicators to gain insights into selecting AR tools that could be used for similar tasks. Table 1 presents the evaluation results corroborated by students' feedback on their learning experiences.

Indicator/Criteria	Evaluation		
Purpose of the tool	The designer-friendly tool is used to create highly accessible interactive AR content using a smartphone without coding.		
Ease of use	During the task, 90% of students in the task considered Zap Works Designer to be an easy tool to use.		
Ease of learning	95% students find the tool is easy to learn since it is coding free, simple in interface, and has steep/short learning curve.		
Satisfaction	The interactive AR content was engaging, and 90% of students expressed satisfaction with the results of using the tool.		
Perceived usefulness	The tool was used to enhance the interactivity of print design and as a pedagogical tool for design learning; 75% of students evaluated it as useful for enhancing their design work, and 65% considered it useful for education purposes.		
Recommendation	Students learned how to use a new interactive tool for design, and 80% of students reported that they would recommend the tool to others.		
Availability for teaching	A free two-weeks trial and an affordable educator account are available for class teaching purpose.		

Table 1. Assessment of Zap Works Designer based on students' learning experiences

Overall, the feedback was positive and reflected students' favourable learning experiences with Zap Works Designer. Many students found the AR toolkit easy to use and cited its simple interface and nocoding-needed feature as key factors. That observation aligns with the findings of Abidin et al. [8], who noted in their interior design class that AR tools devoid of scripting work are more conducive and productive for design students. Satisfaction was measured by the design's final outcome with AR, and the majority of students found the results intriguing and gratifying. They were particularly pleased with their ability to interact with the AR content by using their smartphones to scan their own print design work, which not only gives their work technological breadth but also makes a rich and diverse design portfolio for personal promotion. Moreover, most students expressed interest in using the AR tool beyond the project and recommended the tool to other students. Last, regarding accessibility for teaching purposes, the AR tool used in this project supports education by providing affordable education accounts that facilitate its integration into classroom teaching.

#### 7 CONCLUSIONS

By the conclusion of the course, students are expected to have acquired a deeper appreciation for the value of AR in graphic design. The AR-enhanced pedagogical task demonstrated its capacity to cultivate an open mindset among students, encouraging them to embrace technology within the realm of graphic design. This inclusive approach is particularly pertinent in an era when new media are increasingly reshaping the landscape of the graphic design profession. Since the task was implemented in a lower-level design course, future studies should explore further integrating AR into upper-level design courses,

particularly those centred on 3D imaging, motion graphics, and animation. Such exploration can provide a more comprehensive understanding of AR's potential in the current curricula in design education.

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# CONSTRUCTING A TEACHING AND LEARNING SYSTEM IN HIGH DESIGN EDUCATION

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#### ABSTRACT

In the face of a rapidly changing era, how to construct an adaptable design education framework is a thought-provoking question. This study explores three fundamental issues related to design education: what constitutes the elements of design education, how these elements are interconnected, and why they are interconnected in such ways. By investigating these questions, the research aims to explore what kind of system should be established for design education, how to construct this system, and the reasoning behind such construction. The goal is to provide a conceptual framework for universities planning to initiate design education and offer insights for improvement and development to those already engaged in design education.

*Keywords: Design education, teaching and learning, management organization, interconnect of elements, mechanism* 

#### **1** INTRODUCTION

Sheila Pontis and Karel van der Waarde (2020) found that the need for change in design education has been a topic for discussion for more than twenty years, but still, there seems to be a lack of concrete advice in the form of structural models or practical strategies that can ballast the required change [1]. As to this research, the author believes the key focus to build a structural model should be on how to construct a teaching and learning system that adapts to future change. To address the issue, this research will explore three sub-questions:

- 1. What are the elements of design education?
- 2. How do the elements of design education interconnect with each other?
- 3. Why the elements of design education interconnect in these ways?

The first sub-question involves systematically outline the essential elements of designing educational subjective and objective elements. It should be noted that different universities should have different objective elements in teaching and learning.

The second sub-question suggests that, through the coordinated efforts of management organizations, teachers, and students, the subjective and objective elements should be linked together in curriculum development, and improvement and enhancement of both subjective and objective elements should be promoted through the PDRA cycle (Plan $\rightarrow$  Do $\rightarrow$ Reflect $\rightarrow$ Adjust. Replacing Control by Reflect and moving from PDCA to PDRA).

The third sub-question discusses the underlying logic of linking the subjective and objective elements through curriculum and through the PDRA cycle.

#### 2 RESEARCH METHODS

This research utilizes methods such as literature review, interview research, quantitative analysis, and qualitative analysis. The literature review method is primarily concentrated in Part 3, conducting research on publications by teaching faculty from internationally renowned design schools to extract the essential elements of design education. The interview method is mainly focused in Part 4, involving interviews with teaching faculty and alumni from a university in Shanghai, China. The interviews in this study provide crucial insights into the modes of carrying design education elements, the current status and issues of the linkage of design education elements. The qualitative analysis method includes both inductive and deductive approaches. In the section on the linkage of design education elements in Part 4, the study

extensively uses inductive analysis to summarize and analyse the content of interviews with teachers and alumni. In the section on the mechanism of linking design education elements in Part 5, the explanation of the process and methods of curriculum-linked design education elements and the process and methods of PDRA cycle-linked design education elements is mainly accomplished through deductive reasoning.

#### **3 WHAT ARE THE ELEMENTS OF DESIGN EDUCATION?**

Building upon the foundation of literature research, the elements of design education are initially categorized into two parts: subjective elements and objective elements.

#### 3.1 Subjective Elements of Design Education

Shang Hua et al. (2013) proposed that the subject of the design education system consists of five parts, namely administrative managers, organizers of design education institutions, operators, teachers, and students. They consider educational administrators, organizers of design education institutions, and operators as the management subjects of design education, while teachers and students are viewed as the academic activity subjects of design education [2]. To avoid dedicating excessive efforts to the study of different subjects in design education management and to focus on the construction of the teaching and learning system, this research adopts the term "management organization" to collectively represent the entities defined by Shang Hua – educational administrators, organizers of design education institutions, and operators. This term is used in parallel with "teachers," the subjects of teaching behaviour, and "students," the subjects of learning behaviour, as the three main subjective elements of design education.

#### 3.2 Objective Elements of Design Education

Zhao Juming (2017) points out that by referencing the terminal point, starting from the end, it becomes clear what is needed, why it is needed, when it is needed, and how various parts should coordinate. This makes it less likely for the objectives to be lost during the process, which is particularly crucial in professional design [3]. The terminal point, in this context, refers to the educational philosophy and goals. Different design educational philosophy and goals will impact the definition of objective elements. Based on the "Integration of Knowledge, Skills, and Personality" educational philosophy at a university in Shanghai, China, this research classifies the objective elements of design education into knowledge elements, skill elements, and personality elements. By combining cognitive psychology's understanding of the types encompassed by knowledge, skills, and personality, specific content for the objective elements is extracted from relevant literature on design education.

#### 3.2.1 Scope for Extracting Objective Elements of Design Education

To extract literature on objective elements, two conditions must be met: 1. Authors must be teaching faculty from design schools consistently ranked in the top 50 in the QS "Art and Design" discipline for five consecutive years; 2. The literature must be indexed in the Web of Science.

The retrieval process for these authors' papers involves three steps:

1. Restricting the research direction to Education Research, Education Scientific Disciplines, and Art, using "Design Education" as a keyword to search the subject heading field, resulting in 4599 papers.

2. Refining the search by adding the keywords "course," "education," "learn," and "teach" in the abstract, focusing on the research theme of "design education teaching and learning," resulting in a total of 183 papers.

3. Considering the relatively small number of 183 papers, the scope of the research literature is expanded to include 15 papers published in two education special issues of "She Ji: The Journal of Design, Economics, and Innovation." In total, 198 papers<sup>1</sup> are used for extracting literature on the objective elements of design education.

<sup>&</sup>lt;sup>1</sup> Due to the length of this paper, the 198 papers cannot be listed in the REFERENCES section. They can be accessed at the following link:

https://pan.baidu.com/doc/share/p4CO9dZPaXM58eXggeggWw-34080061269626. Access code: invz.

#### 3.2.2 Extracting Objective Elements of Design Education

There are three steps involved in extracting and summarizing the elements of "knowledge, skills, and personality" in academic literature on design education:

(1) Element Extraction: This includes vocabulary and phrases directly mentioned in the literature related to objective elements, as well as sentences or paragraphs that indirectly reflect objective elements. For both types of elements, they are compiled in their original states, and relevant information from the literature is retained, laying the foundation for subsequent data source tracing.

(2) Element Coding: For sentences or paragraphs that do not directly mention but reflect objective elements, the themes of the elements are determined through first-level coding. The vocabulary or phrases of the directly extracted themes from the previous stage are unified in this step to account for differences in terminology and regional variations in different languages.

(3) Element Classification: The content of the uniformly coded elements is classified into three major modules: knowledge elements, skill elements, and personality elements.

Through these steps, the extraction and classification of knowledge elements, skill elements, and personality elements in design education are completed.

#### 3.2.3 Content of Objective Elements in Design Education

Through a detailed study of the 198 papers, the specific content of knowledge elements, skill elements, and personality elements mentioned in design education is summarized.

#### 1. Knowledge Elements

Categorized according to cognitive learning theories, knowledge elements are divided into declarative knowledge and procedural knowledge. According to the definition by Zhao Weijun (2011), declarative knowledge refers to an individual's knowledge about the facts, background, and relationships of the objective environment, explaining "what things are." Procedural knowledge includes both action skills and cognitive skills and is, to some extent, dynamic and variable. In comparison to declarative knowledge, procedural knowledge not only describes the state of things but also indicates how things should be done. It needs to be gradually stored in the human brain through repeated practice [4].

Through literature review of top-tier teaching faculty at international high-level universities, 16 specific elements of knowledge have been extracted. Declarative knowledge encompasses history, philosophy, sociology, design theory, anthropology, ergonomics, psychology, and business. Procedural knowledge includes rhetoric, data science and analysis, design tools, design techniques, design language, experimental skills, design methods, and research methods.

#### 2. Skill Elements

Peng Danling (2019) suggested that ability can be divided into cognitive ability, operational ability, and social ability. Cognitive ability is the capacity of the human brain to process, store, and retrieve information. Operational ability refers to the ability of individuals to manipulate their own bodies to perform various activities. Social ability are the abilities demonstrated by individuals in social interaction activities [5].

Through literature review of the 198 papers, 13 specific elements of abilities have been extracted. Cognitive ability elements include problem definition, prediction and decision-making, aesthetic ability, thinking skills, reflection ability, and self-education ability. Operational ability elements include problem-solving, interdisciplinary skills, and research skills. Social ability elements include communication, cooperation, leadership, and management.

#### 3. Personality Elements

Costa and McCrae proposed a metatheoretical framework based on the Five-Factor Model in 1992, which encompasses the majority of personality theories – the Five-Factor Personality Theory [6]. Categorized according to the Five-Factor Personality Theory, personality elements are divided into openness, conscientiousness, extraversion, agreeableness, and neuroticism.

Through the review of literature, 8 specific elements of personality have been extracted. Openness elements includes imagination, inclusiveness, emotional richness, and creativity. Conscientiousness elements includes self-drive and a strong desire for knowledge. Extraversion element includes being proactive. Agreeableness element includes empathy. Within the established scope of academic literature, does not feature descriptions related to neurotic personality element.

At this point, through the analysis of literature, the extraction of knowledge elements, ability elements and personality elements are completed. It should be pointed out that, the analysis and refinement of design education object elements in this study represent just one approach to element refinement. Moreover, this approach is conducted based on the educational philosophy and positioning of a specific university in Shanghai, China. The methods and processes can be considered as a reference, but the results do not represent universally applicable standards. Each university should choose a suitable refinement method according to its own educational philosophy to determine the objective elements of design education.

#### 3.3 Overall Framework of Subject and Object Elements in Design Education

The three main subject elements – management organization, teachers, and students – form an overall framework through the layout, impartation, and learning of different combinations of object elements. This composition encompasses the relationships among the subject elements, the object elements, and the interactions between the subject and object elements, as illustrated in Figure 1.





Figure 1. Overview of Design EducationFigure 2. the interconnection of designSubjective Elements and Objective Elementseducation elements through the PDRA cycle

#### 4 HOW DO THE ELEMENTS OF DESIGN EDUCATION INTERCONNECT WITH EACH OTHER?

Colm O'Kane and Robert TULLY (2018) argue that success manifests itself from bringing the right constituent elements together and managing them through the process [7]. Once the essential elements of design education, both subjective and objective, are determined, these elements need to be gathered and interconnected to form an organic talent development system. To analyse the interconnection of design education elements, starting from the frontline participants in actual design education institutions would be the most direct approach. The author conducted interviews with 30 frontline design educators and 15 alumni from the design school from Shanghai, China. Based on these interviews, the author carried out further analysis.

#### 4.1 Achieving the Interconnection of Design Education Elements through Courses

Based on the data analysis derived from interviews with frontline teaching faculty at a design institute in Shanghai, China, it can be concluded that the courses offered by this institute have the capacity to accommodate the cultivation of the three major objective elements of design education: knowledge, skills, and personality.

In higher education institutions, "courses" serve as the primary medium for conducting educational activities and play a crucial role in facilitating the integration of design education elements. Firstly, the management organization needs to structure a professional matrix, which is composed of multiple courses, gathering all objective elements. Secondly, teaching faculty take on the task of delivering specific courses, each responsible for imparting certain objective elements. Lastly, through the study of courses, students acquire various objective elements and eventually form a diverse combination of these elements, achieving the educational goals of design education. It can be observed that, among the three subjective elements and the three different forms of objective element modules, "courses" serve as a continuous carrier, a concept affirmed through interviews with teaching faculty at the design school in Shanghai, China.

# 4.2 Shortcomings in Achieving the Interconnection of Design Education Elements through Courses

At the same time, feedback from interviews with teaching faculty also highlighted the limitations of solely relying on courses to achieve the interconnection of design education elements. Specifically, when facing the demands of educational reform, focusing only on reforming courses to improve the

layout of design education objective elements within the professional matrix has limitations in terms of the comprehensiveness, standardization, and capacity to accommodate the development of reform.

# 4.3 Achieving the Dynamic Interconnection of Design Education Elements through the PDRA Cycle

In response to these shortcomings, the researcher attempted to find improvement strategies during interviews with alumni from the university. During these interviews, alumni were asked to provide suggestions for improving teaching at their respective institutions and offer advice or share experiences for current students. Through the analysis and synthesis of alumni feedback, it was found that the improvement suggestions from alumni for the three subjective elements - management organization, teachers, and current students - all included three aspects: "plan," "do," and "reflect." Combining these aspects with the goal of "adjust," a framework was constructed consisting of "Plan $\rightarrow$ Do $\rightarrow$ Reflect $\rightarrow$ Adjust", abbreviated as the PDRA cycle. This solution approach was integrated with the PDCA cycle, a scientific quality management procedure from management science. The researcher proposed the viewpoint of utilizing the PDRA cycle to dynamically interconnect design education elements, as illustrated in Figure 2.

#### **5 MECHANISM OF INTERCONNECTING DESIGN EDUCATION ELEMENTS**

"Mechanism" refers to the processes and approach of interaction between components or parts within a working system.

# 5.1 Mechanism of Achieving the Interconnection of Design Education Elements through Courses

In terms of the process, the mechanism involves utilizing the course as a carrier to establish the professional matrix by management organization, construct and impart course content by teachers, and acquire objective elements by students. This process results in the personalized combination of the three subjective elements - management organization, teachers, and students - and the three different modules of objective element combinations - professional matrix, course content, and the absorbed objective elements. In terms of the approach, achieving the interconnection of design education elements through courses, whether at the level of subjective elements or objective elements, follows a sequential order, demonstrating characteristics of temporality and linear linkage. The mechanism of achieving the interconnection of design education elements through Courses is shown in Figure 3.



Figure 3. Mechanism of Achieving the Interconnection of Design Education Elements through Courses

#### 5.2 Mechanism of Achieving the Dynamic Interconnection of Design Education Elements through the PDRA Cycle

In terms of the process, the three subjective elements of design education, in their respective PDRA cycles, influence each other during the "Do" and "Adjust" phases. They absorb the behavioural performances changes and generate new demands brought about by the other two subjective elements during the "Plan" and "Reflect" phases. In terms of approach, each subjective element actively engages in a high-quality execution of its own PDRA cycle, simultaneously interacting with the other two subjective elements in a cycle of "active absorption - natural influence - active absorption - natural influence." This interplay occurs while fulfilling the tasks carried by the object elements of design

education. The mechanism of Achieving the Dynamic Interconnection of Design Education Elements through the PDRA Cycle is shown in Figure 4.



Figure 4. Mechanism of Achieving the Dynamic Interconnection of Design Education Elements through the PDRA Cycle

#### **6** CONCLUSIONS

Through the study of the elements of design education, their interconnections, and the inherent logic of these interconnections, the research addresses the overarching research question of "how to construct the design education teaching and learning system," specifically:

1. Constructing a comprehensive framework for design education subjective and objective elements, with the objective elements being extracted using suitable methods guided by design education principles.

2. Using curriculum development to interconnect design education subjective and objective elements. During the curriculum development process, adherence to the sequential principles of the activities of the three design education subjects – management organization, teachers, and students – is crucial. This ensures the smooth transmission of the professional matrix, course content, and objective elements.

3. Propelling the iterative update of the design education teaching and learning system through the PDRA cycle ( $Plan \rightarrow Do \rightarrow Reflect \rightarrow Adjust$ ). In the iterative process, each subjective element should pay attention to absorbing the "Do" and "Adjust" situations of the other two subjective elements during the "Plan" and "Reflect" phases. Simultaneously, considering that one's own "Do" and "Adjust" behaviour may influence the other two subjective elements, stability of the "Do" should be ensured after formulating the "Plan." Unless there is evidence through "Reflect" behavior that improvements are needed, arbitrary adjustments should be avoided without a valid basis.

Building courses through the PDRA cycle to construct the teaching and learning system of design education theoretically applies to design education/curriculum development in different locations. The difference lies in the objective elements, as different universities in different places may vary due to their environmental conditions, developmental backgrounds, and educational philosophies. However, the overall development approach is applicable beyond these differences.

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## CULTURALLY GROUNDED SPECULATION: FRAMEWORK FOR ETHNOGRAPHY INFORMED AI-DRIVEN DESIGN FOR DIVERSE FUTURES

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#### ABSTRACT

Novel advancements in design processes, such as broader consideration of context and culture to address complex global challenges, along with the emergence of generative AI to aid in ideation and iterative prototyping, necessitate equipping design students with a deep understanding of the people and societies they serve, as well as responsible AI usage. Speculative design practices harness the power to envision collective, ideal futures, which is helpful in addressing complex, wicked problems, however, the practice has been accused of producing Western-centric outputs. Generative AI presents an additional challenge in developing culturally relevant design solutions given its inherent biases limiting designers' capabilities. This study employed a mixed-method approach to investigate how designers can utilise AI technology to visualise culturally relevant depictions of the future and create speculative design outputs solving wicked, culturally driven problems. The results showed a clear need for integrating AI into the design process and highlighted the current pitfalls of AI image-generation platforms. The proposed design process addresses these gaps by leveraging ethnographic research principles to create contextually based generative AI outputs for speculative design ideation. This process allows designers to robustly imagine how future trends and technologies fit into wider cultural contexts. It exemplifies the view that responsibly engaged AI technologies augment human abilities, providing a new layer of intelligent sociocultural considerations for creatives to reference in their design process and evaluate with affected communities.

*Keywords: Design education, generative AI, speculative design, innovation design, behavioural science, ethnographic research* 

#### **1** INTRODUCTION

Designers and creatives have begun to employ generative AI platforms for tasks that would have previously been carried out by humans, potentially altering creative processes [1]. Particularly, generative AI is being integrated into the initial stages of a design process for exploration, ideation, and digital prototyping [2, 3]. As a result, there is a rising necessity for design educators to include AI literacy in their curricula to ensure students are integrating the technology collaboratively and are prepared for the job market, especially considering creative professional work is at a high risk of automation [4]. In addition to educating students on AI technology, the scope of design is expanding to include creative solutions for complex, wicked problems - many of which tend to be culturally determined [5]. It has been argued that the nature of global problems has evolved into a network of connected issues that designers should engage with as a system [6]. This skill can be acquired by analysing how communities are affected by an issue as a whole and carving out the space for those affected to be involved in the codesign and co-production of the solution [6]. Moreover, the nature of wicked problems that designers engage with often requires creating innovative solutions to solve for 'value divergence,' defined as stakeholders' conflicting values in the face of complex issues [7]. These notions point to a need for design educators to impart a deep understanding of the context students are operating within to design interventions that tackle system-wide wicked problems whilst including diverse stakeholder perspectives and culturally specific environments. The rise of generative AI in the creative field presents a challenge because AI technology, as it is currently produced, is unable to meet the needs required to co-creatively design solutions for diverse stakeholders and global environments. AI technology is known for propagating cultural biases and Western perspectives [8] limiting its ability to handle complex

and wicked problems presenting potential dangers in its application to the design process. Therefore, when it comes to the implementation of generative AI platforms in the design process, there is a rising demand for creatives to be provided with guidance on ethical AI usage in design [9] and responsible cocreation with generative AI to enhance creativity and innovation [10]. Efforts have been made to ensure an ethical approach to the development and deployment of AI [11], however, how these efforts are put into practice is dependent upon their application and requires more research into ethical AI use for design. Nevertheless, although flawed, AI technology holds the power to collaboratively produce culturally relevant, future-forward solutions alongside designers. The field of AI ethnography proposes an anthropological study of datasets to ensure AI models are capturing the diversity, culture, and values of humans. Through the practice, we can analyse datasets used to build models and pinpoint where the issues of missed cultural representations occur [12]. More research is needed to learn how to use AI to assist in designing for cultures other than our own and further contextualise future innovation by developing diverse and representative datasets. In addition, to untangle wicked problems, speculative design presents a potential solution enabling designers to apply foresight practices to create probes that challenge the limits of our existing systems and provide new forms of visual representation of technology, opening up a variety of possibilities for debate [13]. However, like generative AI, speculative design as a discipline has been criticised for creating outputs made 'by, for, and through the eyes of the western, intellectual, middle classes,' dealing with issues tangible to its own privileged audience and failing to work with surrounding communities [14]. Although speculative design has the potential to be a tool that makes imagining futures and provoking discussion surrounding wicked problems accessible to all, these critiques must be addressed for the practice to live up to this potential. In summary, designers are increasingly being tasked to solve complex, culturally driven wicked problems that require a deep understanding of diverse stakeholders' perspectives and environments to solve. The rise of AI technology's integration in the creative process presents a challenge in developing these solutions given its biases that limit the designer's capabilities in creating culturally relevant outputs. There is a demand for design educators to propose new creative processes that integrate AI in a culturally sensitive way to solve complex, wicked problems. Further research is needed to understand the combined capabilities of AI ethnography and speculative design in a design process to address these gaps. Therefore, in this study, we aim to investigate how designers can harness AI technology to visualise culturally relevant depictions of the future to create speculative design outputs in order to ultimately solve wicked, culturally driven problems. The guiding research questions read as follows:

- RQ1: How are design students currently utilising generative AI technology in their creative process?
- RQ2: How can a creative process be designed to promote cultural relevancy and reduce bias in AI image generation for creative outputs?
- RQ3: How might we utilise generative AI technology to speculate about contextualised future scenarios for creative output inspiration?

#### 2 METHODS

#### 2.1 Participants

A total of 15 students were recruited from a postgraduate campus class for a questionnaire, using convenience sampling in the School of Art, Design, Media by invitation. As students took a course about learning how to use AI image generators for creative outputs including product design, futures scenario building, and artistic pursuits, they held prerequisite knowledge on AI technology for the design process, providing this research with deeper insights on AI usage. Three researchers from this study (and postgraduate Design Engineering students) participated in the subsequent auto-ethnographical phase of the investigation.

#### 2.2 Research design

To best pursue the aims of this research, the study employed a combination of both quantitative and qualitative methods in an explanatory sequential design where a quantitative study phase was used to inform a qualitative investigation [15]. This design is widely employed to evaluate the effects of context and various influences in which one method enriches another for a robust and comprehensive analysis [16]. The study consisted of two stages. In the first, a small-scale exploratory questionnaire was shared with a class of postgraduate design students with background knowledge in AI image generation to gather data on their generative AI usage and validate the research mandate. Following the questionnaire,

a qualitative auto-ethnographic approach was employed to further investigate the capabilities of introducing AI in a design process to contextualise the images generated and produce culturally relevant speculative design outcomes. First, an autobiographical method was utilised to test and select an appropriate image generation platform for the research aim. Subsequently, a criterion was crafted by which to evaluate the generative AI outputs to be able to detect the level of cultural relevancy of the intended context. The last phase consisted of producing culturally relevant speculative imagery grounded and informed by future trends.

#### **3** FINDINGS AND DISCUSSION

#### 3.1 Exploratory questionnaire results

The questionnaire aimed to uncover how students in a postgraduate design program are currently employing generative AI technology, considering the tools and platforms they are utilising, and their opinions on AI integration into the design processes. The questionnaire was completed by students specialised in diverse design fields including product design, urban design, game design, animation, and AI computer engineering with a foundational understanding of AI image-generation. 67% of students had utilised AI image generation products before and 33% of respondents mentioned Stable Diffusion as their most used product. 47% used AI to generate image/video for animation design and when asked what they found most challenging about AI, the majority of respondents selected "prompt writing" and "getting a desired outcome" as their answer. However, 87% of respondents were likely to extremely likely to use AI again in a future creative project. Lastly, when asked if design students saw any issues in using generative AI products for creative ideation and inspiration, respondents answered with "ethical and copywriting issues", "lack of control", "the amount of tweaking you can do with some of the tools can be quite overwhelming and post-processing is often necessary to get decent results". These results show a clear need and enthusiasm by design students to integrate AI technology into their creative process, however, students raised valid concerns regarding responsible and ethical AI usage, further validating the research aim to investigate the potential of a design process that integrates AI in a culturally appropriate and sensitive manner.

#### 3.2 Initial Generative AI Platform Experimentation

Research tells us exposing design students to cutting-edge technology, including its foundations, uses, and development can stimulate innovative solutions to wicked problems [17]. This investigation fulfils the students' needs found in the questionnaire by providing them with a structure to ethically incorporate AI into their practice promoting a stimulus for students to design solutions to wicked problems. Therefore, our second research aim was to investigate how AI can be incorporated into the design process to increase cultural relevancy and reduce the chance of bias. To do this, it was imperative to develop a process that facilitates culturally sensitive outputs operating within current AI technology offerings. We began by identifying Stable Diffusion Automatic 1111 Web UI interface [18] as the most suitable platform to integrate within what we have coined as the "ROOTS: Grounding AI" process. Stable Diffusion as a platform provides the highest level of customisability giving students the option to choose models from online communities such as Huggingface [19]. Additionally, more than 300 plugins are available through the automatic 1111 platform, further expanding students' options. We then evaluated Stable Diffusion's success rate in depicting the present in a culturally informed way. To standardise our results, we used this question: 'How do Hawker Centres function in Singapore today?' during an international placement in the region, as guidance to depict simple, everyday acts of eating or drinking in public hawker food markets. We conducted ethnographic testing, comparing images the researchers took to images generated by Stable Diffusion using descriptive prompts. Results from these initial tests showed us that the model alone could not fully capture the nuances of culturally specific environments and interactions. Figure 1 shows an example from the results of these initial tests.



Figure 1. Initial tests with Stable Diffusion showing stereotypical representations of Singapore

We then conducted further ethnographic research and experimented with the addition of various plugins into the Stable Diffusion workflow to get a more accurate representation of present Singapore. Observational research and photographic artefacts were utilised as inputs to engineer hyper-specific prompts and newly generated images. By employing the ControlNet with Depth extension [20] on users' uploaded photos, a depth map of that image is created. An AI-generated image can be made building onto the depth map of the original photograph, making the overarching structure of the generated image consistent with the uploaded photo [21]. We evaluated the success of the images by assessing "How realistic are the generated outputs?" and "How closely were the prompts followed in the outputs?" for every image generated. The criteria outlined in these two questions allowed for further refinement of the process. The results of this exploration, as shown in Figure 2, showed Stable Diffusion to be successful in generating culturally informed outputs when hyper-specific prompts and real images sourced from the environment were used as the foundation.



Figure 2. ControlNet Extension to generate image depth, leading to a more accurate output

#### 3.3 Applying the "ROOTS" process for generative AI speculative design

Using the guiding question of *"How will Hawker centres function in Singapore in the future?"* we moved to examine how the "ROOTS" process might be applied to imagine how the interaction previously tested might look in the future for speculative design production. The first step in doing so was identifying possible futures to envision. Using the Singapore Centre for Strategic Future's Foresight report [22], two key possible future trends were identified. Firstly, Singapore's movement towards sponge city infrastructure as a solution to increasing inundation, and secondly, Singapore's incorporation of SMART city technologies. Applying our process to imagining how interaction scenarios at Hawker centres might look if these possible futures became a reality allowed us to examine whether generative AI could accomplish a contextualised depiction of future Hawker centre scenarios. To speculatively imagine how these future trends might look in a Singaporean context, we used the Stable Diffusion setup outlined in the prior paragraph and updated prompt keywords from the present-day context with new keywords describing the selected future trend. Figure 3 shows two examples of speculative images depicting Singapore as a sponge city and with SMART city technology respectively. Comparing these future images to the original images of the present taken during ethnographic research, it is clear to see instances where cultural codes and connotations have carried through.



Figure 3. Left to right: original photograph, sponge city future, SMART city future

This last step allowed us to finalise the "ROOTS" process, with the aim being for the process to be used within design research and design education to generate images used to open discussions on wicked problems and critically reflect on how possible futures might look as a solution. Figure 4 depicts the "ROOTS" process, representing a path towards ethnically incorporating AI into the design process, whilst tackling relevant wicked problems in a culturally grounded, focussed manner.



Figure 4. The ROOTS process from input to generation

#### **4** CONCLUSION AND LIMITATIONS

Our research findings demonstrated that students are promptly adopting AI into their workflow for its great potential, however with valid concerns relating to ethical and responsible usage. Design education must provide students with guidance on responsibly incorporating AI in design processes. The rise of generative AI is accompanied by the expansion of design goals to incorporate solving system-wide. wicked problems through speculative design. For these developments to co-exist, designers need to have greater cultural awareness, whilst incorporating AI and speculative design in a culturally sensitive way. The goal being to ethically co-design future solutions with stakeholders, a rising need in collaborative generative AI usage [23]. The "ROOTS" process offers a framework to address these challenges, drawing on principles of AI ethnography to pave the way for ethical AI usage within the design process, particularly in the ideation, visual prototyping, and iteration stages of interventions, including designed products. The process can be applied to creative teams who engage with communities in the creation of a design intervention such as urban planners ideating on the design of public spaces, foresight practitioners looking to conceptually visualise ideal futures, and designers speculating on future services and products. However, it must be noted that this process is not without limitations. Firstly, the images generated using the "ROOTS" process mustn't be seen as final outputs, but rather as a catalyst for critical discussion and ideation. Secondly, the process should be used with caution, and by individuals who have

developed prior knowledge of the biases within AI datasets in order to utilise ethnographically informed inputs. Lastly, future research should further validate the process with diverse stakeholders.

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# A FRAMEWORK FOR INTEGRATING SDGS INTO UNIVERSAL DESIGN EDUCATION IN CHINA

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#### ABSTRACT

Integrating the Sustainable Development Goals (SDGs) into design education and building up the knowledge base in this area is probably one of the most pressing tasks and challenges for Chinese design educators because of the increasingly serious issue of aging. Universal design, considered an effective tool for eliminating inequality and promoting social inclusiveness, is a suitable bridge for implementing SDGs into design education. It has the potential to help students appreciate user capabilities, needs, and expectations, and is increasingly important in mainstream design education. However, adopting SDGs in universal design education still meets many barriers in China. This study focuses on these barriers and tries to find possible corresponding actions based on a series of universal design workshops since 2017 at Shanghai Dianji University organized by the authors. Many research methods have been utilized, such as literature review, expert interview, and case study. Many influencing factors have been hypothesized and examined by questionnaire or interview, including major, grade, real user participation, icebreaker, tea break, variety of teaching places, etc. Through quantitative and qualitative analysis, some key factors are focused and put into discussion. Finally, a preliminary conceptual framework is proposed to embed all positive influencing factors to integrate SDGs into universal design education in China.

Keywords: SDGs, universal design, design education, China

#### **1** INTRODUCTION

China is facing an enormous demographic shift. According to the latest statistical communiqué from the National Bureau of Statistics of China in 2023, the percentage of the population aged 60 and above will be 19.8%, and those aged 65 and above is 14.9% by 2022[1]. "With the occurrence of a rapidly aging population, the issue of universal access and inclusivity is a challenging and complex one" [2]. The SDGs were adopted at the UN Summit held in 2015, which have 17 goals with 169 targets, are designed to build a sustainable world under the motto of "No one will be left behind" [3]. There are various approaches to solving the challenges of SDGs, but in recent years, the power of universal design has been attracting attention. "Universal design" shall not exclude assistive devices for particular groups of persons with disabilities where this is needed" [4], was identified as a response to the issue of aging, has become a worldwide movement [5]. Universal design, which is defined by the United Nations Convention on the Rights of Persons with Disabilities as "the design of products, environments, programs, and services to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design [4]. SDGs have attracted widespread attention in Western countries, the key problem is how to transfer it to implement, and it is significant to develop and nurture a generation of aware and well-equipped young designers. However, it is crucial to integrate SDGs into design education. In China, there are many practices in recent years. A series of universal design workshops towards SDGs have been held since 2017 at Shanghai Dianji University. Similar workshops were held at Tongji University and Donghua University in 2018 and 2019. SDGs design international competition hosted by Kyushu University was introduced to China, and many Chinese university students participated in this competition and won awards.

Although a great deal of effort is made, there are still many challenges in China. For example, SDGs are seldom embedded in courses in the curriculum for undergraduate design education. The involvement

of real users with various capabilities loss is still limited by timetable or funds. In addition, SDGs approaches need to be translated into the Chinese context. Besides these, finding resources and tools to support SDGs in design education in Chinese is hard. There is no ready teaching textbook in Chinese for the moment. The abovementioned phenomenon suggests that SDGs do not widely spread as we hoped in China. This paper tries to identify the barriers and limitations of integrating SDGs into China's universal design education. Corresponding strategies are suggested in the form of a conceptual model in the end.

#### 2 METHODOLOGIES

At first, a literature review focused on SDGs and universal design education was carried out. The practices and perspectives from different countries are synthesized. Compared with the barriers to integrating SDGs into design education from the literature review, related to the author's experience in a series of universal design workshops towards SDGs at Shanghai Dianji University, preliminary barriers were initiated empirically, then demonstrated to expert interview.

The expert interview aims to get some perspectives and insights from interdisciplinary experts, especially from teaching administrators in the Chinese context. Nine experts were interviewed, and they are from these two areas:

- Design education (5 persons on product design, one from Tongji University, one from Donghua University, one from Kyushu University, and the others from Shanghai Dianji University)
- Teaching administration (4 persons from the teaching affairs office of Tongji University and Shanghai Dianji University, covering educational theories, teaching organization, and students' innovation projects administration)

The interview was face-to-face and open-minded, beginning with a free talk on China's education situation, aging problems, challenges, and opportunities. Then the topics moved to in-depth discussion on integrating SDGs into China's education system. A brief introduction of SDGs and universal design was given to the experts from teaching administration in advance. The preliminary barriers were brought forth and assessed. Perspectives from design education and teaching administration experts were absorbed and four aspects of barriers were finally clarified.

Three experts mentioned the effectiveness of the Double-Diamond Model (DDM) in short-term workshops on universal design education. DDM, according to the Design Council, is a visual representation of the design and innovation process. It's a simple way to describe the steps taken in any design and innovation project, irrespective of the methods and tools used [6]. A further case study of Shanghai Dianji University's universal design workshops which was based on DDM was carried out. The student questionnaire results also confirmed this teaching paradigm's positive significance. Based on these, a conceptual framework was outlined under the context of China.

#### **3 LITERATURE REVIEW**

A critical review focused on SDGs and universal design education was carried out. The literature review synthesized many practices and cases from different countries.

During the literature review, some perspectives from Western researchers about strategies and barriers of introducing inclusivity into design education were found [7], which can bring some insights for integrating SDGs into China's universal design education. It is summarized in table 1:

Aspects	Perspectives				
Strategies	To drive a socially inclusive agenda into the heart of a design college or university				
_	through the teachers, tutors, and professors, the people who are the core of design				
	education and management.				
	To work directly with the design students to engender a more inclusive approach in				
	their design practice.				
Barriers	Few design courses teach universal design as a distinct unit and an introduction to the				
	subject is often left to one or two seminars or lectures.				
	Timetable demands mean that little time can be spent exploring the core benefits and				
	wider practice of universal design.				
	Design is a time-pressured profession and teaches both the creative and the				

Table 1. Strategies and barriers to introducing SDGs into Universal Design education

constructive elements of a design course can fill most of the available studio time.
As design is a subject that requires the constant development of both personal taste
and expression, therefore there are few opportunities to get inclusive thinking into an
already packed curriculum.
To drive a socially inclusive agenda into the heart of a design college or university
through the teachers, tutors, and professors, the people who are the core of design
education and management.

#### **4 EXPERT INTERVIEW**

Expert interviews provided information on the barriers from two aspects, one is from the angle of design education, and the other is from the angle of teaching administration. The perspectives are sorted out in table 2:

Aspects	Perspectives				
Design	Design education is sometimes less connected with the industry.				
education	Cannot find appropriate textbooks in Chinese.				
	It's hard to find excellent teaching cases in China.				
	It's difficult to adopt SDGs methodologies.				
	Real user involvement may cause economics, administration, ethics, and				
	problems.				
Teaching	Universities are likely more employment oriented.				
administration	It's difficult to conduct interdisciplinary education because of the limitations of				
	colleges and major divisions.				
	Lack of flexibility of course system and class organization.				

Table	2.	Expert	interview	results

Based on interview results, the barriers to integrating SDGs into China's universal design education can be preliminarily catalogued into four aspects, and corresponding responses are initiated:

• Barrier: Lack of awareness

Response: Propaganda from different representatives and different levels

- Barrier: Lack of resources
- Response: More resources and tools in Chinese
- Barrier: Practical difficulties

Response: More practice, training, and cases

• Barrier: Financial and cultural factors

Response: More funds and guidelines

In response to the barriers and responses, combined with the experts' suggestion to integrate SDGS through a workshop based on DDM, a case study was conducted to address the above issues. This case is based on financial support from the university, guided by the DDM model, and integrated SDGS through a universal workshop. Stakeholders from different fields have been attempted to be introduced, and various resources and tools have been provided. This case provides a good example and attracts public attention to SDGs through different occasions.

#### 5 CASE STUDY

Towards the needs of aging society, the School of Design and Art of Shanghai Dianji University identifies service design and health design as the key development directions of the school's discipline. Under this context, with funding support from the university's "Distinguished Overseas Professor" project, the school invited the second author of this paper from Kyushu University and her assistants to hold a series of Universal Design Workshops since 2017 (summarized in Table 3). The workshops focus on the theme of SDGs and mainly aim to provide proposals for the design challenges of China's aging society in the future. Workshops are offered during the university's summer short semester and organized teaching based on DDM. Over 4 to 5 days, students discover design problems through social research and user interviews, brainstorm design solutions, create product prototypes through prototyping, and continuously iterate and optimize to ultimately produce the best design solution.

Year	2017	2018	2019	2023
Theme	Design Challenge	Design Challenge	Design Challenge for	Sustainable Future
	for Aging Society	for Aging Society	Chinese Future Aging	Design for Children
	2030	2030	Society	
Time	6.27-7.1 (5 days)	6.26-7.2 (5 days)	6.23-6.26 (4 days)	6.18-6.21 (4 days)
Students			<sup>.</sup> ≥×24, <sup>.</sup> ×12	<sup>.</sup> ≥ ×20,  ×13
Real users and	<b>e</b> ×6	<b>e</b> ×6	$\bullet$ ×6. $\bullet$ ×3. $\bullet$ ×3.	/
stakeholders'		-		
participation			• ~2, • ~3	
Teaching place	₽□℃	₽□℃	₽□℃	₽□合
Others	X G 🗖	X G 🗖	X G 🗖	X G 🗖
🙂 = undergraduate student on product design of grade 2; 🙂 = undergraduate student on product design				
of grade 3; 🙂=undergraduate student on digital media design of grade 2; 🔍= undergraduate student				
on digital media design of grade 3; 🖱 = real user; 🕮 = nurse; 🙂 = engineer; 🕮 = international student;				
😇 =other professional; 쯕 =brainstorm room; 🖸 =model workshop; 🏠 =presentational hall; 🛛				
=icebreaker; 🗁=tea break; 🖵=final presentation				
Each process of the workshop is recorded and photographed. The outcome of student works generally				

Table 3. Universal Design Workshops at Shanghai Dianji University

Each process of the workshop is recorded and photographed. The outcome of student works generally includes PPTs, physical models, and demonstration videos. Students are required to complete qualitative and quantitative questionnaires before and after the workshop and write their feedback on the commemorative book. All these materials have been carefully organized for further analysis. Through vertical comparative analysis of workshop student learning outcomes and student evaluations, as well as horizontal comparative analysis with similar workshops and courses at Shanghai Dianji University, some factors that can have a positive impact on student learning outcomes and experiences have been selected, they were summarized in Tabe 4:

Influencing	Implementation status	On-site photos
factors		
Real user	Old volunteers as real users were invited to join each student	
involvement	team, give their insights or advice, evaluate design solutions,	
	assist with the prototyping, and attend the final presentation	
	during the workshop.	
Different	Different stakeholders including nurses, engineers, and other	
stakeholders	professionals were invited to join student teams in the	
	beginning of the workshop. Their professional opinions can	
	help students understand the various factors that design	
	schemes need to consider in the real world.	
Interdisciplinary	The later workshops attempted to build student teams across	
collaboration	different majors and grades. Compared with the early student	R 600 1
	teams composed of a single major and grade, teams who cross	
	major and grade exhibit higher learning enthusiasm, more	
	active thinking, and better design outcomes.	
Icebreaker	The diverse icebreakers activities such as games, mini-	No NACIO
	competition, or outdoor activities, etc. provide students with a	
	different experience from traditional classrooms. According to	
	student questionnaires, they gave high evaluations to	EXT IN SEC
	icebreaking activities, which enliven the classroom atmosphere	Tel martin
	and stimulate innovative thinking.	
Tea break	The students left a deep impression on the tea break during the	A 02
	interview. Although tea breaks are rare in traditional	A A A A
	classrooms, they can alleviate stress and stimulate innovation	
	for short-term high-intensity workshops.	- AAA

Table 4. Positive influencing factors in the workshops

Variety teaching places	According to teaching requirements, the workshop's teaching place is constantly changing from classrooms suitable for lectures, and off-campus locations for social research, to brainstorm rooms for inspiring design proposals, model	YAR
	workshops for prototyping, to auditoriums for final presentation. The conversion of teaching places is more in line with the workshop's progress and promotes better student outcomes.	
Quick prototyping	Quick prototyping runs through the entire process of the workshop. Students were provided with various materials in the early stages of the workshop. They were encouraged to creatively use various items to make quick prototyping. In the later stages of the workshop, students entered professional model workshops to create more detailed physical models.	
Final presentation	The final presentation helps to create a sense of ceremony, and students can combine PPTs, physical models, and videos for comprehensive presentations, and even incorporate performances. The works of students were comprehensively evaluated by teachers and students, and outstanding teams were awarded on-site recognition.	

#### **6** A CONCEPTUAL FRAMEWORK

This conceptual framework (Figure 1) is a proposal and still needs to be continuously improved in practice. It manages to accommodate all the positive influencing factors of integrating SDGs into China's universal design education based on DDM. From left to right are "two diamonds": the first diamond helps students understand, rather than simply assume, what the problem is. It involves speaking to and spending time with people who are affected by the issues. The insight gathered from the discovery phase can help students define the challenge differently; the second diamond encourages students to give different answers to the clearly defined problem, seeking inspiration from elsewhere and co-designing with a range of different people. Delivery involves testing out different solutions at a small scale, rejecting those that will not work, and improving the ones that will.



Figure 1. A Conceptual Framework for integrating SDGs into universal design education in China

During this process, the integration of SDGs into universal design education under the Chinese background has several positive factors. The timing for introducing these factors into DDM is shown in Figure 1. At the beginning is SDGs statement, the background, purpose, and significance of SDGs need to be introduced to students. At the start of the first diamond, students need to consider cross-disciplinary considerations when grouping. It is necessary to invite different stakeholders to join the team at this stage to provide various required information. Real users need to join the team from the beginning to

help students better understand the needs of special users. Real user participation needs to be implemented throughout the entire workshop process. During this period, considering the constraints of funds and energy, online participation can be partially adopted. Icebreakers can be dispersed in the workshop. In the early stages of the workshop, icebreakers can help students from different majors, stakeholders, and real users quickly familiarize themselves with each other and establish good teamwork relationships. In the middle of the workshop, when a task lasts for a period, it is possible to consider engaging in icebreaking activities, which can have a good relaxing effect and help to liven up the atmosphere, promoting divergent thinking. According to the needs of workshop teaching, it is necessary to find different optimal teaching places. There is a need for a learning place suitable for lectures, a place that helps with divergent thinking and the production of simple models, a place for making detailed prototyping, and a place for final presentations. If the furniture and layout in the classroom can be easily moved and assembled, some of these places can also be combined. Starting from the second diamond model, prototyping with different accuracies can be dispersed throughout the process. When discussing the initial plan, a simple model can be used to evaluate the plan. In improving the plan, making different prototyping can help optimize and iterate the plan. After determining the final plan, it is necessary to create a more refined model, which is usually completed in the model workshop. During the workshop, tea breaks can be provided, which can be distributed to teams or placed in designated areas of the classroom for students to enjoy. Finally, after students have completed all their work, a more formal presentation and display can be organized. Student teams will report and showcase their works one by one on stage, which will be evaluated by the teachers and students below. Outstanding works can be awarded certificates. At the end of the final presentation, the goals of SDGs need to be reviewed and reflected upon, and the social responsibility of designers should be emphasized.

#### 7 CONCLUSION AND FUTURE WORK

The study focuses on integrating SDGs into China's universal design education, a literature review was conducted mainly among key publications on SDGs and universal design education. Practice and perspectives were synthesized and barriers to integrating SDGs into China's universal design education were initiated and judged through expert interviews. A case study was carried out to find the positive influencing factors. Then a preliminary framework based on DDM was generated. The framework suggests the likely route of integrating SDGs into China's universal design education. It shows the possibility of potential application for China's design educators.

However, the framework is primarily based on empirical study. More literature review and practice may take place in the future to improve this framework.

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### VISUALISING SPECULATIVE MATERIALS: USING TEXT-TO-IMAGE PROMPTING TO ELABORATE LIVINGNESS AS A DESIGNED MATERIAL QUALITY

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#### ABSTRACT

Generative AI (GAI) technologies have started to transform design processes through integration into various stages such as research, ideation, visualisation, and reporting. Designers use textual prompts to quickly incorporate AI into their workflow, involving crafting precise sentences and keywords to guide desired outcomes. This paper focuses on using Midjourney, a popular text-to-image GAI program, in an academic research-through-design (RtD) process within a bio design workshop. The workshop explored future cohabitation possibilities with living materials, using design fiction to gain empirical data. Midjourney was used to convert design fiction narratives into visual representations to provoke design discussion. The narratives were initially created through recordings and creative outputs. Then, each was analysed and transformed into a GAI prompt, incorporating specific descriptive elements from each workshop participant's narrative. Midjourney was effective in this context because it visually bridges the gap between the abstract nature of fiction and the tangible aspects of material design, contextualising design proposals in futuristic settings. The approach facilitated the quick generation of visual interpretations of living materials, prompting discussions on the viability of their qualities. The results underline two key insights: text-to-image GAI programs like Midjourney offer significant potential for visualising narrative-based design concepts and broader story worlds. Secondly, these programs can aid in exploring and communicating the functional and experiential qualities of new or proposed materials, improving stakeholder engagement in design education and practice and indicating one of the emerging roles of GAIs in future design processes.

*Keywords: Design fiction, material design, speculative materials, text-to-image prompting* 

#### **1** INTRODUCTION

Marking a milestone within the design domain, the emergence of Generative AI (GAI) models in 2022 created a new playing field for designers. Since then, GAI models have been refined daily and proved helpful as a professional design tool with a 'fun factor.' Designers increasingly use GAIs to contribute to their research, ideation, visualisation and reporting [1], [2]. Design research, on the other hand, is increasingly carrying out research around these models, seeking out their impact on practice and education [3]. Parallelly, higher education institutions (HEIs) seek legitimate ways to integrate such models into curricula to raise tomorrow's graduates [4]. Recent publications have investigated the use of text-to-image models from the perspectives of prompt crafting [5], co-creativity [6], and visualisation [7]. Research in these areas will likely grow substantially as novel features are integrated and new methodologies are developed.

Starting initially through improvision, then embedded into an academic research process, this paper presents the outcomes and potentials of a text-to-image model in a design practice context. The application area is materials and design, focusing on cohabitation possibilities with living materials in scenarios at least a decade away. Future forecasting and design fiction are necessary because living materials are not mainstream. With necessary technological and practical advances, they are predicted to slowly become part of the designer's material possibilities. To prepare and raise awareness of design, interaction, and societal potentials, this research utilised Midjourney to visualise speculative living materials whilst communicating what 'livingness' might mean within story worlds that feature artefacts or spaces made with living materials.

#### 2 BACKGROUNDS

#### 2.1 Biodesign

Biodesign is a design paradigm that incorporates livingness in the design processes. Myers [8] defines the field as creating designed artefacts where an organism's livingness is an essential design factor. A broader definition still needs to be made, making the paradigm yet to be clarified.

Accordingly, perspectives towards integrating living entities within design outcomes revolve around two significant milestones. The first is biofabrication as biodesign, coming from the point that every living organism is matter that designers can use and where livingness occurs during fabrication to obtain bio-based material(s). With the emergence of more-than-human discourse [9], the biodesign paradigm turned to a second milestone, in which bio-entities form the basis of living artefacts where livingness is extended into the use phase of a product, implying cohabitation possibilities between bio-entities and human users/occupants [10]. Often, living artefacts are a hybrid of conventional material(s) and organisms, which was one of the general approaches adopted in this research.

#### 2.2 Relation of Livingness to Material Qualities

Karana et al. [11] define four potentials of materials: form, function, experience, and affordance. These potentials are realised or harnessed by designers according to the Materials Experience (MX) framework, which in its most developed version has four distinct categories of keywords/adjectives (e.g. senses, meanings, emotions, actions) [12]. However, for living materials, typical entries under these keyword/adjective categories (e.g. *fragile, natural, sustainable*) are found insufficient [13]. Instead, each category requires specialist elaboration since living materials show different qualities from conventional materials. On this point, Ertürkan et al. [14] devised a livingness vocabulary considering the unique qualities of living materials. Keywords such as *growing, decaying, temporal, dying, etc.*, were proposed.

#### 2.3 Biodesign Fiction and Investigating Cohabitation Possibilities

As one of the popular speculative spaces in design research and practice, design fiction refers to envisioning and designing an artefact or other design outcome for a probable (though often far off) future setting. Multiple media are used to construct what is referred to as a diegesis: usually, a verbal narrative intertwined with visual or tangible artefacts, which, when combined, give a speculative but persuasive character. Sterling defines design fiction as "...the deliberate use of diegetic prototypes to suspend disbelief about change" [15]. Accordingly, biodesign fiction, coined by Camere and Karana [16], is the merging of design fiction and biodesign to define design outcomes based on or around biological entities, which are speculative and can be positioned within probable futures. Using biodesign fiction as the theoretical foundation, this research explored the potential effects and impacts of living artefacts on user experiences (i.e., living aesthetics, mutualistic care, habitabilities, and cohabitation practices).

#### 2.4 Research through Design Fiction

Research through Design Fiction (RtDF) is an approach to design research in which design fiction is deployed as the primary instrument for generating relevant data [17]. RtDF notably emphasises the creation of diegetic prototypes (or simulations) specifically crafted to align with a constructed narrative or diegesis, envisioned with future contexts in mind. Besides tangible assets, diegetic prototypes can be in various formats, such as narratives, scenarios, films, and drawings. These diverse forms serve as engaging and provocative gateways into the diegesis and, in the context of RtDF, serve as the primary medium for leveraging the research questions and reaching new insights and knowledge [18], [19].

#### **3 RESEARCH DESIGN**

A design fiction workshop was conducted to gain participants' insights into the speculation of futures where people cohabit or co-work with living artefacts. The research was conducted in four consecutive steps following a RtDF approach: sensitisation towards biodesign, design and implementation of the workshop, analysis of workshop outcomes, and generation (by the first author) of narratives and Midjourney visualisations.
#### 3.1 The First Three Steps

First, a sensitisation field trip to a biodesign lab in the Netherlands was arranged. This provided an opportunity to become acquainted with living materials, converse with researchers, and help design the workshop. Nine design graduates from various backgrounds (industrial design, interior architecture, and architecture) participated in the full-day workshop by working in three groups. The participants' voice recordings and design outcomes were analysed qualitatively, principally via thematic analysis, to reveal possible futures for living material and, secondly, to evaluate the RtDF workshop as a tool for generating empirical research.

#### 3.2 Creating the Narratives

After the thematic analysis, narratives were created by reorganising the fragmented definitions of participants' story worlds throughout the workshop into an orderly sequence. A narrative for each group was shaped by combining and selecting items that participants had mentioned based on their speculations. It is essential to highlight that these narratives were created to enhance understanding of the living material futures put forward by participants rather than forming an additional dataset. To ensure the narratives were true to original intentions, approval – and, where necessary, suggestions for adaptation or change – was sought from members of each participant group. An effort was made to interpret the story worlds with as much neutrality as possible. In creating these narratives, advantage was taken of all the materials produced and recorded during the workshop, such as internal group discussions, debriefings, the creative outcomes, and data collection sheets.

We used MAXQDA software to thematically analyse transcripts and create narratives. Keywords and relevant sentences were extracted from the data. Most narratives used direct sentences from the data, with minor adjustments for coherence. Below is an example of a part of the narrative creation process based on one of the groups' discussions. The first set of sentences from the debriefing:

At the beginning of this study, the two cards we drew triggered the formation of the whole. One is <u>soil degradation</u>, and the other is <u>goods consumption and production</u>. <u>There is a state of absence</u>. The second card we chose was the opposite of that. So, on the one hand, we are told that there is nothing, and no problem is presented. On the other hand, <u>what could happen if you do not have such a human need comes to life in our minds</u>. This contrast was two statically different elements from the beginning.

Additionally, during the internal group discussions of the session, participants from the group explored reasons behind soil degradation and its possible consequences - these points are also noted, e.g.:

[There is] soilless farming, unplanned farming. Human mistakes killed the land. We had to give up the land to produce food.

Accordingly, the narrative was formed as follows:

After years of neglect and irresponsible usage of soil to produce goods to match consumption habits, the soil on Earth has degraded so much that humans cannot cultivate and produce anymore.

The narratives were completed and shared with the participants. No changes were requested. Three narratives, averaging 1000 words each, were created, serving as a starting point for visualising the workshop's stories and materials.

#### 3.3 From Narratives to Speculative Living Material Visuals via Midjourney

Midjourney is a GAI program that quickly generates high-quality images from text descriptions. Designers use it for ideation, conceptualisation, visualisation, and creating images of future concepts. When employing a design fiction approach, using Midjourney's ability to synthesise keywords leads to unique and sophisticated visual results that would be challenging to achieve manually.

The narratives provided the basis for prompts that enabled the GAI program to generate images, offering vivid phrases and imaginative concepts for visualisation. From a review of research on Midjourney AI, it was possible to establish some good practices regarding prompting: 1) describe the overarching scene, for instance, *a scene of reticulated hubs made of futuristic sticky knitted material on the sea*, then 2) incorporate specific adjectives, additional descriptions, and nouns, such as *people, surfaces, futuristic, etc.*, and 3) use common adjectives, nouns, and phrases popular within the Midjourney AI community to influence the style of the images, such as *hyper-realistic, cinematic lighting,* and *intricate details*. It is worth noting that prompting is an iterative process [5], so the tool was used multiple times to produce images that best matched the narratives in the authors' judgment.

Over 200 images were created and evaluated to determine whether they should be archived or kept as examples for the narratives. The decision to keep an image as an example was based on several criteria, including coherence with the narratives and accurate representation of physical aspects and sensory elements. The example images were shared with participants to confirm their accuracy. Table 1 provides examples of participants' sketches, related narrative phrases/keywords, and Midjourney outcome.

Phrases and keywords from narratives	Participants' sketches	Midjourney outcome				
"a novel habitat on the water / secretion of a novel marine microorganism species / affords insulation and wrapping / forming a structure for a semi-finished product that can be knitted / a form they can knit as if weaving a cloth / immense reticulated structures / habitable hubs"						
Prompt →	(/imagine) a scene of reticulated hubs made of futuristic sticky knitted material on the sea, people, hyper-realistic, futuristic, green cinematic lighting					
"a living material that can give sound which is fed on the extremity of actions carried out by people / a little slimy, soft / instantly hardens and forms crusts on it / crusts vibrate increasing a rattlesnake-like sound / it scares and needs a hiding place"						
Prompt →	(/imagine) a picture of a partly crusted softly seamless orbicular organic slime vibrating its crusts, hyper-realistic, futuristic, orange cinematic lighting					
"reflect the light / a type of camouflage for the culture / diamond / organisms live in the same habitat, which is like human skin / microorganisms in water / spraying the culture liquid on humans / human body as a catalyst for the initial chemical reaction to trigger the second"						
Prompt →	(/imagine) a picture of a huma which makes the human bo	an body sprayed by a blue liquid dy invisible, cyberpunk, hyper-				

 Table 1. Comparison of a) phrases and keywords from narratives, b) participants' sketches,

 c) Midjourney outcome, and d) Midjourney text prompt

#### **4 DISCUSSIONS**

In this study, Midjourney was employed to visually represent and communicate fictional concepts centred on speculative living materials. The application of GAI visualisation tools in design fiction research holds the potential for creating visual narratives of story worlds that can spark, extend, complement, or replace designers' visualisations. These points were precious for the research conducted for this paper, where the main topic (future scenarios in biodesign) and the chosen methodology (design fiction) were intended to initiate dialogue, raise questions, and stimulate discussion in areas which are inherently conceptual and discursive [20]. Utilising and embracing the discussion, which in turn help

realistic, blue cinematic lighting, 32k

elaborate questions and ideas that emerge around specific concepts. In this sense, instead of implementing Midjourney as an end deliverable, the visual narratives produced via Midjourney could instead act as an initial step to deliberately drive the discussion in a design fiction workshop setting. Furthermore, since the developers of Midjourney now provide the option to use images as prompts, combining images and text may yield even tighter representations of narratives.

The narratives and the speculative materials designed through the workshop were dominantly fictional. However, the GAI's potential to represent material qualities irrespective of fiction or reality was apparent even with short prompting. Through carefully selecting which aspects of materials are planned to be shown and using a purposeful definitive vocabulary [14], [21], the functional and experiential qualities of materials can be visualised or anticipated through text-to-image models. Furthermore, introducing images as prompt inputs allows speculative materials to be embodied in foreseen artefacts or other physical entities. Direct mapping of fiction and reality may offer great benefits for investigating material experiences around specific product design proposals. However, this issue needs further research on crafting prompts to represent material qualities and measuring their success in representing such qualities. Effective communication of experiential qualities of materials can be difficult because the affective and interpretive levels of materials experience are highly subjective [21]. Today, it is commonplace for a design school to teach visual communication skills to help novice designers communicate their design concepts, including materials communication. In a broader sense, GAI might be a more efficient and faster alternative for communicating such concepts. It may help educators deliver design curricula that focus more on the changing problems of the real world [22].

Despite the study underscoring the significant potential of GAI tools like Midjourney in visualising speculative materials, there are potential drawbacks to utilising such tools in the first place. GAI tools offer unique benefits in rapidly creating diverse visual representations. Yet, the potential biases in GAI-generated images and the challenges such as accurately representing living materials' qualities, reinforcement of existing stereotypes and the lack of diversity in generated outputs must be considered, along with broader issues around these tools, such as their effect on human creativity, copyright issues and causing misuse and misinformation scenarios. Also, analysing the outcomes of Midjourney and human sketches comparatively, while GAIs can produce compelling images, the depth of understanding and the scrutiny often captured in human sketches may be lacking. Also, human sketches, including the designer's intuition and creativity, still pose a challenge for GAIs to replicate. Hence, a nuanced utilisation of GAI tools in design processes will remain a prominent research subject.

#### **5 CONCLUSIONS**

There is increasing interest in using both GAI tools and design fiction in design education, but currently, only some examples of practices and applications exist. The paper has presented a systematic implementation of a text-to-image GAI tool, namely Midjourney, as the final step in a RtDF process to communicate story worlds and speculative material qualities. Text prompts for Midjourney were carefully crafted from narratives extracted from a generative design fiction workshop. The workshop delved into potential future user/human scenarios with living materials, employing design fiction to collect a pool of ideas for analysis.

The use of Midjourney in this research underscores the potential of text-to-image models to effectively bridge the conceptual gap between the speculative nature of design fiction and the tangible nature of materials in design. The findings highlight the significant role of GAIs in expanding the possibilities for design and material communication. GAIs could revolutionise how design education and practice communicate conceptual ideas – in this case, material designs – from early abstract versions to refined and developed proposals. A systematic evaluation of GAI tools to communicate specific material qualities is needed to establish the value of such tools within designers' materials decision-making.

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## ASSESSING COMPETENCIES FOR SUSTAINABILITY IN ENGINEERING EDUCATION – PROPOSAL OF METHOD THROUGH A PILOT STUDY

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#### ABSTRACT

Since 2010, the literature on Education for Sustainable Development has converged on a framework of key competencies that enable students to become relevant professional actors in the sustainability transition. We believe that the E&PDE community should build on this framework to improve the quality of pedagogical activities in design for sustainability. Our aim, through this paper, is to propose an assessment method to systematically evaluate students' competencies in relation to sustainability. We believe that this proposal will help researchers of our community by enabling teachers to have a better understanding of the level of their students in each competence. The self-assessment questionnaire we propose has been tested on 48 students, from 6 different classes. This Pilot-study enabled us to propose a ready-to-use questionnaire for colleagues of E&PDE community.

Keywords: Engineering for sustainability, key competencies, questionnaire, sustainability

#### **1** INTRODUCTION

Since 2010, the literature on education for sustainable development has converged on a framework of key competencies that enable students to become relevant professional actors in the sustainability transition. This framework is a "minimal set of distinct (non-overlapping) but functionally related key competencies, synthesized into an integrated perspective". Key competencies mean that the competencies are distinct from each other. The key competencies that make up a framework are systems thinking, future thinking, values thinking, strategic thinking, and interpersonal competence (collaboration). Some researchers have added intrapersonal and implementation competencies [1]. This framework has been adapted to engineering in general and can be applied to design engineering [2]. This framework can be considered as a strong basis for education for sustainability. We believe that E&PDE community do not build enough on this framework. Indeed, only 2 papers directly refer to key competencies for sustainability, in 2021 and 2023 [3], [4]. The first paper tends to understand which engineering competencies for sustainability have been developed in an engineering course; while the second paper focus on the assessment of critical thinking (1 competences added by [2]) through a specific learning activity - ideation process through design journals. Our goal, through this paper, is to propose an assessment method to systematically assess the competencies of students regarding sustainability ones. We believe that this proposal will help researcher of our community in three ways. First, it will enable teachers to have a better understanding of the level of their students in each competence. Second, it will enable teachers to reflect on their pedagogical practices to better relate their pedagogical activities with competencies for sustainability. Third, it will provide to researchers a stronger validation process to evaluate the efficiency of pedagogical activities regarding competencies for sustainability. Thus, the research question we are targeting in this paper is the following: how to systematically assess the competencies of students regarding sustainability issues? This paper describes a self-assessment method used to identify the level of students in each competency at the beginning of each semester. The method section will present the self-assessment questionnaire we have set up. The results section details the qualitative and quantitative data we gathered. The interpretation section discusses the usefulness of such evaluation for our community and proposes next steps.

#### 2 METHOD

[5] identified eight categories of tools for assessing students' sustainability competences that can contribute to promoting sustainability transformation within an integrated framework. We decided to build the scaled self-assessment tool: "Students are asked to rate their own competency development based on a pre-determined scale" [5]. To evaluate students' competencies for sustainability, we designed a questionnaire. For each competency, the questionnaire assesses the students' proficiency level and identifies the activities that helped them develop it:

- 1. The eight different definitions of the competencies translated in German from [6]
- 2. Open text box "Can you describe a situation in which you (further) developed this competence?"
- 3. Self-assessment (5 levels)
- 4. Self-assessment (5 levels) regarding 3 or 4 methods related to the competence.

Self-assessment has some weakness, one of them being that students can "inconsistently interpret the prompt and the scale" (Cebrian et al., 2019). This is why we decided to not go for a likert-scale but to use a precise self-assessment scale that is easy to understand by students (see scale on Figure 1 and 2). Thus, the levels defined are the following: "Level 0: I do not know the method; Level 1: I know the method but have never used it; Level 2: I can talk about this method; Level 3: I know this method because I have used it before; Level 4: I am very familiar with this method as I have used it several times."

Please indicate your level regarding the Systems-thinking Competency:

#### O Choose one of the following answers

Level 0: I have no knowledge or experience of this.

Level 1: I have a basic understanding but feel unsure about talking about it.

Level 2: I have basic knowledge and can talk about this competence.

Level 3: I have used some tools and methods to develop this competence.

Level 4: I am very familiar with the methods and tools and can use them successfully.

#### Figure 1. Level used for the self-assessment work in each competence

	Level 0: I do not know the method.	Level 1: I know the method but have never used it.	Level 2: I can talk about this method.	Level 3: I know this method because I have used it before.	Level 4: I am very fa- miliar with this method as I have used it several times.	No answer
Quantitative modelling (e.g. system dynamics or statistical modelling)						•
Qualitative Systemanalyse						•
Qualitative system analysis						•
Causal problem analy- sis (causal chain analy- sis, root cause analysis, etc.)						•

## Figure 2. Self-assessment on different methods related to the competence (competence systemic thinking in the screenshot)

#### **3 RESULTS**

Through the questionnaire, we gathered quantitative and qualitative data. We are going to present our conclusions and then show how this type of data collection can be used for further experiments. In our sample, we had 7 bachelor student and 41 master students. Half of master students were following

engineering curricula with a bit of sustainability issues whereas the other half were following a sustainable development curriculum with an emphasize in technical projects. This heterogeneity of students enabled us to test our questionnaire over different student population related to design for sustainability. We used the framework from [7] but the one from [2] could also be used to have the critical thinking competence in the results. For space reasons, we won't present intrapersonal, interpersonal and integrated problem-solving competency in the quantitative and qualitative data.

#### 3.1 Level of students in each competency

 Table 1. Level of students regarding each competency for sustainability (results gathered at the start of the semester, n=48)

Competency (definition)		Level 1	Level 2	Level 3	Level 4
Systemic thinking (The ability to analyse complex systems of	21%	52%	23%	4%	0%
different domains in a collaborative way and to consider both					
local and global dimensions. The ability to consider systemic					
features and interactions in terms of sustainable development					
challenges and solution-oriented frameworks.)					
Future thinking (The competence to develop future scenarios	35%	35%	27%	2%	0%
based on analyses and assessments as well as to design images					
of (strong) sustainable development and solution-oriented					
framework conditions. The ability to continuously reflect					
critically on and adapt developed visions of the future.)					
Value thinking (The competence to be able to describe, apply	44%	38%	8%	10%	0%
and negotiate community sustainability-oriented values,					
principles and goals; based on concepts such as justice and					
responsibility. The ability to contextualise (historically,					
culturally, etc.), critically reflect, evaluate and compare					
individual and societal values.)					
Strategic-thinking (The competence to jointly develop and test	50%	31%	15%	4%	0%
(innovative) intervention, transition and transformation					
strategies towards sustainability (taking into account knock-on					
effects).)					
Implementation competency (The ability to solve problems	35%	25%	23%	13%	2%
relevant to sustainability and to consciously implement					
interventions, i.e. to take concrete action and design (ability to					
act). The ability to design participatory, inclusive and					
equitable processes of implementation and evaluation.)					

# 3.2 Relation between pedagogical activities and level of students for each competence

#### 3.2.1 Systemic thinking

21% of students don't have any knowledge in systemic-thinking, 52% of students have a basic understanding of it but don't feel to talk about it; 23% of students can talk about the competence and only 4% know a method to develop their systemic thinking competence. The only student who put themself to level 3 (already used a method to develop systemic thinking), justified their competence by saying they designed and developed an IT system and had to integrate the wishes of the users.

In the qualitative data, we found that students developed systemic thinking through a combination of practical and theoretical activities. These activities, characterized by their intensity and duration, include completing a bachelor's thesis, conducting company audits, or engaging in software development over several months. Those activities were also recurrent, as reflected by quotes like "we talked a lot about...". This suggests that long-term, sustained pedagogical activities are more effective for cultivating systemic thinking than one-time, isolated lectures. Furthermore, students perceived systemic thinking as the ability to reconcile divergent viewpoints from different stakeholders ("Different perspectives and data shoulder thinking on a larger or different scale."), especially among those with prior corporate experience through internships or long-term employment before returning to master studies. A comprehensive understanding of systemic thinking was shared by all but two students, who explicitly

stated they hadn't developed this competence before. Most students recognized instances of systemic thinking in technical contexts, such as designing mobility solutions for specific areas or creating IT and supply chain system, likely due to their prevalent technical backgrounds.

#### 3.2.2 Future-thinking

6 students explicitly mentioned that they had not acquired this competency. Four students connected the development of future-thinking competence to personal activities, such as engaging in discussions with friends or making decisions about which classes to attend at the next semester. One student explained in the open box answers that he gained to Level 3 through visiting a lecture in the field of environmental management. Also, no one referred to the role of future-thinking in the development of critical thinking competence.

To enhance their capacity for future-oriented thinking, students engaged in case studies. For instance, some were tasked with pinpointing mobility use cases within an urban intersection, while others were assigned the challenge of identifying necessary changes for a more sustainable textile industry.

Another student underscored the integration of future-thinking skills with strategic acumen, citing the development of these skills during the formulation of their team's strategy. This student accentuated that cultivating future-thinking abilities necessitates the fostering of systemic thinking to comprehensively grasp all facets of a given problem. Through this example, we can see how competencies were interlinked.

#### 3.2.3 Value-thinking

44% of the students said that they were unfamiliar with the value-thinking competence. Additionally, 38% of the students possess a basic understanding without the ability to discuss it, while 8% have both a basic understanding and the capability to articulate it. These findings highlight a noticeable discomfort among students regarding this competence.

6 students explicitly stated that they didn't develop value-thinking competence. For this competence, 6 students referred to stand-alone ethical classes as situations in which they developed value-thinking competence. 6 other students referred to informal activities (discussions, watching videos, debates). The case studies were less anchored into technical examples than the systemic thinking competence ones. 10% of the students demonstrate normative competence at Level 3 based on their in-depth engagement with norms and value development as social scientists and their experiences in the Life Cycle Assessment module in the Bachelor of Environmental Engineering, including a project and thesis that questioned environmental sustainability assessment systems and led to more complex thinking about sustainability. In addition, they demonstrate their normative competence through their involvement in debates on various policy issues.

#### 3.2.4 Strategic thinking

8 students explicitly stated that they had acquired strategic thinking competence through professional experiences. Specifically, they linked this competence to activities such as internships, presenting concepts to municipalities (real-world clients in academic projects), or applying a norm in a company (norm 31000). Interestingly, one student highlighted a yoga class as a scenario in which they developed strategic thinking competence. In contrast, twelve students admitted that they were unable to identify any situation in which they had developed this particular competence.

Despite providing 10 examples in the text-box answers, these instances failed to instil confidence in students when discussing strategic thinking. Indeed, 50% of the students admitted to lacking knowledge or experience on this topic. Some students offered examples but rated themselves at level 0 or 1. For instance, a response like "Bachelor modules Innovation and Change, Innovative Value Chains" indicates a student who categorizes their knowledge or experience at "level 1," implying a lack of confidence in identifying activities that have enhanced their strategic thinking skills. There is only one student who would rate him at level 3. He refers to the fact that strategic thinking is an integral part of the work of a process engineer. However, the methodology was not used with a focus on sustainability.

#### 3.2.5 Implementation competence

Students strongly linked this competency to real-world projects. Specifically, 13 students clearly identified their professional practice as a significant source of development for this competence. Only 2 related this competence to theoretical work, and 5 students gave examples about non-pedagogical projects (discussions, participation in a climate workshop, group work).

A breakdown of the quantitative responses reveals that 35% of the students claimed to lack any experience in implementation competence. Additionally, 25% positioned themselves with a modest level of knowledge but expressed uncertainty about discussing the topic. On the other hand, 23% of the students feel confident in discussing the competence. Furthermore, 13% have utilized a tool and method to develop implementation competence at least once, while 2% confirmed their familiarity with the tools and methods associated with this competence. Students demonstrate their implementation skills at Level 3 or 4 through their experience in implementing projects with their dual partners and within their company, leading to successful project completion and adherence to schedules. In addition, they actively participated in the planning and implementation of a funding project and gained experience in project implementation during an internship. They have also participated in a climate workshop, which demonstrates their ability to implement and design participatory, inclusive and equitable processes.

#### **4** INTERPRETATIONS

The interpretation of the results focuses on the quality of the answers we succeeded to collect through the questionnaire. This analysis will help us determine if the questionnaire is ready for use by colleagues to evaluate their students' engineering competencies for sustainability.

#### 4.1 Relating pedagogical activities and competencies

Students perceive real-world case studies as an effective way to acquire sustainability competencies. They feel more mature in various competencies after designing technical systems involving multiple stakeholders and considering diverse perspectives and long-term impacts. This is in line with current research [8], [9], suggesting that self-assessment results can be a good basis for a pilot-study. However, we've observed a deficiency in references related to future-thinking competence and normative thinking. It appears beneficial to delve into more extensive research on particular pedagogical activities to establish a clearer link between these activities and the relevant competencies. With this conclusion, we can identify a limit of our method, which is the direct link between pedagogical activities and competences when the competency is not clearly understood by students. Also, some links have been made between some activities and competencies (a yoga class to develop strategic thinking) and this statement would need some more justification to be taken into account. As the questionnaires were anonymous, it was not possible to get more information through individual interviews. One way of overcoming this limitation is to combine this self-assessment method with pedagogical assessments during the semester focusing on certain skills (critical review to develop critical thinking, for example). This multi-assessment approach would help to get a more objective understanding of the relations between pedagogical activities and competences. Additionally, students mentioned some pedagogical activities they remembered but not all of them. To enhance the questionnaire's effectiveness, a possible next step could be to list all the pedagogical activities first and then ask students to relate each activity to one or several competences.

The five levels of self-assessment were found to be understandable for the students. The results are somewhat easier to interpret than a Likert scale, as they allow students to indicate whether they understand the competence, can discuss it, and have experienced it. This approach provides teachers with a clearer picture of whether their pedagogical activities have enabled students to acquire a competence—understanding its meaning, experiencing it, and managing methods to improve their level.

#### 4.2 Use of the questionnaire and quality of data collection

This survey is versatile and can be administered at different points throughout the semester, offering insights into students' progress in developing competencies. It is applicable not only at the outset but also in the middle and at the conclusion of a specific class, enabling the assessment of improvement over time. Additionally, the questionnaire serves as a valuable tool for prompting students to reflect on their overall learning experiences, not limited to a particular course but encompassing their bachelor or master program as a whole. Among the survey, approximately 1/3 of the answers were not detailed enough to know which pedagogical activities were targeted by the students. The time required to complete the questionnaire may vary, typically ranging from 10 to 25 minutes. To encourage student engagement in responding to the questionnaires, the authors incorporated "memes" into the process. Specifically, when students entered more than 20 characters in the open text box, a relevant meme associated with the competency being addressed would appear. This creative approach aimed to add a touch of humour and visual appeal, potentially enhancing the overall survey experience and motivating

students to provide thoughtful responses. Unfortunately, we don't know if this strategy has an impact on students' motivation to answer the questionnaire.

Also, it is important to note that only a few students from each class completed the questionnaire (56 students out of 300 students initially targeted), so we advise the teachers to give some incentives for the students to answer the questionnaire (15 minutes during a class, not a task to be done after the class).

#### 5 CONCLUSIONS

In this paper, we presented a questionnaire designed to assess competencies for sustainability. We tested it on students at a university of applied sciences who were enrolled in sustainability classes or curricula. Currently, the questionnaire can help other teachers understand the impact of their pedagogical activities on their students. We identified both advantages and drawbacks of our questionnaire. First, it is understandable for students, allowing them to reflect on their semester's pedagogical activities. Second, it enables teachers to gauge how students perceive the teaching activities offered. Third, it is easily reproducible across different disciplines. If researchers in the community use the same competencies and self-assessment scales, it will create a large database linking pedagogical activities with engineering competencies for sustainability.

However, there are some drawbacks: students might forget some pedagogical activities they participated in during the semester, the questionnaire takes time to complete, and some links between activities and competencies expressed by students can be difficult to understand. We recommend that teachers remind students of the activities they undertook during the semester before administering the questionnaire and allocate dedicated time during classes for completing it. This will help improve the quality of the collected data.

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### PRODUCT DESIGN EDUCATION FOR DEAF & HARD OF HEARING LEARNERS: EXAMINING THE FOUR-YEAR UNDERGRADUATE LEARNERS EXPERIENCE

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#### ABSTRACT

Deaf and Hard Of hearing (D/HOH) learners face unique challenges on a day-to-day basis, especially in a higher education environment. Consider being D/HOH over the past four years in higher education having to contend with distance learning, socially distanced learning, and face to face learning. These differing environments and teaching methods require a range of setups. The variability in methods/types of teaching within Product Design Education means there are various challenges to overcome. Accessibility and disability considerations differ from student to student and thus require a significant amount of planning and testing for academic teams to ensure D/HOH learners gain access to the same quality and consistency of education as other students do, regardless of the setting. This paper presents a case study examining the four-year learning experience of a student with Auditory Neuropathy Spectrum Disorder (ANSD) and permanent bilateral severe-profound hearing loss who studied BSc (Hons) Product Design SW at Nottingham Trent University. This included a placement/year in industry at Kinneir Dufort (KD) as a Product Design Intern. We reflect on the education adjustments designed into the course curriculum which have benefitted all students, whilst summarizing/reflecting on the support provided for applying for placements ensuring a successful placement/internship can be secured. Observations on the placement application process and work experience will be present highlighting the necessary adjustments made in relation to the access to work guidelines. A student testimonial of their learning journey is presented reflecting on their educational development and support systems.

*Keywords: Accessible learning, collaborative/cooperative learning, deaf/hard of hearing learners, design education, year in industry* 

#### **1 INTRODUCTION & CONTEXT**

Over the past four years, students in higher education (HE) have faced numerous challenges, most notably due to the impact of the COVID-19 pandemic and the migration of all learning, teaching, and assessment into online domains [1]. Post COVID-19 pandemic adjustments to the integration of digital learning that has remained [2], and with the return to face-to-face teaching, students often weigh up the value of face-to-face teaching compared to hybrid and online approaches [3]. However, imagine being a D/HOH learner studying a creative course such as BSc Product Design SW, having to study under all three learning arrangements and having to navigate the ever-changing teaching/learning settings; difficult to say the least. D/HOH learners have faced many challenges over the past four years as identified in our previous case study [4]. However, the impact of COVID-19 on D/HOH learners extends beyond the pandemic, with many adjustments post pandemic needing consideration. The National Deaf Children's Society identified that deaf children and young people have suffered from language stagnation or language loss, inaccessible education, and additional social, emotional, and behavioural challenges both during and post pandemic [5]. The inability of some in the hearing academic community to understand, comprehend and empathize with D/HOH learners has been problematic [6].

Studying product design (PD) often requires teamwork and collaboration, which can be problematic for students with hearing impairments to feel fully integrated. To create an inclusive and collaborative working environment adjustments must be made, in the teaching environment, through the use of digital technologies, or via peer-to-peer/tutor communication considerations. Managing the stigma associated

with D/HOH learners in different settings [7] often means that students and staff must be appropriately educated when considering the overall learning experience. This paper discusses the successes and challenges of methods of managing the PD teaching environment in combination with the use of electronic/handwritten notetakers, British Sign Language (BSL) interpreters, and the accompanying technologies across a four-year period where online learning, blended learning and face to face delivery were all a part of the learner's experience. This paper follows-up our previous case study where we reviewed the successes and challenges from the first year of supporting PD education for D/HOH learners during a pandemic [4]. This paper holistically reviews the four-year undergraduate journey, which included a placement year in industry, reflecting on the impacts of our teaching and course design, but also the placement/year in industry arrangements. Creating an inclusive education and work environment to support D/HOH learners in the PD sector requires a proactive approach. Factors ranging from promoting a supportive inclusive learning community, to integrating/embracing the network of specialist support staff must be considered if an inclusive work environment that covers the necessary access to work arrangements available to all of the D/HOH community is to be achieved.

#### 2 FOUR YEAR COURSE OVERVIEW

The D/HOH student enrolled onto BSc PD; this course is designed to allow students to immerse themselves with engaging lectures, seminars, workshops, and design studio sessions. The standard structure for the first/second year consists of two days based in the design studio, supported by design sketching, CAD, and electronics vocational workshops. 3D printing, mechanics, design context/history and workshop appreciation taught sessions are also integrated. Students leverage our virtual learning environment, NOW (Nottingham Online Workspace), for self-directed projects which promotes independent study including, researching, completing coursework, and curating design portfolios. Students benefit from external professional practitioners, ensuring a continual enhancement of learning with real-world perspectives; placement support and professional practice development is also embedded. During the third year the D/HOH student was enrolled onto a 12-month industrial placement at KD. The fourth year consists of a commercial project, a self-directed project, and a dissertation/thesis supported by a lecture series, one to one/group tutorials, and computer aided design sessions.

#### **3 LEARNER TIMELINE & ARRANGEMENTS**

This case study focusses on a D/HOH student who has Auditory Neuropathy Spectrum Disorder (ANSD) and permanent bilateral severe-profound hearing loss. They joined BSc PD at Nottingham Trent University (NTU) in September 2020 during the height of the COVID-19 pandemic and studied fully online during their first year, in a blended learning environment during their second year, conducted a year in industry with no restrictions in their third year and studied in a fully face to face environment during their fourth year. The learner's needs were defined by a statement of access (SOA) which was updated annually. This identified that the student wears hearing aids in both ears due to hearing loss (Deafness), requiring timetabling in rooms with induction loops and transcripts produced for all audio-visual material. Environmental factors needed considering as the student uses radio aids requiring lecturers to wear a supporting microphone. British Sign Language (BSL) interpreters are utilised in all formal learning environments requiring lecturers to speak at a reasonable pace for accurate translation. Notetakers were arranged for all sessions. To aid the planning/delivery of sessions, the student was provided with specialist one-to-one support including a specialist notetaker for HOH students (448 hrs/yr.), a specialist support professional for HOH students (36 hrs/yr.) and a BSL Interpreter (840hrs/yr.). The full learner's arrangements are discussed in our previous case study [7].

#### 3.1 Face to Face Academic / Course Arrangements

Building upon the key course arrangements that were previously discussed for the first year of studying BSc PD online/blended [4], this section highlights the additional teaching and learning arrangements put in place for the second year and final year studies that took place in a blended and face to face setting. In-person design studios were again possible post COVID-19 pandemic, as such adjusting to an inperson delivery of a practical subject was key. The daily ordering of activities was important in order to facilitate D/HOH student optimal concentration times. Resources required meticulous planning with all presentations/resources needing to be 100% accessibility compliant with all images requiring ALT text. Activities needed to be ordered appropriately to ensure that the D/HOH student was able to maintain concentration appropriately throughout the day. A minimal number of pre-recorded self-directed study

activities were utilised, however when used they required full captions with supporting worksheets that helped facilitate student comprehension of subject topics, skills, and software literacy. Group work was limited to five people apart from the larger design sprint events to facilitate optimal learning environments. For design sketching and CAD sessions, these were now 100% face to face, as such the teaching spaces were set up the student's visual access of presentations, but supported with a BSL interpreter and notetaker who were strategically positioned for optimal communication. For computerwork, dual screen setups were provided for efficiency, with the D/HOH student positioned opposite the tutor for necessary adjustments. Electronics learning, now in person, featured live and pre-recorded content. One-to-one's/technical support was offered when complex circuitry/coding taught. Tailored placement support was provided in the second year to ensure that accessibility factors were considered. A dedicated employability team provided one-to-one support. Studios/lecture theatres had hearing loops, lecture capture/recordings, and audio adjustments. Virtual Learning Environments were configured for accessibility, providing relevant access for preparatory work to BSL interpreters and Notetakers.

For the final year, project supervision and dissertation/thesis support was introduced. Traditional lectures were reintroduced at final year for research methods/design and dissertation/thesis writing. The D/HOH student chose to pursue a dissertation route that addresses an area of controversy or point of debate within design. Taught aspects included a combination of a lecture series and ten individual supervisions. To support access to content, several strategies/resources were deployed, the most notable being ensuring that BSL interpreters and notetakers were present for lectures. Crucially, it was learned that both interpreter and notetaker required all the supporting resources for a given lecture at least 24hrs in advance to provide time for the BSL interpreter to identify words that do not currently have a sign attributed to them, and for the notetaker to read over the lecture slides to prepare fully and reduce pressure during lectures. Further improving these adjustments was the consistency of personnel; working with the same BSL interpreter/notetaker proved vital for content planning/delivery. As previously mentioned, the BSL interpreter was positioned at the front of the lecture theatre where they could be seen easily and the lecturer was instructed to deliver the content from the lectern without moving across the stage, so as to not impact lip reading. A number of drop-in sessions where students can engage with group seminars, peer reviews, tutor support and independent writing was also offered.

#### 3.2 Placement/Year in Industry Arrangements

Many factors needed to be considered during the process of recruiting/hiring, working, and supporting a D/HOH employee. For KD, the recruitment process to accommodate for a potential D/HOH consisted of ensuring flexibility in terms of interview location. We were willing to learn how we can better our recruitment process to accommodate D/HOH individuals. Prior to the D/HOH student's application, the recruitment process/interviews were held online. To KDs benefit, the D/HOH individual was vocal about being Deaf, therefore KD adjusted the interview process. KD accommodated the in-person interview request to ensure the applicant felt comfortable to perform at their best. A new expenses policy was introduced following the D/HOH applicant's request to hold the interview in person, to cover travel to KD for interns, graduates, and junior interviewees travelling from outside of Bristol. Another key insight that came from the recruitment process was that KD are usually inclined to communicate via the phone. However, learnings from the D/HOH applicant enabled us to understand why this may not always be a suitable method of communication for everyone and we make adjustments when needed.

Once the D/HOH intern was hired, KD wanted to ensure that all arrangements were put in place to provide an authentic intern experience. All interns are paired with a mentor, usually a junior member of staff from the same team. This enables the interns to have the space to talk openly/freely and have the opportunity to address positive and possibly uncomfortable situations with the support of someone not too senior, which we understand can often be more daunting when being new in the industry. We see it as incredibly important for everyone to have that relationship with someone in the business. Allowing our interns the space to build a relationship with our more junior members allows them to ask questions more openly, and helps our junior members build confidence in speaking about learnt experiences. KD tend to ensure that we hire more than one intern for each year which gives interns a cohort of immediate peer support. Interns are tasked with an introductory non-client facing project in the first weeks of their internship. This helps interns get to grips with KD's way of working with access to support from other members of staff with the freedom to learn, and opportunity to make mistakes. All interns have an informal 4-week and 6-week check, and a formal 3-month and 6-month progress check.

KD made a number of adjustments; one key factor was to immediately address Health & Safety (H&S). For example, our fire alarm system was not appropriate for D/HOH individuals. We therefore introduced a suitable fire alarm system that is a lot more inclusive. During the D/HOH interns time at KD we were very involved in the process of supporting their hearing dog application, introducing adjustments such as giving the intern a dedicated space where they could be located, whilst ensuring they could sit within our usual hot desking setup. KD were also very keen to help other employees understand what adjustments were needed when working with D/HOH individuals. This was something that the D/HOH intern was very open to support, being very vocal about the D/HOH. We also want to address some things that did not go so well to acknowledge that it's not all smooth sailing. One example was the KD companywide meetings, which due to Covid, are still mostly held remotely. It's still common that individuals. As such we now encourage our meetings to be held in person, or where not possible, ensure everyone is aware of the MS Teams etiquette that accommodates D/HOH individuals e.g. turning cameras on when speaking, good lighting, facing cameras etc.

The Access to Work government scheme/adjustments application was led by the D/HOH intern, with KD providing the necessary information. Going through the process of answering specific questions about our accessibility as a company for D/HOH individuals was a useful process that helped us assess where we sit in terms of accessibility and being able to support D/HOH individuals. This made it an incredibly easy process to know what needed to be changed to accommodate D/HOH individuals, but it is critical to learn from each individual what their specific needs are. It was helpful that the Access to Work scheme gave the D/HOH intern access to a BSL resource, although we only required them once. It is worth noting that, as far as we are aware, the D/HOH intern was the first employee at KD that was Deaf, therefore a lot of this was a learning process, and we are grateful to the D/HOH intern for being a real voice for the D/HOH community. We are now better equipped to accommodate individuals, although there are still things we need to improve on, and overall, we're keen to reiterate that employing a D/HOH individual is not a complicated process; had we shied away from hiring the D/HOH intern, we would have missed out on an incredible design talent that was an asset to KD.

#### 4 ACADEMIC & EMPLOYER PERSPECTIVES & REFLECTIONS

Further to our previous reflections on the first year of studies conducted in an online/blended environment [4], further learning opportunities can be highlighted for in person learning. While accustomed to collaborating with support services across NTU to address student learning adjustments, our experience working with the disability team continued to be beneficial. Consistency of British Sign Language (BSL) interpreters proved challenging at times due to enforced changes at the institutional level. Based on availability/constant changes in arrangements/processes, BSL services were challenging to manage for staff/student. After a difficult second year and based on feedback, NTU changed its approach to hiring BSL's; recruitment became personalised to everyone's needs. Consistency in the support services and facilitates is key for session planning/delivery to normalize the learning environment. Insights provided by support teams enhanced our understanding of learning/educational challenges faced by D/HOH students and made the process of preparing course materials more effective. The working arrangements with BSL's and notetakers was different in the final year, with cross course traditional lectures and writing workshops provided. Individual tutorials for dissertation support were setup/aligned to the student's personal tutor for consistency. Room planning was critical; several room changes were made to accommodate noisy surrounding environments. One-to-one support for dissertation supervision was simple to arrange with only the notetaker being required. Each tutorial was recorded for notetaking accuracy with additional one-to-ones arranged where required.

Interns give KD a fresh perspective from someone entirely new to the industry. We value having mixed experience teams; interns key to this. We pride ourselves on our mentor/mentee relationship, especially between our interns/junior members of staff. Our interns create a valuable future employee candidate pool. KD are always incredibly excited to welcome back past interns into junior positions following graduation. One of the most valuable effects following supporting a D/HOH employee is KDs new/improved adjustments to our style of working/work environment, but also each employee's individual awareness and learnings of ways of interacting/ ways of working to accommodate everyone. KD pride ourselves on our people, therefore psychological safety and considering our employees welfare is incredibly important. Understanding the importance of having safe spaces for potentially vulnerable employees is key. Establishing a mentor/mentee relationship is critical/valuable; this allowed KD to

build to learn what adjustments are needed to create safe space for all. This has further improved our openness to accommodate flexible working practices. It is incredibly important to understand how we can best support someone to ensure they can present themselves in the best/most comfortable way. There are many key learnings that KD have taken away from supporting a D/HOH employee/intern. The most important was taking the time to understand the standard ways of working and etiquette for all individuals; both in person and remotely. As a company we did not find it complicated to introduce adjustments for D/HOH individuals, although some may assume it is. Although specific adjustments had to be made, many of these are still in place, even though the D/HOH interns' placement is now finished. This makes it an even easier process for any individuals in the future to be fully integrated into KD, especially D/HOH individuals. We have also gained really valuable insights into what is more difficult to adjust for in terms of any future employees. We also picked up on bigger issues that we are keen to explore and address, for example, our office is a Grade 2 listed building which makes big structural changes more difficult – and there are some things we cannot do. In the case of D/HOH employees, we have seen how minor adjustments can have a huge difference to someone's experience, and the process of making those adjustments, in most cases, is incredibly easy.

#### **5 LEARNER PERSPECTIVES & REFLECTIONS**

The COVID-19 pandemic posed many challenges during the first year of study due to the increased use of masks [4]. Academics/support services ensured the availability of 1-1 sessions to address missed information/clarify new content (e.g., workshops/electronics). Peer selection for group tutorials/projects involved identifying students with familiar accents from friendship groups, enhancing familiarity/work progress. When specialist sessions were arranged, I was able to select the relevant academic staff to provide support, for example I was able to pick my dissertation/project supervisors for my final year. Having the same personal tutor throughout my degree ensured familiarity and ongoing support, making it easy to address concerns. NTU provided the opportunity for me to book extra BSL support for external trips i.e. for factory visits. Additional services i.e. employability provided a supportive environment whereby sensitive questions around the perceptions of my disability to employers could be addressed. They advised on establishing a position in the sector with a strong Deaf identity, a non-negotiable factor in selecting future employers. NTU was open to having an assistance dog on campus supporting the application process. Challenges faced included managing BSL interpreters/notetakers bookings which added an extra workload. Even with timetables published in advance, and academics liaising with external support services, student approval was still required. As many initiatives as possible were made fully accessible, some student led initiatives were not always as accommodating, such as a student curated video podcast series, where captions were not provided, and funding fell outside of the scope of accessible provisions. This unfortunately created barriers/inaccessibility for the D/HOH community. When applying for the internship at KD an in-person interview (originally scheduled to be online) was made available. Beforehand, a provided telephone number allowed for sending a text message in case of travel delays. Once at KD, a workplace mentor was provided creating a unique partnership whereby they had an increased sense of deaf awareness, allowing them to advocate on my behalf (with permission). Weekly mentor check-in sessions were completed, alongside 3-month and 6-month reviews. The workplace culture meant everyone was approachable, from the Head of Design to the CEO. KD's workplace culture enabled me to maximize my placement experience; KD's support allowed me to really focus on the work that I was doing, rather than having to worry about access. This made it easier for me to ask people if they could repeat themselves or turn on a light so lipreading could take place when on MS Teams. KD provided me opportunities to explore areas of passion allowing me to share my own lived experience internally/externally. As such the experience allowed for my attendance of an EDI conference, engagement with Inclusive Design Workshops (Lunch and Learn) and Inclusivity Initiatives whilst allowing me to write press releases for Deaf Awareness Week about my experience as a young Deaf designer. KD supported the application of getting an assistance dog (Hearing Dogs for the Deaf) during the internship, allowing the Hearing Dog team to complete an assessment of the workspace.

#### 6 DISCUSSION, CONCLUSIONS & RECOMMENDATIONS

Previously we identified numerous support mechanisms to consider when supporting D/HOH learners in online or blended learning environments [4]. Various factors include learner environment, communication strategies, flexible assessments, technology integration, collaboration with support services, personalised feedback, peer support, and professional development. The most important factors to consider are inclusion, diversity, and cultural sensitivity. Factoring in arrangements that are not only culturally sensitive, but diverse to accommodate all learners is critical. We've encountered various arrangements, collaborating with external suppliers/charities like hearing dog charities, BSL providers, and notetakers. Collaborating with external agencies can pose challenges due to the time needed to organize/deploy support staff. While it may not easy due to the advanced timescale required for implementing the support, effective communication and coordination among the right team and administrators can resolve any issues or delays. Acknowledging the unique preferences and requirements of each student is crucial. Within an academic environment, exploring various strategies used for D/HOH students with differing degrees of deafness would be an intriguing aspect to examine. Through employing a D/HOH intern KD have developed greater understanding/approach to supporting people's individual needs. It is important to listen and create spaces in which people feel comfortable to share what works and does not work well. This creates a work environment/culture that works for everybody ensuring no one gets left behind or struggles. By working closely together, KD have learnt some key lessons but also understood what we still need to address to accommodate not only D/HOH employees/interns/clients, but also others with additional needs ensuring inclusive ways of working and appropriate environments can be created. Seeing the possibility of change and the impact small adjustments have made has enabled us to improve for not only D/HOH individuals, but also our wider team. There are things that are more difficult than others to address, but overall companies should never shy away from employing an individual because of an impairment. It is the company's own doing and reluctancy to accommodate any reasonable adjustments that makes it difficult for an individual to perform. KD have a responsibility to ensure we are accessible for everyone, this not only supports our current/future employees, but also diversifies our team enabling even better work to be produced.

Educators new to supporting D/HOH individuals can learn valuable lessons. Some insights are simple, like ensuring accessibility of course materials, videos, and online content. This includes using captions/transcripts and visual aids to enhance comprehension when verbal/BSL communication lacks context. The importance of one-to-one support, personal tutoring/mentoring and collaborative working alongside BSL and notetaking support services is critical. In the last four years, we worked with four BSL interpreter suppliers and one consistent notetaking service. Maintaining consistency is crucial for effective information exchange, but support service providers' processes can pose challenges. Support providers offering flexibility and personalization enhance the D/HOH learners' experience. Those that do not, create additional challenges/barriers for learners/academics. Every D/HOH student is unique and has individual needs/requirements dependent on their condition. To conclude, academic staff/industry professionals working with the D/HOH learner have been empowered by the experience of supporting D/HOH learners but acknowledge that improvement in teaching and industry interactions can always be made. The recommendations, successes, and challenges identified are now integrated as best practices within NTU and KD to enabling optimal learning, teaching, and working methods.

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## REIMAGINING DESIGN FUNDAMENTALS: DESCHOOLING 1<sup>st</sup> YEAR PRODUCT DESIGN STUDENTS

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#### ABSTRACT

The transition from secondary education to higher education (HE) for many students can present several challenges. New university students not only have to prepare themselves to delve into the realms of HE, but they must also learn/adapt to living independently for the first time. New first year students are not only exploring their identity as young aspiring professionals, but within the product design (PD) sector, they are also getting explore for the first time what it means to be a designer. The skills gap between secondary and HE in product design (PD) widens yearly, and this is particularly evident within the past four years whereby students have been joining HE with at least one or two GCSE or A-Level years effected by COVID-19 resulting in increased distance/virtual learning thus diminishing practical skills development. This paper highlights the skills deficiency between secondary education and HE expectations. We discuss a module refresh and implementation of new schemes in a module entitled "Design Fundamentals" aimed at deschooling and upskilling students rapidly. This involves tailoring design studios, sketching, CAD, and projects accordingly. The paper presents student feedback via a survey (n=34), where students feedback on their overall satisfaction, module teaching, assessment and feedback considerations and module organisation and resources. Recommendations are provided for HE providers to focus on key areas for upskilling students, establishing a platform for further development.

Keywords: Deschooling, design education, design & technology, secondary education, upskilling

#### **1 INTRODUCTION & CONTEXT**

Regardless of the route taken before joining HE, recent observations have demonstrated that the majority of first year PD students have significant skill deficiencies due to the current structure of Design and Technology (D&T) education within secondary education in the UK. This is due to a lack of clarity and direction the subject currently faces coupled with a significant funding crisis in the D&T education sector [1]. This is also having an impact on the funding and recruitment of D&T teachers [2]. As such HE PD courses are facing significant challenges with student recruitment numbers falling rapidly, but also the type of student being recruited. Students often lack autonomy, self-directed learning, and deep learning skills. The varying educational backgrounds, learner expectations, spoon-feeding tendencies of teachers, limited teacher autonomy and large classes are some of the many factors that often result in struggles transitioning into HE [3]. The transition shock from a highly structured and teacher-centred learning environment compared to a more independent self-driven approach often surprises new students, many of which struggle when required to move away from a 'spoon fed education culture'. This paper presents the approach taken to reimagine a ten-week module entitled 'Design Fundamentals' for BSc Product Design (BSc PD) by taking a deschooling and rapid upskilling approach to allow students to become better prepared for the remainder of the HE journey. The module seeks to not only deschool students but also help them embrace their chosen course but also the course identity. An overview of the refreshed module focuses on the approaches taken to enhance student experience. The guidance, mentorship, and support systems implemented help students transition towards selfdirected/independent learning. Student feedback seeks to identify how several educational schemes/projects conducted within the module help improve their skills, ranging from debates, team bonding away days, CAD Bash, design sketching, 3D printing sessions, design projects, amongst others.

#### **2 POINTS OF ENTRY**

In the product design/industrial design sector, the shift from secondary education to HE in the UK was traditionally facilitated by enrolling in a preparatory year at a foundation education institution, like an art college; alternatively talented students could directly enter HE with grades above the required threshold subject to an interview. Both processes allowed students to develop/showcase their creative passion to explore diverse specialties. More recently students often directly enter HE with universities looking to offer places to as many students as possible subject to several basic requirements, with additional students accepted through clearing who often fall below course entry requirements. Thus, the importance of early deschooling and upskilling is critical. The Higher Education Statistics Agency (HESA) notes a rising trend in students directly enrolling in degree-level courses, coupled with a decline in foundation degree-level entries [4]. Recent recruitment of PD students has been challenging; this is evidenced by the decline in students studying D&T at school/college. A report by the Education Policy Institute identified that the number of students entering D&T qualifications has declined with just 22% of GCSE students having at least one D&T qualification in 2020, compared to 44% in 2009 [5].

The barriers put in place by examination boards and the contradictory guidance provided results in many students arriving in HE unprepared. An example of this can be evidenced in the form of design sketching assessment. The OCR GCSE guidance identifies that students should be given the opportunity to cultivate confidence through communication/drawing skills as designers, not artists and promotes the use of quick sketching for conveying initial design ideas. However, the guidance later states that learners are not assessed on their sketching proficiency [6]. Similarly, AQA sets maximum page parameters for assessment [7] which means that with such a tightly controlled portfolio the time and space to develop/showcase a wide range of skills is limited. The limitations placed on creativity and exploration by exam boards coupled with the contradictory guidance inevitably results in significant disparity in student skill sets entering PD at HE, hence the need for subject specific syllabuses exploring the individual specialisms/disciplines. When considering prospective students applying and entering Nottingham Trent University (NTU) and our BSc PD course, students are required to attain a UCAS points tariff of 112pts (Grades: B, B, C). There is no explicit requirement for design and technology (D&T), sciences or maths as prior subjects studied, but these are beneficial. The breadth of students recruited, and the skills presented often requires all students to de-schooled and upskilled quickly.

#### **3 RE-DESIGN OF DESIGN FUNDAMENTALS**

The module Design Fundamentals was first initiated in 2018 with the goal of engaging students more in the principles of PD in an engaging design studio environment, moving away from the more traditional lecture, seminar, and workshop approach. This core module aimed to provide the fundamental skills and knowledge to aspiring product designers to allow them to understand the core practices required as young professionals, in both practical and contextual subjects. The distinctive features of the module focus on the initial stages of developing as a designer, providing opportunities to reflect on the journey taken thus far, considering the skills, knowledge and experiences developed and what further skills need to be developed linked to the relevant professional practice ambitions. The module seeks to provide a process of exploration based on a student's own experience as well as facts, opinions, and case studies from the world of design. Students develop key design research techniques and contextual thinking allowing them to promote their development, thinking and critical debate around art and design. The original module timetable consisted of two full days of design studio, supported by weekly design sketching and 2D Computer Aided Design (CAD) vocational sessions in addition to a weekly design theory/context lecture and workshop. Students were provided with the opportunity to complete an online and practical workshop induction as well as take part in several team building activities including an out of bounds experience at Lea Green Learning and Development Centre in Derbyshire.

The set up of the assessment within the module initially focused on completing four formative assessments whereby weekly design challenges were set including an infographic poster, an ideation project, a set of modelling workshops, and a social media focused set of activities based on "Why I Design". This was then followed by a six-week summative project entitled "*Design In The Manner Of*" which focused on the designing of a piece of homeware in the manner of a specific company/designer. Upon reviewing and reflecting on the module post COVID-19 pandemic, upon returning to campus and reviewing a wide range of student feedback, it was discovered that the module needed to be refreshed; several factors can be attributed to this. Firstly, due to the COVID-19 pandemic the skills that the incoming first years possessed were significantly lower than expected, mainly due to the lack of practical

experiences undertaken at school/college. Second, it was deemed necessary to "Deschool" students away from a system of consistent hand holding and instead work towards providing students with a framework/approach of creative freedom and autonomy. Thirdly, student feedback identified that the module needed more course identity and specifically for the BSc PD course students identified that earlier introduction to 3D CAD and the practical/technical skills was essential to help them progress and not become overwhelmed later in the first year. Finally, students identified that the initial weeks of one week or one day mini briefs were less engaging and deemed 'too easy'. They wanted to get hands on with a project earlier within the course. Staff also noted that the reliance on mini projects gave the perception that the course workload was minimal resulting in issues with time/project management when the workload expectations suddenly/rapidly increased. As a result of this, a course specific refresh of the module was conducted focusing on skills required specifically for the BSc PD course.

#### 3.1 Refreshed Design Fundamentals Structure

To begin, the refresh of the module focused on creating a structure that provides opportunities for rapid upskilling of core competencies whilst creating a highly engaged studio environment. To facilitate this, rotations of breakout groups/activities delivered by various academics ensured students were engaged and proactive with project-based learning. Key vocational skills such as design sketching and 2D/3D CAD were integrated further whilst focusing was also place on project specific skills such as research methods, ideation, concept generation, sketch modelling, visualisation, amongst others. Critically it was necessary to address key areas of knowledge generation as well as core skills, qualities, and attributes. As such it was determined that students should demonstrate, through design activities, an understanding of the basic concepts of form, balance, and proportion in 2D and 3D design as well as understanding of design processes that encompasses marketing, aesthetics, ergonomics, manufacturing, materials, commercial and technical aspects. Students needed to be capable of evaluating and applying complex solutions that consider conceptual, aesthetic, and practical considerations as well as conflicting constraints in design whilst learning to evaluate and compare historical and latest trends in design thinking. To do this, it was decided that the module should commence with two weeks of core skills being taught in an accelerated format before delving into project-based learning.

#### 3.1.1 Early Intervention & Upskilling

The first week of the term focused on a debates project, where students learn to utilize university facilities/resources to quickly research a topic, comprehend and understand the topic in detail, before delivering a short presentation and then defending their argument in a live debate. Subject specific topics are assigned to groups randomly exploring perceived controversial topics such as "plastic is good", "AI will replace designers", "anyone can be a designer" etc. The second week of the term focuses on an accelerated program of 3D CAD entitled CAD Bash, focussed on teaching SolidWorks. CAD Bash is an accelerated program of eight 1.5/2-hour engineering CAD sessions, held over a five-day period that seeks to give a broad overview of essential approaches/practices. The premise of CAD Bash was to employ a new strategy for up skilling first year PD students, to enable rapid progression and positive association within engineering CAD. CAD Bash was designed to complement a weekly design sketching syllabus that introduces engineering drawing principals whilst supporting studio sessions where engineering drawing interpretation is taught [8]. After the first two weeks, students are introduced to their first mini design project set for a period of two and half weeks and based on design iteration. The project focuses on the ethos that "your first ideas will never be your final idea". In this project students are required to redesign a power tool using iterative design processes. Utilizing a breakout session rotation approach, research and ideation activities are delivered in a rapid manner to help facilitate the early parts of the design process. This is also complemented by key reverse engineering principles such as product teardowns. The project focuses on the front end of the design process up until the final design stage. Students are required to emphasize with a user persona from a demographic that they are not used to designing for; they also select to redesigning a power tool from the list provided.

#### 3.1.2 Developing & Applying Core Skills Within Projects

After completing their first design project where various ideation and iteration techniques are taught, a second project is set immediately building on the momentum from the previous project. The second project is a five-week lighting project focusing on applying the double diamond process, thus exposing the students to new skills such as sketch modelling, concept reviews, final modelling etc. In this project

students are required to design a light through iterative design, following the Double Diamond design process. The process covers research, design, development through sketching and modelling, and production of a fully resolved final model. To inspire the students to produce a high-quality output, students are given the opportunity to be selected for the Nottingham Light Night exhibition (Figure 1).



Figure 1. Nottingham Light Night 2024 Student Outputs (Student Work Credit: Hugo Andersson, Gavin Jones, Tom Evans & Olly Lendrum; Photographers: Charlotte Bradford & Ellen Burke)

Students are tasked through research to identify the type of light they intend to design, but also to choose a location within the home where the light would be used. Students are taught how to conduct primary research and expected to visit several homeware and lighting stores to explore the current scope of the market. To set some basic parameters students are given a standard light fitting and light bulb which can be manipulated in any way deemed safe, whilst also managing a material restriction of using cardboard for construction. Key requirements cover initial and developmental sketching and sketch modelling to better understand 3D form and construction before producing the final high quality cardboard model.

#### 3.1.3 Developing Fundamental Skills & Competencies

To complement the design projects and encourage good time management, students are also set a concurrent contextual project that runs for the entirety of the ten-week module. This project entitled "Perceptions on Design" is a visual essay which focusses on design history and the critical context of the design field. This brief encourages students to explore their passion for design as a subject by gaining a greater understanding of key designers and products and their influence on design today. Weekly mini lectures are supported by workshops ranging from reflective writing, exploring what it means to be a designer, exploring what design is, and exploring what the future holds for design. The visual essay is an opportunity for students to become inspired by piece of design and designers by gaining a greater awareness of past designers, icons, iconic designs, and ideologies/processes. As such students are required to track a product, product type or product category of their choosing over time/history. To complement the accelerated projects/workshops and the critical context of design, students are also provided with weekly CAD and design sketching classes, five weeks of 3D printing classes, and specialist one to one and group-based inductions on laser cutting, metal/woodworking workshop inductions and photography studio inductions. As such by the end of the first ten-week module students can not only research and design, but also sketch model, model, fabricate and photograph their produced outcomes. Student engagement and attendance remained high throughout the entire module resulting in minimal progression issues. High engagement can be attributed to the use of the breakout group rotations and critically by subconsciously structuring the module so that all workshops, activities, and inductions complement taught content, this ensures all students are upskilled on a wide range of core competencies.

#### 4 MODULE SURVEY FEEDBACK & REVIEW

To review the success or failure of the module refresh, fifty-six first year BSc PD students studying across the full time and sandwich routes were given the opportunity to complete a module feedback survey covering overall satisfaction, feedback on module teaching, assessment and feedback considerations and module organisation and resources. Thirty-four students voluntarily provided feedback (response rate of 60.7%); responses captured feedback from twenty-four SW students and ten FT students. The anonymised survey was distributed via an in-person studio briefing and powered by the MySay survey platform. Five-point Likert scale questions were utilised with students asked to give testimonials and written feedback via open ended questions. These questions focus on "What things do

you like about this module and why? Which aspects of the teaching do you particularly value and why??" and "What do you feel could be improved about this module and why?

The average student satisfaction scores for the module were 3.8/5.0 (FT) and 4.7/5.0 (SW) with 80% of FT students stating that they "Overall Agree" that they are satisfied with the module; 100% of SW students providing an "Overall Agree" response. Students identified that module teaching staff made the subject interesting with 90% of FT students and 100% of SW students providing an "Overall Agree" response. Students also identified that the teaching methods used on this module helped their learning, with 100% of FT students and 91.7% of SW students providing an "Overall Agree" response to this question; no student provided a response of "overall disagree" with only 8.3% of SW students providing an "overall agree" response to this question; the remaining 8.3% of SW students provided a "Neither Agree nor Disagree" response. All student respondents provided an "Overall Agree" response when asked if they were satisfied with the teaching quality on this module, if they understood how the module helps develop skills and knowledge relevant to the subject discipline and if they under understood the importance of attendance and engagement in the context of their studies and future professional career.

The design iteration and design intervention project outputs showed a marked improvement from the previous years with several students producing more work beyond the requirements of the brief and to a higher standard. Numerically the average module student grades for the module increased yearly when aligned to NTU's 16-point scale assessment scheme with 20/21 averaging a Mid 2:2 (7.61/16), 21/22 a Mid 2:2 (8.28/16), 22/23 a High 2:2 (8.69/16) and 23/24 a High 2:2 (8.76/16). Specific/tailored breakout sessions delivered throughout the module aided student progression with students highlighting how the sessions fed into their assignments. When reviewing key aspects of the redesign, it was identified that 85% of students maintained an attendance average for the module greater than 75% of a total 88 sessions (excluding authorised absences). Additional sketching sessions aligned with each brief were beneficial, as acknowledged by the students. CAD Bash went very well with excellent attendance throughout.

A key aspect to the success of the reimagining of the module was the attendance/engagement of the students which was generally very good. For BSc PD students, early engagement with technology was positively received benefitting from 3D printing, laser cutter, photography sessions etc., all of which were well attended. To cultivate a supportive studio culture, students valued the team bonding experiences that were organised at the department and school level with "out of bounds" experiences such as Lea Green, pizza and board game events, crazy golf and bowling socials all integrated.

#### 4.1 Observations & Feedback on Skills Development

A key area for consideration moving forward highlighted that the weekly sketching sessions although well attended and effective at teaching the core skills would benefit from some more engaging and varied mini briefs that are course specific. Interestingly holistic observations by the tutor team identified that the sketching classes were often the first to be sacrificed if deadlines were approaching. Although attendance and engagement were generally high across the module, this was always not consistent for the design in context element of the module delivered on Wednesday mornings where focus on research skills and the contextual outlook on design as a subject was examined. With this being the written element of the module, students often cited that they *"enrolled onto a design course to design, not to write"*. A clear trend observed was if the students found the critical context aspect of the module less engaging, they were more likely to disengage with this session or not attend and as such this aspect of the module still requires further refinement to use a greater variety of activities and less lectures.

Student feedback identified that they also wanted an Adobe Bash, an accelerated upskilling syllabus on Adobe software packages, like CAD Bash which focuses on SolidWorks. An accelerated Adobe teaching approach may help upskill students quicker and provide greater confidence in producing process documents with higher quality visual outputs. A key challenge that students continue to cite is the pressures of dealing with/completing two projects (practice and context) at once, however this is a key skill that needs to be developed for the rest of the course, placements and ultimately in industry. Student testimonials identify how the integrated approach to taught content with the studio sessions, supported by vocational classes and accelerated programs complement their learning experiences.

"I like how each teaching session is relevant and important to the development of our projects. I would say I like the tutorials the most and appreciate the 1 on 1 time I get to spend with the tutors. It is moments like this that I can develop my ideas with them more." "I like the structure of the module and how it builds up your skills. Classes allowed me to think deeper about my work and gave me insight into my field. The tutors are very supportive and helped to direct me in the right direction".

"I like the way the inductions and the sketching and CAD classes are timed alongside the projects forcing us to work on them and gain hands on experience".

#### **5 CONCLUSION & RECOMMENDATIONS**

The redesign of the 'Design Fundamentals' has been successful; within ten weeks incoming students are now able to receive an intense de-schooling/upskilling program which results in high quality outputs. The rapid de-schooling process has allowed for a personalized student-centred learning approach to be tailored to the individual needs, interests, and learning styles for the BSc PD cohort. By setting early standards/expectations in combination with providing an interactive and engaging learning environment through the implementation of breakout group rotations and rapid upskilling/intense delivery methods, students are now in a better position to succeed in their first-year studies but also push on and further develop their skills. With an emphasis placed on real-world applications of knowledge and skills from both a theoretical and practical viewpoint, this has ensured that the student group can apply the taught/learnt skills throughout all their modules. Furthermore, the emphasis on deschooling has also facilitated students taking greater pride in their academic achievements whilst also ensuring as a cohort of designers that they have become more socially engaged with each other. Although the rapid deschooling and upskilling of students does have many benefits, an important factor to consider is how the first few weeks of this process can also be applied to any student that may be late arriving for their first-year studies due to international visa delays; this a point for future consideration. Additionally, it must be noted that the use of this approach must be done so with an element of caution, with the methods needing to be tailored for each individual year group needs. It's important to highlight that with the high number of creative students that have additional learning support requirements, whether this be for dyslexia, ADHD, autism etc, the teaching mechanism employed must be flexible and adaptable for everyone's preferences and learning styles regardless of the level of support available. Moving forward, the approaches discussed will be applied to other modules within the course where the rapid upskilling of specific content is required, whether this is for software teaching, projects that may need to be taught in a design sprint format, or for the teaching of practical model making/prototyping skills.

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## THE TRAJECTORY OF DESIGN SKETCHING: AN INQUIRY INTO EDUCATIONAL PATHWAYS, HIGHER EDUCATION TRANSITIONS & DESIGN SKETCHING SYLLABUS DEVELOPMENT FOR 1<sup>ST</sup> YEAR PRODUCT DESIGN STUDENTS

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#### ABSTRACT

The transition from secondary education to higher education (HE) for students pursuing a Product Design (PD) course is fraught with challenges. It is commonplace for first year PD students to face various difficulties, with one of the most common being attempting to understanding/apply design sketching techniques. Most students find the transition from secondary education hard due to having to either unlearn bad habits or overcome poor tuition or guidance given to start learning good design sketching process in the form of perspective, proportion, and composition. Students are also quickly transitioning to digital sketching solutions and AI platforms without grasping the fundamentals of design sketching first. The understanding and implementation of the foundations of core design sketching skills is a critical aspect to grasp at the start of the HE journey within the PD curriculum. This paper seeks to discuss the design sketching background of students entering HE and their transition from secondary education. We present a student survey completed by sixty-seven students across BA/BSc Product Design FT/SW at Nottingham Trent University (NTU) which identifies the student perceived skill set before and after their first-year studies. This paper discusses the implementation of a 1st year design sketching syllabus aimed at upskilling students in the fundamentals of traditional design sketching tools/communication, thus providing a platform to explore digital/immersive technologies in the future. The hurdles faced when trying to implement a seamless transition from secondary education to HE are identified whilst attempting to further understand the needs/wants of PD students. Recommendations made in this paper will help inform PD educators on design sketching syllabus design.

*Keywords: Design sketching, design education, higher education transitioning, product design, secondary education* 

#### **1 INTRODUCTION & CONTEXT**

Design sketching within product design (PD) and industrial design (ID) education at HE level is a core subject. It is noted by several academics including Aldoy and Evans [1], that there are opportunities for development of learning and teaching in this area of the ID/PD curriculum. Fava [2] also identifies that drawing as process is emphasized in HE, however, lecturers are often concerned about an over-emphasis on outcomes rather than process. In recent years the use of digital tools/platforms within design sketching has dramatically increased and there is evidence that shows that digital sketching and haptic sketch modeling can be very beneficial [3]. Although digital tools have many benefits, they have also had an impact on traditional skills, leading to a perceived decrease in drawing abilities. This will only be further impacted with the expected rapid rise in AI sketch to image generators/tools such as NewArc.Ai, Vizxom etc. With the general population shifting towards a more technology driven society, this is also starting to impact design education at primary and secondary level with growing enthusiasm shown for technology focused approaches rather than being considerate of traditional skills.

Secondary school design courses often focus on the basics, leaving students with limited exposure to more advanced sketching techniques and tools commonly used in HE and the industry. Ensuring that students gain this new knowledge gradually is an important factor to consider when preparing a design

sketching syllabus. The teaching of core design sketching skills within the HE environment coupled with the greater expectation for ideation/iteration in a design studio context is a hurdle most students face and subsequently, this has an impact on the quality and quantity of work produced. Many students often favour computer aided design approaches to visualise their ideas, however Hilton et al identified that it is often necessary to go back to basics and encourage sketching over CAD skills, with this being deemed critical to improving essential engineering design skills [4]. The shift in expectations from secondary education to HE can be overwhelming for students who are not adequately prepared and as such it is important to understand this transition and educational pathway to suitably prepare taught design sketching skills before moving to digital alternatives. Consequently, they often design within the limitations of digital tools, neglecting essential steps in the design process.

This paper discusses the design sketching background of students entering UK HE in the PD sector. We seek to examine the PD student design sketching pathway by exploring the education background prior to joining NTU, the design sketching education conducted at NTU within the first-year studies, and the aspirations of students moving forward with regards to preferred future education syllabi and their thoughts on design sketching in the industry context. We also seek to understand the hurdles faced when trying to implement a seamless transition from secondary education to HE whilst attempting to further understand the needs/wants of PD students. To conclude we will present recommendations with regards to traditional/digital design sketching for higher education syllabus development and implementation.

#### **2 POINTS OF ENTRY**

Within the PD/ID sector, the transition from secondary education to HE in the UK used to be aided by enrolling in a preparatory year at a foundation education institution such as an art college. This period played a vital role enabling individuals with a passion for the creative fields to delve into various specialties. However, in the modern era of UK HE it is reported by the Higher Education Statistics Agency (HESA) that the trend of students enrolling directly in degree-level courses is increasing, with a decrease in students pursuing foundation degree level qualifications [5]. As such, the design sketching skills presented by incoming first year students often demonstrate a lack of understanding of perspective and proportion. When exploring the factors that have affected the decline in core/fundamental skills in recent years, this can be attributed to the COVID-19 pandemic and absence of face to face/practical teaching. However, many of these issues can be attributed to the decline in design and technology teaching in schools. The Education Policy Institute identified that the number of students entering D&T qualifications has declined considerably with just 22% of GCSE students having at least one D&T qualification in 2020, compared to 44% in 2009; this represents a decline of 280,000 to 136,000 students studying D&T [6]. This has also impacted D&T teacher numbers and the skill set attributed to them. To better understand the factors contributing to the competency of students when entering HE, the syllabuses and assessment guidance provided by examination boards to secondary schools was consulted. One examination board highlights several key positive points such as, encouraging students to build confidence by developing communication and drawing skills as designers rather than artists, in addition to encouraging quick sketching skills for communicating initial design ideas. However, the documentation also states that it is important for learners to understand that they are not assessed on how well they can sketch, which is somewhat surprising, potentially lessening the perceived importance of sketching by students [7]. Further to this, another exam board sets maximum (NEA project) page parameters [8] meaning that with such a tightly controlled portfolio the time and space available to develop design sketching/communication skills is difficult, which means from a teaching perspective the amount of time dedicated to this skill is diminishing. As a result of the falling number of students studying D&T, the limitations placed on creativity and exploration by exam boards and the contradictory

guidance provided has inevitably resulted in a significant and clearly discernible disparity in student skill sets entering PD at HE, hence the need for subject specific syllabuses such as design sketching.

#### 3 DESIGN SKETCHING 1<sup>ST</sup> YEAR SYLLABUS OVERVIEW

Upon joining NTU students undertake a 24-week design sketching syllabus within their first year of studies prior to undertaking a 15-week design sketching syllabus in their second year. To transition the varying skill levels of students, the initial 24-week syllabus focusses on traditional design sketching skills with weekly one hour thirty-minute classes. Weeks 1-3 focus on exploring basic form, perspective,

and proportions of sketching to provide a foundation of basic skills to develop upon. Next, weeks 4-7 build upon this exploring the general methodologies and approaches of basic elliptical and circular forms alongside methodologies for construction of forms using contoured lines and sectional shapes. Weeks 8-10 focuses both on refining detail, through transitional forms such as fillets and blends, alongside developing methodologies to further increase spatial cognition, and frameworks for implementation. Alongside this, learning is completed on the application of colour/shading in relation to-perspective forms. Weeks 11-12 continues exploring the use of colour in relation to form, through shading and texture using markers, chalk pastels and colouring pencils. Weeks 13-16 focuses on exploring products, form and proportion, sketch work narrative, product detailing, design narrative and dynamic expression of views. Weeks 17-20 focus is on utilising mini design briefs to develop independence and sketch competency through product interrogation, product sketches, interfaces, detailed forms, and human interaction. The final four weeks focus on an exploded sketch assignment where the students learning is evaluated through the production of individual component drawings and the final exploded sketch.

#### 4 METHODS

Sixty BA Product Design Students second years and fifty-five BSc Product Design second years who had successfully completed their first-year studies at NTU were given the opportunity to complete the PD year one design sketching review survey. Sixty-seven students responded to the survey, thirty BA PD students and thirty-seven BSc PD students, representing a response rate of 58.2%. Distribution of the survey was conducted via in person briefings and several e-mail circulations. The thirty-one-question survey was reviewed and approved by the AADH Research Ethic Committee at Nottingham Trent University. The survey was curated on Microsoft Forms and was made available for a two-week period. The survey consisted of open ended and close ended questions which were utilised to gain a variety of insights regarding the PD year one design sketching syllabus and teaching approaches. The type of data collected varied from student testimonials, Likert scale question data, rating scale data and open text box question responses. Quantitative data was extracted and refined within a Microsoft Excel spreadsheet with a comparative analysis approach undertaken. Student demographic data, course data and prior education data collected enabled us to assess whether any trends can be established. Students aged 18 – 24 completed the survey highlighting varying education backgrounds ranging from GCSE's, A-Levels, BTEC's, International Baccalaureates, Art Foundation courses, amongst others. Student prior education backgrounds varied from no prior experience with creative subjects to three/four relevant qualifications. A summary of the key results and findings is presented in section five.

#### **5 RESULTS**

Upon reviewing the general perception of the students perceived sketching ability prior to joining NTU, students rated their design sketching skills as, very poor 4.5%, poor 22.5%, satisfactory 38.8%, good 20.9%, very good 9% and excellent 4.5%. However, after completing the design sketching syllabus, students rated their perceived design sketching skills as satisfactory 26.9%, good 50.7%, very good 19.4% and excellent 3%; no student rated their perceived skill level as poor or very poor. The percentage of students rating their skill level as excellent decreased, this could be due to an inflated perceived skill level prior to gaining a full understanding of perspective/proportion and the expectations from HE and industry. The overall experience with design sketching classes was rated at an average of 3.96/5.0, with BA PD averaging at 4.1/5.0 and BSc PD at 3.9/5.0. The main differences between the two student groups are small subject specific differences in the syllabus and the tutor team that delivers the content. Students were also asked to identify how important they thought design sketching classes were for their

Students were also asked to identify how important they thought design sketching classes were for their development as a product designer of which 1.5% of students respectively said it was "not important at all" or "somewhat not important", whereas 7.5% of students provided a neutral opinion with 34.3% of students stating is "somewhat important" and 55.2% stating it is "extremely important". However, when asked how important they thought design sketching skills are for their future professional practice in industry, 1.5% of students respectively said it was "not important at all", 4.5% students state it is "somewhat not important", whereas 14.9% of students provided a neutral opinion with 26.9% of students stating is "somewhat important" and 52.2% stating it is "extremely important". The slight drop in perceived importance may be attributed to the desirable industries that the students may seek to work in, with many of the BSc PD students seeking more technical or CAD focussed roles. For many students, engaging with design sketching can be quite a frustrating activity, especially for the BSc PD students who often struggle more with design sketching as a subject. When asking students about their level of

frustration when engaging with design sketching as an activity, 6% of students find it very frustrating, with 26.9% of students finding it frustrating. Conversely, 32.8% of students find design sketching "neither frustrating nor satisfying" but 28.4% of students find design sketching activities "satisfying" with 6% of students finding it "very satisfying". As demonstrated in Figure 1 the student perceived design sketching skill level/confidence level prior to studying 1st year PD and after completion of the 24-week syllabus dramatically increases. Most importantly all the core design sketching skills such as sketching with pens, pencils, use of fine tip pens/fine liners to communicate have moved to an acceptable or a greater outcome. With more complex skills/tools to master such as using rendering makers, sharpie's, coloured pencils for sketching and rendering, all these areas drastically improved, and of note only a few students still had negative responses.



# Figure 1. Student perceived skill level/confidence level prior to studying 1st year product design (Left); Student perceived skill level/confidence level after studying 1st year product design (Right)

An interesting outcome from the survey was the student perception on how important they think practicing design sketching is in relation to their ability to complete project work and design sketching assignments. Only 1.5% of students and 4.5% of students think that practicing design sketching is either "very unimportant" or "unimportant", whereas 11.9% of students take a neutral view, with 55.2% of students rating this as "important" and 26.9% of students rating this "extremely important". Contradictory to this, when the students were asked how many hours per week, they practiced their design sketching outside of classes (i.e. sketch work not related to project or a class), 32.8% of students do not do any practice outside of sketching classes with 29.9% of students only completing 1-2 hours of practice. 23.9% of students practice 3-4 hours per week with 9% of students practicing 5-6 hours per week and 4.5% of student practicing 7-8 hours per week. Interestingly the number of students who fail to practice any sketching per week is equal for both the BSc PD and BA PD courses. Student feedback identified several areas where improvements could be made to the syllabus design. Suggestions included, assigning sketch activities/tasks between design sketching classes, weekly one-page assignments to force students to practice, providing guidance on transitioning from traditional to digital outputs, sessions on sketch work editing in 2D/3D CAD platforms, providing support on page composition, and providing opportunities for exploration with a wider variety of mediums.

Assign more tasks for students to hand in every sketch session, for example, when doing exploded views during the session, set an exploded view drawing of an object of the student's choice, due for the next session (P12). Apart from helping us more with the transition from physical to digital i.e., moving designs on paper to photoshop and making sure they're presentable (P19).

We could do traditional to digital sketching tools studies. Could do with learning all the features on a digital sketching platform for introduction to it. (P27).

More space to choose what medium is used to a point i.e. range of pencils and pens but not too technical too quickly such as charcoals and pastels (P52).

Having a hand in every week of a single page of non-project sketching as a way to ensure student's practice (P59).

Although a number of these recommendations are valid, some of the recommendations do need to be carefully reflected upon to consider the full spectrum of abilities of the student cohort. Providing weekly deliverables for sketching classes although a great idea in practice, could result in loss of student engagement with classes or result in students having a sense of perfectionism due to trying to polish every page. Conversely this could create issues with imposter syndrome whereby students compare themselves to one another and the lower achievers stop engaging with classes due to comparing themselves to a peer whose skills may be significantly better. Another factor to consider with sketching assignments is that the current student mindset is to work deadline to deadline, as they struggle to manage multiple project/submissions. Contributing to this further could negatively impact project work deadlines. Providing opportunities to explore with a greater variety of mediums again could be integrated, but this must be done strategically so not to overwhelm students, yet at the same time we should not deviate from teaching the core principles. Additionally, it is imperative to consider the class as a whole and the varying student skill set which may differ class to class on a yearly basis. Within the PD subject, students come from varying backgrounds ranging from design technology, art, engineering, sciences, business, amongst others, and as such some students have no background in design sketching. Flexibility in the syllabus and the variety of activities and demonstrations available would provide students with the opportunity to not only improve their core skills but also give students who are more proficient the opportunity to expand their skill set further.

Based on the collected feedback it is clear that key areas demanding attention for improvement include elevating levels of 3D spatial awareness and cognition, instilling confidence, exploring problem-solving through construction methodologies, engaging through illustration, recognizing the importance of detail, effectively communicating technical narratives and annotations, creating a sense of accomplishment in one's work, and ultimately cultivating a practice that actively encourages engagement/attendance.

#### 6 DISCUSSION, CONCLUSIONS & RECOMMENDATIONS

This paper has identified the substantial differences in the entry points and early education experiences of design students entering HE who are studying at secondary and foundation education level. It is evident that recent alterations in the pathways to higher education have had an impact and negatively influenced the fundamental skill levels of students, particularly in design sketching. As such a key recommendation for all PD courses in HE is that a well-structured/detailed design sketching syllabus is required within the first year of studies covering the core principles resisting the urge to delve into digital and AI activities before the core principles have been taught and evidenced.

The foundation of the design sketching syllabus described in section 3 is formulated on the principles of upskilling all first year PD students to a similar level in terms of the skills and competencies required to succeed in HE. As such core values such as instilling confidence, practicing skills through repetition, reinforcing reflection and critique, applying sketch development techniques, and incorporating diverse activities help reinforce continuous improvement. Additionally, course identity and alignment with industrial perspectives play crucial roles in ensuring students comprehend the significance and motivations underlying their education. As identified in the results section, a worrying trend identified is that most students either do no practice their designs sketching skills or practice these for a small period of time, regardless of the consistent reminder by staff/tutors to do so. Conversely, 74.6% of students identified that they would be prepared to undertake more sketching assignments based on their design sketching classes if they were to receive a graded outcome or written/verbal feedback. As such it is clear that students place more value in completing project work/assignments where assessments are involved rather than self-directed skills development. Encouraging autonomy is a core value at higher

education level and as such finding methods to engage students with passion projects or design sketching activities that encourage students to practice the fundamental skills is important.

An interesting finding from the survey identified that students would be willing to learn more about artificial intelligence text to image idea/concept generation (Y:70.1% N:18% M:11.9%). Also, many students want to learn more about digital sketching using drawing tablets, graphic tablets (Y:88% N:12% M:0%) and also want to learn more about virtual reality design sketching i.e. idea/concept generation in a 3D space using VR headsets (Y:70.1% N:29.9% M:0%). Conversely, 73.1% of students stated that their preferred method of design sketching would still be via traditional methods (i.e. pen/pencil). When this survey was conducted all students had been exposed to digital sketching, text to image AI and VR sketching and as such this highlights the importance of teaching the fundamentals of design sketching as a core aspect of a PD courses syllabus. Critically, although there is rapid growth in digital, immersive, and AI technologies which is providing expanded opportunities within design sketching, ideation, development, and concept visualization, based on the point of entry information and the survey data collected and through holistic observations, it is imperative that students master the fundamentals before embracing the complexity of digital tools. Another important factor to consider is that when setting tasks within design sketching sessions, students prefer a mixture of tasks that are not directly related to their studio project work, but also want occasional tasks/project focussed sketching classes that help them improve their project work or provide the initial upskilling required.

Key recommendations for design educators when developing design sketching syllabuses include gaining a full understanding of the student cohorts' previous education at point of entry, whilst also getting comprehensive data via a skills audit. This would allow the syllabus content to be tailored to the correct level. Regular design sketching classes on a weekly basis for a minimum of the first two years of study is crucial for imparting the fundamental skills. While the rapid advancements in digital, immersive, and artificial intelligence (AI) technologies for design sketching syllabuses should be taught methodically and systematically by gradually introducing skills steadily over a sustained period of time so not to overwhelm students. Finally, syllabuses implemented should be tailored to the courses specialism to ensure students see the value/relevance to the course assignments as well as a clear connection to industrial employability. In conclusion, it is critical that students develop design sketching throughout their time in HE, by gaining confidence in this core skillset, this will not only improve their proficiency in this specific skillset, but it will also translate to their overall communication as a designer, both with in design projects and within their professional practice in industry.

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## FUTURE PROOFING COMPUTER-AIDED DESIGN EDUCATION THROUGH AI-DRIVEN E-LEARNING

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#### ABSTRACT

In response to the dynamic landscape of Computer-Aided Design (CAD) software and the emergence of Artificial Intelligence (AI) tools, this paper characterises a theoretical system for a Personalised AI Learning System (PALS) tailored to individual student needs. The system aims to generate personalised learning content for various CAD software as well as facilitating efficient and adaptable learning experiences. By doing so, PALS could streamline individual student learning and therefore future proof the ability to learn new software independently and frequently depending on educational needs and the commercial and technology landscape. The system is characterised as a result of literature review, student and staff surveys as well as AI experts' feedback.

Keywords: CAD, E-Learning, AI

#### 1 HOW STUDENTS LEARN CAD AND CAD LANDSCAPE

To characterise a theoretical system for a Personalised AI Learning System (PALS), we need to understand current CAD learning methods and the potential that generative AI has in e-learning. In the early days of CAD education, SolidWorks (Dassault Systèmes), Rhino 3D (McNeel & Associates), and Autodesk Maya dominated the CAD market. The past decade saw a proliferation in popularity of additional products such as Blender, Gravity Sketch, Onshape, and SketchUp, alongside independent rendering engines like Keyshot. Blender and Rhino's Grasshopper saw a surge in user-generated custom add-ons, enhancing features of software. This expanding and dynamic nature of CAD software landscape

along with a surge in e-learning resources has altered the way students learn and tutors teach CAD. CAD in design is not only about the quality of surfaces and model history structure but also about the ability to express design engineering ideas and be able to use it as naturally as sketching to express designs. In modern CAD education, students employ various learning methods tailored to their preferences and skill levels. Access to e-courses, tutorials, and online resources allows for self-paced learning and exploration of diverse CAD tools [1]. Instructor-led sessions and practical workshops provide structured learning experiences, complemented by guidance from instructors and real-world project applications [1]. Peer collaboration is also pivotal, enabling knowledge exchange and troubleshooting, while mentorship from CAD professionals fosters continuous improvement [2]. The challenge-based or project-based learning model promotes real-world problem-solving and critical thinking, encouraging students to take ownership of their learning [3]. Furthermore, research highlights the cognitive nature of CAD training, emphasising the separation of declarative and procedural knowledge components [4]. This understanding informs the design of effective educational tools and interfaces.

In summary, CAD education relies on independent learning facilitated by online resources, complemented by instructor guidance and peer collaboration. Mentorship remains crucial for continuous improvement, however changes in the CAD software landscape underscores the dynamic nature of CAD education and the need for adaptable learning approaches to cater to diverse student needs.

#### 2 E-LEARNING AND GENERATIVE AI IN EDUCATION

E-learning tools are crucial in modern education, providing various learning approaches and resources like e-courses, tutorials, and online materials, along with instructor-led sessions, workshops, mentorship, peer collaboration, and challenge-based learning models [5]. Future trends in e-learning include integrating virtual and augmented reality (VR/AR), mobile learning, social media, gamification, big

data, cloud e-learning, and online video [6]. These trends highlight the integration of innovative technologies to enhance the learning experience.

Generative AI technologies, such as large language models and generative models, automatically create diverse content from text prompts, advancing rapidly in complexity and accessibility [7]. These advancements leverage deep learning to generate text, graphics, audio, and video content efficiently. AI systems such as IBM's "Watson" system, is applied in medicine to aid medical students in navigating complex oncology treatment choices through evidence-based learning models [8].

Integrating interactive self-assessment graphical tools in CAD pedagogy enhances students' learning experiences [9]. Auto-assessment tools designed for CAD education, based on neutral file formats like STEP, compare students' CAD models with reference models to identify surface differences and provide valuable feedback [9]. This allows educators to gauge students' proficiency and track their learning trajectory in CAD.

Currently, ai's role in cad software primarily concentrates on design tasks such as generative design. however, its potential in educational content creation holds significant promise [9]. by enhancing the learning experience, ai can help adapt cad education to future trends, fostering student engagement and skill development. therefore, comprehending the technical challenges linked to ai implementation in cad education is vital for its effective utilisation and adaptation to evolving educational landscapes.

#### 3 METHOD: SURVEYS TO DEFINE PALS

The study methods involved a literature review, conducting surveys among students, staff and AI experts. The literature review provided a theoretical foundation by summarising existing knowledge on CAD learning methodologies, challenges, and trends in educational technology. It informed the development of the survey questionnaire by highlighting key areas of inquiry and potential variables to explore. Additionally, it shed light on the significance of personalised learning, the role of AI in education, and emerging trends in e-learning tools, which directly influenced the conceptualisation of PALS. To gain insights into current CAD learning practices of Design Engineering students, a structured survey was disseminated among third year students on an MEng programme at a leading university. The survey included 50 students who have intermediate experience with CAD such as Fusion 360 and SolidWorks but were required to learn a new software: Rhino and Grasshopper. Student participants were asked about: the resources they use for CAD learning, examples of helpful learning experiences, challenges encountered during CAD learning, methods to adapt to the evolving landscape, familiarity with CAD software, associations between CAD software and career prospects, ease of learning various CAD software, factors contributing to ease of learning CAD software, and common methods of learning CAD. The survey results were analysed using text-to-data analysis techniques, which involved parsing and categorising responses to recognise sentiment and sort comments, thereby extracting meaningful insights to inform the characteristics of the PALS.

#### 4 RESULTS: STUDENT CAD LEARNING EXPERIENCE

The student survey demonstrated that student CAD learning in the sampled group, comes from three main sources (Figure 1, left). 50% from online resources such as YouTube tutorials, forums, and LinkedIn Learning for CAD. 27% from collaborative learning and practice. What students gain from tutors is the ability to ask or prompt specific questions as well as learning from suggestions/demonstrations in real time. The most familiar CAD software among participants is Fusion 360, followed by SolidWorks, Blender, Rhino 3D, and AutoCAD. Participants associate SolidWorks and Fusion 360 with better career prospects, with the later considered the easiest software to learn. Factors contributing to ease of learning CAD software in students' minds include the availability of open-source add-ons and tutorials, intuitive design, simplicity, previous exposure, customisation options, and ease of transfer of files to other software.

The primary challenges encountered during CAD learning (Figure 1, right) provided insights that will feed into PALS. Firstly, students struggle to initiate their very first CAD model since there are too many unknowns. This is the step students most require tutor instruction for, so PALS needs to recognise the specific learning curve of each student, for example providing high levels of input at early stages and reducing as students' progress. In addition, students can be limited by slow access to answers as they are waiting for the next session and are unable to find the answer online. This is where it would be particularly useful for students to be able to prompt PALS for answers.

One significant challenge students brought up is CAD software setup differences and computing power limitation. Often students can be unaware that their layout of the software is different to the tutorial they are watching, for example if using a different operating system or version of the software. Secondly, 3D modelling is computationally heavy and inexperienced users often will submit a task that could require computing over ten thousand different calculations without realising it. The PALS could generate content specifically for the user's software version and operating system. Warning about potential software crashes is harder to avoid but perhaps PALS could suggest explanations as to why the software crashed based on user explanation of the steps taken. Students are aware of the evolving landscape of CAD software and adapt to it and often focus on learning new software/tools on their own.

When asked about the potential usefulness of PALS, students have made suggestions for features such as auto-creating tutorials for new software, providing suggestions for faster or more efficient methods of working, troubleshooting, or working with AI to break down constructing objects in CAD, using video or image assets and learning how to create designs



Figure 1. Sample of student survey results: ways to learn CAD (left) and types of challenges encountered when learning CAD (right)

The staff survey included Teaching Fellows who deliver CAD training to students. Their main feedback was to calibrate the feasibility of PALS. Should it be software specific, can it be an add on to existing software and how to overcome the variation in the UI of various software.

AI experts from UWE Bristol advised on the system architecture of PALS. Their feedback was positive and PALS was deemed plausible from a technical perspective.

#### 5 CHARACTERISATIONS OF PALS

In characterisation of PALS, learnings from the student surveys together with usability factors were considered. The system comprises three modes: content generation, interactive learning, and analytics for learners and tutors. The content generation mode leverages generative AI techniques to create tailored learning materials. The interactive learning mode serves as a personalised library, recommending relevant resources and collaborative projects to inspire creativity and skill development in CAD learners. Lastly, the analytics for learners and tutors' mode provides personalised feedback to learners and comprehensive data insights to tutors, facilitating informed decision-making and instructional planning.

Generative AI systems such as PALS can employ a basic architecture comprising data input, processing, generation, and presentation layers, alongside a wrapper to manage system functionality and interactions. Data can be sourced from existing online videos and educational materials such as textbooks, user interactions, and other repositories.

#### 5.1 Usability consideration

Critical to the PALS characterisation methodology was the evaluation of usability aspects inherent in existing CAD learning platforms. Usability can be considered to comprise of five components: learnability (initial task ease), efficiency (task speed and effectiveness), memorability (re-learning ease), errors (error frequency and recovery), and satisfaction (overall user experience) [10].

#### 5.2 Personalised learning content generation mode

The system architecture (Figure 2) comprises several interconnected modules designed to facilitate personalised learning of CAD. The data acquisition module collects educational content from online

sources such as YouTube videos, LinkedIn Learning courses, and online forums. This data is then processed and sorted based on user preferences, including the type of software, version, and operating system. Next, the content generation module utilises generative AI techniques such as natural language generation (NLG), sequence-to-sequence (Seq2Seq) models, conditional variational autoencoders (CVAEs), and template-based generation to create step-by-step tutorials tailored to the student's query and level. A user interface chatbot module provides an intuitive interface for interacting with the system, while a feedback loop module ensures continuous improvement by collecting user feedback and integrating it back into the system. This architecture enables the system to deliver personalised step-bystep instructions, explanations, code snippets, diagrams. For troubleshooting issues in real time, students can input their query or describe the issue to the system. Based on the input provided by the student, the system can diagnose the issue by comparing it with a database of common errors, troubleshooting steps, and solutions. It can also leverage machine learning algorithms to identify patterns in previous troubleshooting interactions and recommend appropriate solutions. Once the issue is identified, the system can generate step-by-step instructions, explanations, and visual aids to guide the student through the troubleshooting process. These instructions can include screenshots, diagrams, or video tutorials illustrating the necessary steps to resolve the problem.



Figure 2. System architecture for the content generation mode

#### 5.3 Interactive learning mode

In this mode, users access a personalised library of online content tailored to their software, version, and operating system set-up. It aims to inspire and challenge users by showcasing recent advancements and user-generated models. The goal is to foster learning beyond mere model creation, emphasising design skills development. Leveraging natural language processing (NLP), the system interprets user queries and retrieves relevant learning materials. It employs content filtering and recommendation systems to suggest tutorials, articles, and resources matching user needs. Additionally, web scraping and API integration access online resources and showcase user-generated content from forums and social media platforms. The mode includes an Inspiration Zone with curated designs and techniques and a Challenge Repository offering diverse design challenges. Suggestions for faster or more efficient methods of working, such as exploring the Sub-D feature in Rhino for surface control points, are also provided.

#### 5.4 Analytics for learners and tutors' mode

PALS provides the opportunity for a considerable amount of personalised overall learning gain feedback to both learners and tutors. For students, learning does not only happen during the in-task CAD activity, but also through receiving feedback from tutors and peers following completion of activities or stages

of work, and as an ongoing aggregate of student's reflection on and appreciation of gains in knowledge, skills and understanding.

This mode will gather various metrics such as engagement levels, performance on tasks, learning progress, feedback analysis, resource utilisation, collaboration patterns, retention rates, learning outcomes, comparative analysis, and predictive analytics. By collecting and analysing these data points, valuable insights into student learning experiences, areas for improvement, and tailored interventions to meet individual student needs can be effectively defined.

#### 6 CONCLUSIONS AND FURTHER RESEARCH

PALS systems promise to revolutionise CAD education by integrating current methodologies, usability factors, and student feedback. The concept aims to cater to the changing CAD software landscape and diverse learner needs, empowering students as independent learners while offering valuable feedback to tutors for optimising teaching strategies and tracking student progress.

The PALS concept also raises several avenues for further research to enhance its effectiveness and impact in CAD education. Firstly, future studies could focus on refining the generative AI algorithms used for content generation to improve the accuracy, relevance, and diversity of learning materials produced. Additionally, exploring innovative methods for user interaction and feedback collection, such as natural language processing and sentiment analysis, could enrich the user experience and provide deeper insights into learner needs and preferences. Moreover, investigating the scalability and interoperability of PALS across different CAD software versions, operating systems, and user devices would ensure broader accessibility and usability for learners worldwide. Furthermore, longitudinal studies evaluating the long-term effectiveness and learning outcomes of PALS compared to traditional CAD education methods could provide valuable insights into impact on student learning and skill development over time.

The integration of generative AI in educational systems such as PALS raises important ethical considerations regarding the potential negative impact on students' learning experiences and core understanding of CAD and engineering principles. One significant concern is the risk that heavy reliance on generative AI-generated content may diminish students' engagement in critical thinking and independent problem-solving skills. Students may experience a similar effect to introducing GPS navigation, that reduced our own sense of orientation. By providing personalised and readily available learning materials, there is a possibility that students may become overly reliant on AI-generated solutions without fully understanding the underlying concepts or principles. This could lead to a superficial understanding of CAD and engineering principles, hindering their ability to apply theoretical knowledge to real-world problems and innovate creatively.

If AI-generated content is not adequately curated or validated by educators, there is a risk of disseminating inaccurate or biased information, potentially leading to misconceptions or reinforcing existing biases in students' learning.

To mitigate these ethical concerns, it is essential for educational institutions and developers of AI-driven systems like PALS to prioritise the promotion of critical thinking, problem-solving, and conceptual understanding alongside AI-generated content. This can be achieved by integrating opportunities for active learning, peer collaboration, and hands-on experiences into the curriculum, complementing the personalised learning materials provided by the AI system. Additionally, transparent communication about the role of AI in the learning process, including its limitations and the importance of independent inquiry, can help empower students to engage critically with AI-generated content and develop a deeper understanding of CAD and engineering principles. Overall, a balanced approach that leverages the benefits of generative AI while fostering students' autonomy and critical thinking skills is essential to ensure ethical and effective educational outcomes.

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## TOWARDS AN EDUCATION SYSTEM AIMED AT ENHANCING THE EMBODIED, ENACTIVE AND INTERACTIVE EXPERIENCE THROUGH NEW REALITIES

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#### ABSTRACT

The rapid evolution of immersive XR technologies has led to enhanced experiences by blurring the line between the real (physical) and unreal (virtual) worlds. However, there is a dearth of research clarifying the types of learning paradigms to consider when integrating immersive technologies in design education and enhancing learner experience. How can we further enhance our design education system by using immersive technologies to upgrade learning experiences? What type of approach is appropriate to make the best use of the unreal in design education to enhance learners' experiences in the real? The integration of knowledge from recent neuroscience research into education, through a multidisciplinary translational approach, can be transformative for advancing the comprehension and development of new learning experiences. This research aimed to clarify several questions. It began by (1) reviewing current trends and the role of immersive technologies. Next, it (2) identified their role and value in design education, and (3) highlighted the limitations and possibilities of using immersive technologies as tools in design education with *The Enactive Embodied Experience Model*. Finally, (4) it proposed an approach based on recent neuroscience research. This approach uses a multidisciplinary translational strategy to advance the comprehension and development of new learning experiences in design education and to provide experience-based knowledge through immersive technologies. The findings of this research will act as guidelines for the implementation of immersive technologies in design education and will be one of the considerable methods to enhance students' enactive learning experiences.

Keywords: Embodied-Enactive-Interactive, immersive technology, experience-based knowledge

#### **1** INTRODUCTION

The rapid evolution of immersive technologies such as, Virtual Reality (VR) and Augmented Reality (AR), blur the lines between the *real* (physical) and *unreal* (virtual) worlds by enabling the creation, manipulation, and testing of realistic and complex immersive experiences and solving many of the design constraints. However, accelerating forward and making these technologies mainstream design tools can be hindered by the need for human resource training, rigid time schedules, budget issues, and other constraints of the design industry. Failing to overcome this challenge will lead present and future designers to face difficulties in exploring new possibilities, gaining new knowledge, and eventually unlocking the full potential of immersive technologies as design tools for enhancing the human experience. How can we further enhance our design education system by utilizing immersive technologies to upgrade learning experiences? What type of approach is appropriate to unlock the full potential of the *unreal* (immersive technologies) as design tools to enhance human experiences in the *real* world?

A solution to this is to rethink the role of immersive technologies in the learning experience provided by the design education system. Nowadays, design students enter higher education with significant computing knowledge and higher expectations from academia to introduce them to relevant theoretical as well as practical knowledge and application of high-end immersive tools for a successful transition into the design industry. Even though immersive technologies have indeed been introduced in education for several years, they are yet to gain broad acceptance in design schools. This research aimed to gain clarity to these issues by, (1) reviewing the current trends and role of immersive technologies in design industry, (2) identifying their role and value in design education, (3) highlighting the limitations in using immersive technologies as design education tools with *The Enactive Embodied Experience Model*, and (4) proposing an approach in design education to provide experience-based knowledge using immersive technologies.

Designs are concerned with how things work, how humans interact with something, and how they solve real-world problems and human needs. The issue with traditional design practices is that they were based on the designer's or engineer's logical assumption of how they wanted or expected them to be used, not the way the users would use them. In future design, human cognitive and emotional demands must be prioritised over high-end and technologically advanced designs. Current design practices such as industrial, engineering, and interactive design are adopting this approach by producing form-function-based objects upon analysing what the users expect from the objects or services and their experience, i.e., human-centred experience design. Further implementation of this approach requires multiple design prototypes and testing to ensure that the users' needs and problems are met.

#### 2 LITERATURE REVIEW

Immersive Extended Reality (XR) technologies, encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), have revolutionized how we interact with digital content. By blending the digital and physical realms, these technologies create experiences where the real and unreal seamlessly converge, offering users a new dimension of interaction. VR immerses users in entirely digital environments, AR overlays virtual objects onto the real world, and MR combines elements of both to create interactive environments that integrate real and virtual elements. This fusion of realities enhances the perception of presence, making digital interactions feel as tangible and immediate as those in the physical world. In education, particularly design education, these technologies offer a rich, interactive canvas for students to explore concepts, visualize designs in three dimensions, and engage with content in a deeply personal and impactful way. By simulating real-world scenarios and enabling hands-on experiences without the constraints of physical materials or geographic boundaries, immersive XR technologies have the potential to revolutionize not only design but also broad learning methodologies, making education more accessible, engaging, and effective. To delve into the potential of immersive technologies in revolutionizing design education systems and learning experiences, it's essential to build upon the recognition of the existing research gap. Understanding that the integration of Extended Reality (XR) technologies-Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—into design education lacks a comprehensive pedagogical framework, we can begin to explore innovative avenues for their application. This exploration aims to not only harness the technological capabilities of XR but also to align these tools with educational strategies that significantly enhance learning outcomes. In other words, it is expected that understanding how the experiences that build individual knowledge and the personalized perspectives (the Innate/Inherent Subjective Filters in this study) interact with the introduction of immersive technologies can provide direction for immersive education.

# 2.1 Current Trends in Immersive Technologies & Learning Paradigms in Design Education

Immersive technologies offer unparalleled opportunities to enhance the evolving learning paradigms in design education. Specifically, VR and AR provide simulated environments and scenarios that are otherwise impossible or impractical in a traditional classroom. These innovations allow students to explore, experiment, and refine their designs in a safe, virtual space, fostering an environment ripe for active learning and discovery. This, in turn, amplifies the principles of constructivist learning. Additionally, MR and AR technologies can enhance collaborative projects, even when participants are geographically dispersed. They enable students to share and interact within virtual spaces, collaborate in real-time, and provide immediate feedback, effectively overcoming physical and geographical barriers. This promotes a community of practice, where students gain from diverse insights and feedback from their peers. Moreover, immersive technologies can replicate real-world environments and conditions, offering students the chance to apply their designs in various contexts and scenarios. This approach not only enriches the learning experience but also equips students with the necessary skills and understanding to tackle real-world design challenges, enhancing experiential learning. The integration of immersive technologies into design education promises to significantly enrich learning paradigms, providing more interactive, engaging, and personalized experiences. As these technologies continue to evolve, their role in education is set to expand, fundamentally transforming how design is
taught and learned. However, when implementing these possibilities in design education, an important point is to reconsider the perspectives and methods of immersive education tailored to the knowledge and experience of each individual learner. This leads us to critical questions for the future of design education: How can immersive technologies improve learning experiences? And what are the most effective strategies for incorporating virtual elements into design education to enhance real-world outcomes? These questions will be addressed in the Methodology section.

## 3 METHODOLOGIES AND DISCUSSIONS

The revised Enactive Embodied Experience Model (for the previous model, refer to references 1,2 and 3), depicted in Figure 1, advances our understanding of how affective processes shape personal choice and desire through the lens of an innate/inherent subjective filter. This filter posits that individual experiences and transformations cultivate a distinct perceptual lens for each person. Central to the model is the mechanism by which human sensory receptors-such as the eyes, ears, and nose-capture environmental stimuli. This sensory data is then synthesized in the brain, influenced by a filter that modulates affective responses. Additionally, the model introduces the concept of a 'driven filter', either logical or aesthetic, which plays a pivotal role in the development of an individual's unique subjective filter. As illustrated in Figure 1, this driven filter elucidates the dynamic interplay between the innate subjective filter and the process of sentient behavioural modification. This process, informed by personal experiences, culminates in the manifestation of sentient behaviour. The notion of the oriented/driven *filter* is critical in understanding how it guides the evolution of *the innate subjective filter*, be it logical or aesthetic. Individuals with a predilection for logic-oriented learning-such as language or mathematics, which demands a conceptual grasp of principles-tend to enhance their logic-focused dimension over the aesthetic one. Conversely, those inclined towards aesthetic-oriented learning, exemplified by pursuits in art and music, which require a more flexible and intuitive approach, are likely to cultivate their aesthetic dimension. It is posited that these divergent learning orientations significantly influence and nurture the individual's innate subjective filter, reinforcing the model's premise on the formation of unique perceptual lenses shaped by personal experiences. In other words, by individualizing the stimuli provided through immersive technologies according to each person's 'driven filter', it is expected that the same stimuli can lead to a diversification of experiences influenced by the inherently modified subjective filter unique to each individual.

In the domain of design education, integrating virtual elements opens transformative paths to enrich learning experiences. By embracing immersive technologies, educators create environments where students do more than just absorb theoretical knowledge; they apply it within simulated real-world contexts, bridging the gap between classroom learning and professional practice. This holistic approach fosters the development of a unique perceptual lens for each student, rooted in experiential learning and shaped by the nuances of human emotion and cognition, as detailed in the revised Enactive Embodied Experience Model. This includes methods such as Project-Based Learning with Immersive Technologies, Gamification, and Real-World Simulations and Case Studies, described as follows: (1) Project-Based Learning with Immersive Technologies: Utilizing VR and AR transforms project-based learning into an engaging activity that reflects the complexity and dynamism of real-life professional scenarios. This approach enables students to design and test virtual models, offering immediate feedback and enhancing engagement through a hands-on, experiential learning process. By tailoring stimuli (e.g., stimuli based on the characteristics of sensory organs such as sight, smell, and hearing) to each individual's specific 'driven filter', and by providing these stimuli at varying frequencies and intensities, it is expected that, even with the same amount of time and technology invested, more effective immersion can be achieved compared to existing methods. (2) Gamification: Integrating game design elements into the curriculum, a method known as gamification, significantly increases student motivation and engagement. Introducing challenges and competitions in a virtual environment not only makes learning more enjoyable but also strengthens the connection with the material. By adjusting the level of challenges to suit each individual's specific driven filter, it will enable the practical implementation of personalized education rather than a one-size-fits-all approach. (3) Real-World Simulations and Case Studies: Employing VR or AR to mimic real scenarios provides students with practical insights and prepares them for the diverse challenges of the design industry. This experiential learning method allows for the application of theoretical concepts in real-life situations, thus improving the educational experience. By selecting simulation subjects and conducting in-depth case studies tailored to each individual's specific driven filter, the accumulated data will make it easier to identify

the types and explanations of simulations suitable for that individual and to point out specific issues. This will enable individualized learning through diversified simulations based on the innate subjective filter.

The strategic implementation of these methods enables educators to fully harness the potential of immersive technologies, not only elevating the design education experience but also equipping students with the skills necessary for success in the contemporary design landscape. Furthermore, these pedagogical strategies foster the growth of individual subjective filters, as informed by *the Enactive Embodied Experience Model* (Figure 1). This model illuminates the intricate relationship between affective processes and personal development, highlighting the role of logical and aesthetic 'driven filters' in shaping one's unique perspective. Whether through logic-oriented subjects like language and mathematics or through aesthetic pursuits such as art and music, these varied learning orientations significantly influence and enrich the individual's perceptual lens, promoting a culture of innovation and originality in design proposals and enriching the overall learning and creative process. In other words, the innate subjective filter that each individual is born with is strengthened and integrated with a specific 'driven filter' (logical or aesthetic) through the individual's experiences and learning. This development of the subjective filter leads to personalized understanding and accumulation of knowledge, even in response to the same external stimuli.



Figure 1. The Enactive Embodied Experience Model which explains the relationship between an innate / inherent subjective filter and the individual sentient behavioural modification process through their experiences, resulting in sentient behaviour by Kim

The inherent subjective filter not only endows individual meaning based on one's experiences and understandings but also underscores the significant differences between human cognition and Artificial Intelligence (AI). Humans interpret and integrate external information through a deeply personal and constantly evolving lens, whereas AI processes data based on predefined algorithms and models, lacking the capacity to be influenced by emotions or to adapt from experiences. This distinction highlights the nuanced and dynamic nature of human decision-making, wherein emotions, personal experiences, and the subjective interpretation of stimuli play pivotal roles. In contrast, AI's decision-making relies on logical analysis and pattern recognition, which, although powerful, fails to grasp the personal significance or emotional value that humans attribute to their choices and perceptions. In other words, individual experiences and understanding through the inherent subjective filter provide hints about the importance of personalization in immersive technology within design education.

Incorporating immersive technologies into design education presents a unique blend of challenges and opportunities, especially when analysed through *The Enactive Embodied Experience Model*. This model suggests that learning experiences are processed through cognitive frameworks unique to each individual, which can evolve or be further reinforced through new experiences. Within the realm of

design education, integrating immersive technologies provides valuable insights into the capacity of these tools to reshape cognitive filters that fundamentally influence our understanding and application of design concepts. Thus, the critical question emerges: how can we effectively facilitate this transformation? Insights from neuroscience and learning within immersive environments suggest several effective approaches. Neuroscience, which explores the nervous system and brain, has unveiled crucial insights into our learning processes and the profound impact immersive experiences can have on educational outcomes. Recent studies have started to reveal how our brains process, store, and retrieve information, especially within immersive learning spaces enabled by VR, AR, and MR. This summary highlights key neuroscience findings relevant to education, with a focus on how immersive experiences influence the brain.

Immersive environments significantly boost learner engagement and attention. By immersing learners in virtual scenarios that mimic the real world, their sensory systems are fully engaged, which allocates more attention to the task. This increased focus supports deeper learning and better retention of information due to enhanced engagement and attention. Moreover, neuroscience has shown the critical role emotions play in learning and memory. Immersive experiences can provoke strong emotional responses because they can simulate real-life situations. These emotional reactions are linked to the amygdala, a brain region involved in emotional processing and crucial for memory formation and retrieval. Consequently, learning experiences that evoke emotions are more likely to be remembered due to the emotional connection and memory formation. Interacting with immersive technologies can also boost problem-solving abilities and creativity. The interactive nature of VR, AR, and MR environments prompts learners to explore, experiment, and critically think about encountered problems. This active learning approach fosters higher-order thinking skills such as analysis, evaluation, and creation, essential for the 21st-century workforce, enhancing problem-solving skills and creativity. Immersive learning experiences promote neuroplasticity, the brain's capacity to form new neural connections in response to learning and experiences. This is vital for acquiring skills and mastering complex concepts. By engaging multiple senses and providing hands-on experiences, immersive technologies enhance the brain's adaptability and learning capacity, improving cognitive functions and knowledge retention.

Immersive learning experiences, while offering unique opportunities, also pose challenges. One significant issue is the risk of cognitive overload, where the brain is overwhelmed by an excess of information from virtual environments. Another critical concern is the imperative to develop educational content that fully harnesses the capabilities of immersive technologies without compromising the quality of education. *The Enactive Embodied Experience Model* plays a crucial role in this context (Figure 1). This model elucidates the interconnectedness of affective processes and personal development, highlighting how both logical and aesthetic preferences—or 'driven filters'—shape our distinct perspectives. These unique viewpoints allow us to concentrate on design education issues within an aesthetic-related learning framework, which cannot be fully understood through a purely logic-driven filter. Whether through logical disciplines such as language and mathematics or aesthetic fields like art and music, these varied approaches to learning profoundly influence and enhance our perceptions. This could cultivate a culture of innovation and creativity in design proposals, thus enhancing both the educational experience and the creative process.

## 4 CONCLUSIONS

The intersection of design education and immersive technology—VR, AR, and MR—presents an unparalleled opportunity to revolutionize how we teach and learn design. By moving away from a predominantly theoretical approach to one that prioritizes hands-on, experiential learning, we can better prepare students for the complexities of real-world design challenges. This shift requires not just an investment in new technology but a reimagining of the curriculum to make learning more interactive, engaging, and effective. As we integrate these technologies, we must also address challenges such as accessibility and the development of relevant educational content. By leveraging VR, AR, and MR, we can create a more immersive learning environment that fosters creativity, collaboration, and problem-solving skills—key competencies for any future designer. The question for us, as educators and researchers, is not if but how we will embrace these technologies to enrich design education and better prepare our students for the future.

In the context of "Towards an education system aimed at enhancing the embodied, enactive, and interactive experience through new realities," the focus shifts towards reimagining the educational

landscape. This is achieved by leveraging emerging technologies to craft more immersive, interactive, and engaging learning environments. Such an approach acknowledges the constraints of traditional education systems, which tend to prioritize theoretical knowledge over practical, hands-on learning experiences. By incorporating technologies based on *The Enactive Embodied Experience Model* (Figure 1), this initiative underscores the importance of how both logical and aesthetic preferences—or 'driven filters'—influence our unique viewpoints. The proposal aims to cultivate a learning atmosphere that accentuates embodied learning. Here, students learn through action, experiencing, and interaction within simulated environments that replicate real-world scenarios. This model emphasizes the integration of cognitive processes with physical experiences, thereby offering a holistic approach to education. By doing so, it encourages students to apply logical reasoning and aesthetic judgment in concert, enhancing their ability to navigate complex design challenges. *The Enactive Embodied Experience Model* provides a theoretical framework that illuminates how individuals perceive and interact with the world through a blend of sensory experiences and cognitive interpretations. It suggests that learning is most effective when it is situated in contexts that engage the learner's body and mind in active exploration and problem-solving.

In this reimagined educational paradigm, design academic field researchers are encouraged to explore how these technologies can be seamlessly woven into the curriculum. The goal is not just to integrate new tools for the sake of novelty but to fundamentally transform the learning process. This transformation involves making education more dynamic and responsive to the needs of students, preparing them for the complexities of contemporary and future design landscapes. The context centres around three key dimensions: (1) Embodied Learning: This dimension focuses on learning experiences that engage the whole body, allowing students to gain knowledge through physical interaction with their environment. Technologies like VR can simulate environments where learners can physically manipulate objects, conduct experiments, or perform tasks, enhancing their understanding through physical experience. (2) Enactive Learning: Enactive learning emphasizes active engagement and interaction with the learning material. Instead of passively receiving information, students actively construct knowledge by exploring, experimenting, and solving problems. AR applications, for instance, can overlay digital information onto the physical world, enabling students to interact with both simultaneously, thereby deepening their engagement and comprehension. (3) Interactive Experience: This aspect highlights the importance of interactivity in learning, where students are not mere spectators but active participants. Through MR and other interactive technologies, learners can collaborate in shared virtual spaces, engage in simulations that adapt to their actions, and receive immediate feedback, making the learning process more dynamic and personalized.

The proposed educational system combines three core dimensions to address the shortcomings of traditional methods. It envisages an inclusive learning environment engaging learners from diverse backgrounds, nurturing exploration, innovation, and creativity. This method strives to furnish students with versatile skills and innovative thinking necessary for navigating contemporary society. By integrating technologies grounded in *The Enactive Embodied Experience Model*, the system highlights how both logical and aesthetic preferences shape our viewpoints. This initiative aims to foster a learning atmosphere that emphasizes embodied learning, essential for design educators and researchers. This forward-looking approach ensures that the educational system remains adaptable and responsive to the changing needs of learners and the broader societal landscape.

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## TRAINING DESIGN FOR DISTANCE RUNNING; HOW TO APPLY STATISTICS, DESIGN OF EXPERIMENTS, AND DATA SCIENCE FOR ACTIVE LEARNING IN UNIVERSITY STUDENTS

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#### ABSTRACT

In recent years, long-distance races have boomed all over the world. Mexico is no exception, but just as the enthusiasm for races over 5k has increased, the rate of sudden heart attacks has also increased. This is due to not having personalised and adequate training. The following paper describes how, based on design and engineering techniques, young students at the Tecnologico de Monterrey have trained to increase their performance as athletes. Statistical methods allow the design of focused training to improve their time without affecting their physical and mental health. The introduction of data science, as well as the design of experiments, allows customising each training session according to information from each athlete, such as heart rate,  $VO_2$  Max, weight, blood pressure, and the level of red and white blood cells, as well as running technique factors such as stride length, arm stroke technique, and stride. This allows students to actively learn about the application of statistical engineering, which will later allow them to transfer said knowledge to their professional field, making analogies between sport and a disciplinary competition. The results of more than five editions of the 5k and 10k race of the annual race of the Tecnologico de Monterrey Campus Querétaro are analysed, as well as of students who record daily data through recording devices which were processed in databases to calculate descriptive statistics and correlate efforts with the designed workouts.

Keywords: Distance training, data science, statistics, educational innovation, higher education

#### **1** INTRODUCTION

"Design is everything; without design, science tends to be nothing."

Learning data science, as applied statistics is now known, is usually a bit traumatic for students. Antony & Antony [1] presents a UK study where students feel extremely comfortable solving book problems but cannot pose a real-life problem and solve it with statistical methods. In Latin America, the fear of learning statistical topics is constant [2]. In Mexico, this is a deeper problem that arises from the design of curricula of the Secretariat of Public Education (SEP), and which is evidenced in the evaluations of the Pisa test [3].

According to Gonzalez *et al.* [4], the design of a learning activity in the Tec21 educational model must be composed of three determining variables: student engagement, disciplinary learning, and competence development. Students who practice background races will likely have learn statistics concepts and apply them in data science to improving their time records on street racing circuits in Mexico or federated student competitions.

In recent years, there have been coaches who, although they have been good runners, lack the studies that support their ability to train other people who are initiating endurance training. This has led to an increase in injuries, physical problems attributed to poor diets, and an increase in deaths attributed to sudden death syndrome [5]. There have been studies that confirm this, an example is one presented by Bester *et al.* [6] where they show how an inadequate workout and training can lead to liver cancer due to training loads, volume, and intensity that are not specifically designed for each individual and their metabolism. Another example done by Nielsen *et al.* [7] in which they describe the negative effects of training without a scientific and technical foundation and the benefits of using statistics to improve health and competition times.

This research involves applying long-distance training to students from Tecnologico de Monterrey, using track tests of 5,000 metres and 10,000 metres and marathon routes of 5k, 10k, and 21k. It serves as a practical laboratory for learning data science and understanding inferential statistics through specially designed learning activities. The study has been extended to include alumni, who have developed a passion for long-distance races in Mexico and abroad. Moreover, the present research fills up a gap by utilising data science and statistics to achieves its objective of creating a comprehensive training program tailored for university students who want to participate in long-distance running doing it in safe and healthy way.

### 2 WHAT IS LONG-DISTANCE DESIGN TRAINING?

Long-distance training primarily focuses on the ability to run at the fastest pace with increased oxygen consumption, contrary to speed competitions that run without oxygen. Therefore, the variables studied in this research are  $VO_2$  Max, which refers to the maximum amount of oxygen your body can absorb and use during exercise, in short words it measures your aerobic fitness levels, and heart rate per minute (bpm), which in turn affect three levels of activity that directly impact a runner's performance: maximum aerobic capacity, effort economy and anaerobic threshold.

Long-distance training is multifactorial. The following research is only focused on the three most crucial factors for reducing time versus distance travelled. In Figure 1, the variables under study, their relationships, and the constraints are described in a rich picture based on soft systems methodologies.



Figure 1. Soft System analysis with critical long-distance variables

### 3 TEACHING DATA SCIENCE, DESIGN OF EXPERIMENTS AND STATISTICS THROUGH RUNNING

All sports training starts with the diagnosis or analysis of the problem situation. Soft methodologies for problem-solving were used to design the analysis strategy. To do this, the Tec race database, which was held on August 25<sup>th</sup>, 2019, was considered. In this race, fifty male and female students were invited to participate in the "Improve your times through data science and applied statistics" program to help them improve their competition times while learning statistics and data science. The other source of detailed information is from specific devices such as smart watches, phone apps, and cardiac monitoring bands. The first finding was that they conducted a situational analysis of how they were assessing their performance in the race. They were asked to analyse the race participants' results and perform data mining by discarding variables (columns) that did not add value. Then, by understanding the meaning of each column, they would transform it into highly significant variables. All this was done using Excel and Minitab software.

Through the construction of the database, they were able to apply descriptive statistics to all participants with the following variables:

- Age
- Starting time
- End time

- Partial time
- Average speed

Some invited students contributed by the phone app or with specific devices to monitor their physical performance, heart rate, altimetry, and average per kilometre. Before starting the program, a survey was carried out among them to know their level of learning statistics and data science through specific questions about their level of learning in certain concepts and a test with descriptive and inferential statistics exercises. For example, for the 10k Race, in the men's category, the media was 50 min and 32 seconds, with a standard deviation of 28 minutes, the winner's time was 37 min and 18 seconds, and the last runner to cross the finish line was of 1 hour, 36 minutes and 7 seconds. The most critical information to the training design is the heart rate. Figure 2 and Table 1 show the results of the Tec race of August 2019 with the statistic of 1352 participants. The students' interest in scientifically analysing the data was surprising since most did not belong to academic programs linked to engineering; from this moment, they achieved commitment and engagement in the activity. They had already realised that monitoring sensitive variables could enable them to improve their workouts.



Figure 2. Comparison between Age and Pace (min/km) segmented by Woman (up) and Men (below)

Table 1. Statistics of 1,352 long distance runners to analyse VO <sub>2</sub> Max and Pace per minute;
StDev: Standard deviation; Q1: first quartile; Q3: third quartile; FT Minute: finish time

Variable	Mean	StDev	Minimum	Q1	Median	Q3	Maximum	Mo	de
Age	35.953	14.06	14	23	34	47	103	20	121
FT Minute	48.102	14.34	18.73	36.41	46.98	58.68	102.43	33.1	4
Pace Min	7.5067	2.15	3.73	6.02	7.03	8.47	18.35	7.51	13
VO <sub>2</sub> Max	10.134	2.90	5.04	8.12	9.50	11.43	24.77	10.14	13

#### 4 DESIGN A TRAINING PLAN BASED ON SCIENCE

One mistake in long-distance training is following other athletes' workouts when the workout should be fully personally customised. Therefore, the goal was to design proper training for each student based on

personal diagnosis. The data was collected with manual chronometer and personal devices (smart watches).

Tec conducted a Cooper test on the track to make a better diagnosis regardless of the race results. This test consisted of running 2400 metres (six laps of 400 m) at the maximum possible speed, a flexibility test, and strength test. The test was done through three mixed groups integrated by the best times, either final or partial, in the 5k race.

Pat Bradley [9], former United States Olympic Committee physiologist, argues that most people can keep their speed at  $VO_2$  Max level for eight to ten minutes, so a runner can do it for ten to twelve minutes. The test must do at two miles is 2200 m, equivalent to five and a half laps to the official track of four hundred metres, having a group not so homogeneous in athletic performance was considered better to follow the test Cooper.

Through these results, the VO<sub>2</sub> Max was calculated, which is the ability to use oxygen at maximum effort. In an analogy, the VO<sub>2</sub> Max is the engine, and the heart and lungs are those that pump fuel through the body, so having a high VO<sub>2</sub> Max equals having a powerful engine. It proceeded to calculate 65% of VO<sub>2</sub> Max, equation 1, for each student taking the average per kilometre in the Cooper test with the following formula where BT is the best time per kilometre in seconds, and TTP is the target training time in percent per kilometre.

$$BT^{*}Km^{+}(1-TTP^{*}Km^{*}BT^{*}Km))$$
(1)

For example, if in the Cooper test a student had four min and 20 seconds on average per kilometre, this measurement is equivalent to 260 seconds, so to have a training at 65% of your VO<sub>2</sub> Max capacity, you must run every kilometre at 351 seconds, which is equivalent to five min with 51 seconds.

The intensity of training is correlated with possible cardiac affections, which can be related to comorbidity diseases such as overweight, diabetes, high blood pressure and which can cause sudden death if not well designed. In figure 3, the VO<sub>2</sub> Max calculation is shown with the part time of one kilometre during the Tec race for both categories, 5 and 10k. An acceptable VO<sub>2</sub> Max would be below six min/km, it can also be observed that most runners are well above with an average of 10 min, which statistically infers that they are not prepared for a competition for this distance and that in conditions of greater stress such as food, heat, humidity, sleep and consumption of alcohol or some drug this effort can be dangerous to health at the time of competition. Overall, VO<sub>2</sub> Max is a good measure of the ability of the heart to make a physical effort, in the data observed to the 1352 participants we can observe only a smaller percentage is suitable for this type of competition.



Figure 3. Calculation of VO2 Max for all participants in the Tec race

It is also important to determine the training threshold by age, this is calculated in a quite simple way, and is to take as constant 220 beats per minute and subtract age. For example, a 19-year-old student's maximum ability to strain his heart is 201 beats. Furthermore, training must be individually designed to increase your VO<sub>2</sub> Max without reaching maximum beats per minute. This is achieved through training stages over a period of time. According to Tadeuz Kempka [8], who was one of the most brilliant long-

distance coaches in Mexico, there are four stages to reach the maximum performance of a competition, this is shown in Table 2.

Stage 1	Stage 2	Stage 2 Stage 3	
Development of aerobic	Anaerobic	Increased tolerance of lactic	Advanced anaerobic
resistance	training	acid	training
1 to 6 Week	7 to 12 Week	13 to 18 Week	19 to 24 Week

Table 2. The four training stages to reach the maximum performance

Through experiment design, the intensity parameters can be modified according to the reports of heart rate and average speed to improve the  $VO_2$  Max, the variables that are under observation are distance, speed, and training ground time. Using Saavedra's [10] methodology of data science and applying concatenated experiment designs significant improvement in sports training can achieved.

### 5 DESIGN A TRAINING PLAN BASED ON SCIENCE

One common mistake made by long-distance runners is to copy the workouts of other athletes when they ought to be completely tailored to them. Designing appropriate instruction for each student based on their unique diagnoses was the aim. Thus, wrist band sensors were used to gather the data, which included heart rate, run pace, and height.

From October 2019 to February 2020, training and learning in statistics and data science could be carried out without any problem. However, COVID-19 confinement put a stop on the experiment, which later was resumed in October 2021 by performing a physical conditioning (weight, flexibility, and strength) stage to recover the lost form during confinement. In August 2022, the results from thirty-two students who resumed and followed the training program were received. Figure 4 shows a graph of the results obtained in a 10 km race in the sea level vs the Tec Race at 1885 metre over sea level, as average the rate per kilometre decrease from 5 minutes 54 seconds per km to 4 min 37 seconds per km, and the heart rate decrease from 182 ppm to 154 ppm, this is an excellent performance.



Figure 4. Comparison between race in altitude vs sea level analysing heart rate; using height, run pace, and heart rate variables

## **6** CONCLUSIONS

The design of long-distance racing training based on data science and statistics achieves substantial improvement on the athlete's performance. But in academic terms, it generates and increases learning by providing real-life scenarios and improves students' engagement. The student's performance in long-distance street tests was highly significant, but it was more remarkable in those who entered the athletics team and improved their times. In terms of academics, the learning of statistics was reflected in its training units for students of the Tec21 educational model and in the previous programs, and it offered students a hands-on approach to learning complex concepts, making the experience more relevant and engaging. In terms of educational design, such research can enhance engagement, provide practical learning experiences, improve outcomes, and lead to innovative curriculum development. Students say that this learning could be transferred to the professional sphere.

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# OPMITISING LEARNING IN INDUSTRIAL ENGINEERING; IMPROVING SKILLS THROUGH XR ENHANCED LEARNING SCENARIOS

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## ABSTRACT

Extended reality facilitates better learning in less time while optimising resources. This paper explores a student-centric course experiment rooted in the application and practice of a recently developed educational platform, the Tec21 educational model, which is based on the development of disciplinary and transversal competencies. For this purpose, the design of educational innovations is fundamental. In recent years, the design of virtual simulations has rapidly increased in number as well as in sophistication. Virtual laboratories based on virtual reality and augmented reality have experienced exponential growth, which has led to the creation of new platforms for lessons based on XR technology. Although present research has presented several examples that showcase virtual environments designed for students to learn from, platform independence is growing, allowing users to experience different learning formats with minimal disturbance as technology strives to reach further seamless solutions. This research presents the results from specific learning scenarios through so-called design-build-test (DBT) exercises for different groups of industrial engineering students. The students were introduced to the MxREP simulator and the TecXR platform, which offer augmented guideline design tracking, intuitive support, and virtual reality design scenarios that allow students to repeat physical DBT exercises in a timely manner to gain deeper understanding of stepwise design parameters. The specific course exercise was designed to emphasise life cycle educational activities originating from the lecture design objectives, instructions, and activities, as well as the definition of educational objectives. Also, the design of simulator parameters and the interface with virtual and augmented reality lessons are used to achieve three essential objectives: development of skills, learning, and engagement. The findings showed that students greatly appreciate utilising XR as part of their learning. The variation of the platform noted that the more fixed VR process enables it to focus more on process-related design steps, whereas augmented support increased co-design engagement among student cohorts that participated.

Keywords: XR reality, gamification, simulator, higher education, educational innovation

## **1** INTRODUCTION

Adversity fosters creativity, and Tecnologico de Monterrey's Educational Innovation remains constant. As distance learning gained momentum, academics worldwide were compelled to design and develop virtual laboratories, with extended reality emerging as a leading technology. Tecnologico de Monterrey stood out in this global shift for its unique approach. While transitioning to a new educational model, TEC21, where the central process revolves around challenges provided by external partners, the institution had to accelerate its distance learning efforts. This involved supporting students in tackling real-world problems, with knowledge transfer occurring in the classroom through competency development, problem definition, and solution proposal, all encapsulated in a project [1].

This document shares the lessons learned from the design, development, and classroom application of virtual laboratories supported and enhanced by practices based on XR technology, mainly virtual and augmented reality, as a learning complement for our students. Utilising XR to enhance the learning environment, providing enriched depth through immersive scenarios, has been explored and deemed critical to gain important professional skills recognition. This collaboration, together with Mälardalen University, Sweden aims to improve the learning experience of Industrial Engineering students. [2].

## 2 METHODOLOGIES

The first step involved forming a task force group responsible for designing learning activities focusing on specific industrial engineering topics. The training unit IN2006 – Project Feasibility Analysis with a Systemic Perspective was targeted, running at module three, during fifth semester. A problem situation was identified regarding the teaching-learning process. This problem aimed to enhance students' understanding of the process of determining the capacity of a production line from a systemic perspective, where various factors such as machinery and equipment performance, supplier training, material quality, assembly process, and materials management throughout the product supply chain influence the outcome.

The R&EIT (Research and Educational Innovation Team from Tecnologico de Monterrey) employed two support methodologies to construct the academic activity. The first methodology is based on Design Thinking and Design of Experiments [3] to identify the measurement factors of the activity's efficiency in the teaching-learning process and its corresponding levels. The second methodology utilises soft systems to define the problem and the activities that are necessary for designing an academic activity [4].

The training unit comprised two DBT groups: 501 and 502 in the five semester, third period. The first group (course 501) consisted of 29 students, and the second group had 23 students. Both groups had the objective to develop and determine the capacity of a production line, first group used the simulator while the second group would rely on traditional classroom methods for learning. Both groups would undergo two tests, one before and one after the activity for group 501, and one before and one after the class for group 502. The exams would consist of 15 items drawn from a database containing 40 questions related to the learning topic.

The hypothesis under research aims to confirm whether there is a significant difference between groups 501 and 502 concerning learning, and the utilisation of the activity designed for learning this topic. To assess this, the paired t-test will be employed.

## **3 DEVELOPMENTS**

The initial step involved applying soft systems methodologies to analyse the problem related to learning about line capacity, define the problem, and commence generating solution ideas utilising the chosen methodology. This methodology was employed to design academic activities based on Design Thinking and Design of Experiments. [3].

Figure one illustrates the enhanced rich picture, which is based on soft systems methodology enhancement by R&EIT [4]. This figure depicts the problem situation and the system restrictions, enabling a focus on realistic solutions. It consists of two frames: the first frame explains how the four thinking ways (Systemic, Prospective, Resilient, and Concurrent Thinking) contribute to problem definition, while the next frame delineates the restrictions or guidelines for the activity, including the assembly process, statistical process control, quality plan, syllabus, and competencies. Within the red line lies the problematic situation, represented by a diagram connecting actors and elements and describing the workings of the activity design.

In the solution proposal, factors contributing to poor learning of the topic in the classroom are identified through brainstorming, weighted numerically, and subjected to Pareto analysis. This analysis identifies the three critical factors to be addressed through a design of experiments, employing three levels for each factor to determine the appropriate parameters for an optimal academic activity aligned with our academic objectives. The three factors to be analysed are:

- A Skills Development.
- B Learning.
- C Student engagement in the activity.



Figure 1. Soft Systems Methodology applied to explain the challenge and design process activities

Three levels will be used for each factor, and the parameters of these levels will be determined through Anova analysis to obtain the learning results. Figure 2 illustrates the interaction between the three factors, while the table delineates the zone for an ideal learning activity.

For factor A, competencies, the design incorporates four levels: Excellent, Solid, Basic, and Incipient [1,4]. These levels denote the development of student competencies, which is assessed using a rubric applied to learning evidence.

Factor B pertains to learning performance, with the minimum passing grade for a class unit set at 70, and the scale ranging from 10 to 100. Excellent performance for a student is defined as achieving a grade between 90 and 100.

Factor C delineates the level of engagement among students and the learning activity, measuring the degree of teacher performance creativity in storytelling, which serves as the front end for student engagement.



## Engineering Thinking Model and Design of Experiments Matrix

Figure 2. Engineering Thinking Model and Design of Experiments Work Matrix

The academic activity aimed at achieving the learning objectives is based on the utilisation of an Enterprise Resource Planning (ERP) system, allowing students to simulate processes occurring in a professional manufacturing facility within a controlled environment [5, 6, 7, 8]; The academic activity aimed at achieving the learning objectives is based on the utilisation of an ERP system, allowing students to simulate processes occurring in a professional manufacturing facility within a controlled environment. The academic activity aimed at achieving the learning objectives is based on the utilisation of an ERP system, allowing students to simulate processes occurring in a professional manufacturing facility within a controlled environment. The academic activity aimed at achieving the learning objectives is based on the utilisation of an ERP system, allowing students to simulate processes occurring in a professional manufacturing facility within a controlled environment.

## **4** IMPLEMENTATIONS

The implementation strategy revolved around designing the storyline (academic case) that students would engage with, facilitating team application, and preparing Meccano kits to replicate the manual

process. This approach allowed students to learn about the parts and subassemblies supported by augmented reality on their phones and tablets.

The second phase unfolded in the VR Zone of the Campus, known as Mostla, which translates to "Tomorrow" in the Nahuatl language. Here, students utilised virtual reality lessons in teams to enhance the assembly process and determine assembly time for calculating the line's capacity. They encountered challenges such as the quality sum of tolerances to the motor gears, which they solved and provided a solution for. Finally, they completed a knowledge test.



Figure 3. Implementation using AR (left) and VR (right)

## 5 **RESULTS**

The implementation strategy was centred around designing the storyline (academic case) that students would encounter, facilitating team application, and preparing Meccano kits to replicate the manual process. This approach allowed students to learn about the parts and subassemblies supported by augmented reality on their phones and tablets.

The second phase unfolded in the VR Zone of the Campus, known as Mostla, where students, working in teams, utilised virtual reality lessons to enhance the assembly process and determine assembly time for calculating the line's capacity. They encountered challenges such as the quality sum of tolerances to the motor gears, which they successfully solved and provided a solution for. Finally, they completed a knowledge test. The research protocol analyses four variables: two for the use of Innovative Learning Activity (ILA) and two for traditional learning. Table 1 presents the descriptive statistics for each variable.

Sample	Ν	Mean	Standard Deviation
T before A	29	63.97	16.33
T After A	29	86.9	11.05
T before C	23	66.52	13.27
T After C	23	71.52	13.52

Table 1. Summary Statistics for the two groups, before and after

Before the ILA application, students took a knowledge test on the capacity line theme. The mean score of students the 29 students in 501 group was 63.97 out of 100 for the 20 questions, falling below the minimum passing score of 70. Subsequently, students underwent the ILA process, first in the classroom and then in the VR Zone or Mostla Laboratory. Descriptive statistics reveal an increase in the average

grade from 63.97 to 86.9. Figure 4 illustrates the boxplot depicting the distribution of scores between the "T before A" and "T after A" variables.



Figure 4. Box-plot between Test before and after ILA application

With a p-value of 1.1066E-07 and a confidence level of 95%, a significant difference exists between the mean grades for before and after the activity. Additionally, the confidence interval for the difference ranges between (-29.57, -16.29), indicating that, on average, the grades in the exam after the ILA application were higher than those before the ILA application. Please refer to Figure 5 for visual representation.

#### Test

			Estimation for Paired Difference				
Null hypothesis $H_{4t} \mu_{-}$ difference = 0 Alternative hypothesis $H_{4t} \mu_{-}$ difference = 0		95% CI for Mean StDev SE Mean µ_difference_					
T-Value P	P-Value		-22.93 17.45	3.24 (-29.57, -16.29)			
-7.0767	0.000		µ_difference: p	opulation mean of (T before A - T Afte	er Aj		

#### Figure 5. Inference for the difference of before and after the ILA application

On the other hand, with the control group, a p-value of 0.154 and a confidence level of 95% indicate that there is no significant difference between the mean grades of before and after the activity. Moreover, the confidence interval for the differences ranges between (-12.02, 2.02), suggesting that the mean grades before and after the activity may be equal at a 95% confidence level. Please refer to Figure 6 for visual representation.

## Test

Null hypothesis H₀: µ\_difference = 0 Alternative hypothesis H₀: µ\_difference ≠ 0

-1.48 0.154

#### **Estimation for Paired Difference**

95% CI for <u>Mean StDev SE Mean μ\_difference</u> -5.00 16.24 3.39 (-12.02, 2.02)

µ\_difference: population mean of (T before C - T After C)

#### Figure 6. Inference for the difference of before and after for the control group

## **6** CONCLUSIONS

The implementation strategy was based on designing the storyline (academic case) that students would engage with, facilitating team collaboration, and preparing Meccano kits to replicate the manual process.

This DBT approach enabled students to learn about the parts and subassemblies supported by augmented reality, accessible on their phones and tablets. The second phase unfolded in the VR Zone of the Campus, known as Mostla. In this VR Lab, students, working in teams, utilised virtual reality lessons to enhance the assembly process and determine the assembly time required to calculate the line's capacity. They encountered challenges such as the quality sum of tolerances to the motor gears, which they successfully addressed and provided a solution for. Students were highly engaged during the sessions and confirmed that it was more joyful to learn this way in comparison to traditional teaching. Afterwards, they completed a knowledge test with the highest mean values ever recorded. In summary, the TEC21 XR challenge is clearly impacting the skills development of students as well as creating a positive learning experience.

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## EMOTIONAL DESIGN IN TRANSFORMING EXCESSIVE SOCIAL MEDIA USE: A CASE STUDY ON YOUNG ADULTS' OVERUSE OF SHORT-FORM VIDEO PRODUCTS

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#### ABSTRACT

Growing concerns have been raised about excessive social media usage among young adults and its adverse effects on mental health. Challenges persist in designing effective strategies to help young adults manage the overuse of social media, especially in the context of short-form video (SFV) products, where the issue is more pronounced. This study explores and discusses design strategies grounded in emotional design principles to assist young adults in managing the excessive use of SFV products, aiming to transform their relationship with social media into a more sustainable one. The study focuses on two main questions: 1) What factors influence young adults' excessive usage of SFV applications? 2) What emotional design-based strategies can effectively regulate this usage? An online ethnography was conducted to understand user motivations, behaviours, and the effectiveness of existing methods for managing overuse. The findings indicate that boredom is a significant factor driving the excessive use of SFV products, with users exhibiting varying levels of awareness and ability to control their usage. Integrating emotional and behavioural design principles, the study presents 'Sustainable Design for User Emotion' recommendations, highlighting key factors for developing effective design strategies to manage users' excessive use of digital products and promote healthier usage patterns. A broad survey was conducted with young adults aged between 18 and 35, further investigating the real-world usage patterns of SFV products and assessing the effectiveness of the proposed design strategies. The results offer insights and actionable recommendations for research and practice in responsible product design.

Keywords: Emotional design, user behaviours, design strategies, social media, short-form video use

#### **1** INTRODUCTION

Social media has become an integral component of digital interaction, particularly among young adults. Research suggests that this demographic constitutes the primary user base of the internet and social media platforms, marking a unique phase of life [1]. Recently, Short-Form Video (SFV) products, such as TikTok and YouTube Shorts, have emerged as the fastest-growing segment within social media [2]. Although short videos are a popular form of digital entertainment and enjoyment, their prolonged use is frequently considered excessive and potentially detrimental. There is growing concern over the negative consequences of such usage patterns, including adverse effects on physical and mental health, the emergence of negative emotions, and a decrease in academic and professional performance [3]. The attractive usability and entertainment value of these SFV products further challenge users' ability to regulate their behaviours [4]. Despite awareness of these adverse effects, young people devote significant time to these platforms. It is crucial to address healthy engagement with SFV applications among young adults. While existing studies have delved into the motivations behind and consequences of excessive SFV use in this demographic, there is an ongoing challenge in helping users manage their consumption. The concept of emotional design is vital in strengthening the connection between users and products by creating positive emotional experiences and resonance [5]. Applications built on emotional design principles are likely better suited to concentrate on emotional well-being, providing support and guidance to help young adults manage their SFV usage.

The study employs online ethnography and a questionnaire survey as research methods to investigate the factors leading to the excessive use of SFV applications among young adults and how strategies based on emotional design may help regulate this use. By integrating emotional design principles, the research proposes 'Sustainable Design for User Emotion' recommendations to moderate excessive use of digital products, offering insights for creating responsible digital products.

### 2 BACKGROUNDS

This section presents existing studies on young adults' use of SFV products, analysing the potential role of emotional design in guiding user behaviours and reducing excessive usage patterns.

#### 2.1 Excessive consumption of SFV products among young adults

Young adults, typically aged 18-35, navigate a pivotal transitional phase, moving from dependence on family and various resources to establishing independence [1]. Given their newfound autonomy, young adults are particularly inclined towards self-expression, identity exploration, and forging or maintaining relationships. This propensity significantly contributes to their pronounced daily engagement with social media, surpassing other activities, thereby making social media a defining aspect of emerging adulthood and the excessive use of social media among young people also becomes a growing concern [6]. Excessive social media usage is characterised by an overwhelming preoccupation with these platforms at the expense of neglecting vital tasks, coupled with an inability to control usage, adversely affecting individuals' lives, mental health, and well-being [7].

SFV content, typically ranging from 15 to 60 seconds, caters effectively to young adults' fast-paced and fragmented lifestyles [8]. The personalised recommendation algorithms and the "anytime, anywhere," "continuous" nature of these videos further accentuate the immersive experience, compelling young adults to devote more time to SFV products [9]. Studies indicate that such excessive use of SFV products can lead to dependency, characterised by an inability to moderate usage behaviours, and potentially result in more severe long-term mental and physical health issues [3]. Therefore, acknowledging young adults' critical developmental stage and the considerable adverse impacts of excessive SFV consumption, it is paramount to assist them in managing their SFV product usage. By understanding the unique vulnerabilities and needs of young adults and the immersive nature of SFV products, we can leverage emotional design principles to develop targeted interventions that guide this demographic group towards more sustainable engagement with SFV.

#### 2.2 Emotional design and user behaviours

Emotional design prioritises individual emotional needs in product and service design and development, aiming to foster positive experiences through elements such as aesthetics, functionality, and usability. Research shows that design focused on emotional impact profoundly influences user experience and evokes desired responses, as emotions affect users' attention, memory, and decision-making [10]. By emphasising users' emotional and psychological responses, designers can create products that generate positive reactions, integrating emotional design deeply with user experience [11]. Emotional design principles are applicable for enhancing the user experience by understanding and addressing user emotions and leveraging emotions to forge connections between humans and products and influence user behaviours [12]. Humans tend to engage in passive information and activities that require less reflective thinking [13], leading many young adults to rely on habitual usage patterns when interacting with SFV products. For example, SFV products enable users to enter a state of heightened positive emotions through features like "infinite scrolling" and "entertainment," making it difficult for users to detach. Some even feel dismayed when they stop using them [14]. By employing emotional design principles, sustainable digital products can support young adults' well-being in coping with emotional fluctuations and in shaping or reshaping their digital daily routines and habits [12]. This can be achieved by leveraging cognitive biases and using nudges to motivate and engage users towards healthier usage of SFV products. Specifically, user experience designers sometimes exploit behavioural models and cognitive biases to encourage habit formation, utilising reward mechanisms and incentive systems to boost intrinsic and extrinsic motivation [15]. Thus, this study aims to further explore emotional design principles to effectively support young adults in managing excessive SFV consumption, aiding them in curtailing their use of SFV products.

#### 3 METHODS

#### 3.1 Internet ethnography

Building upon the existing literature review, we first utilised internet ethnography to observe the SFV

consumers via online forums, aiming to acquire broader and more timely insights into their attitudes, needs, and frustrations regarding their usage of SFV products.

From November to December 2023, we conducted online searches on social forums such as Quora, Douban, and Zhihu for comments and discussions regarding the use of popular SFV products (e.g., TikTok, YouTube Shorts, and Kuaishou). Searches featured keywords in both English and Mandarin, including but not limited to: "[Name of SFV Product] usage/addiction/excessive use", "short video application usage/addiction/excessive use", "manage/control/stop use of short video application", and "manage/control /stop use of [Name of SFV Product]". Approximately 150 comments on this topic, shared between 2020 and 2023, were viewed and selected based on their relevance to the study. We then analysed these comments to understand individuals' challenges and strategies to manage their SFV consumption. Insights gathered were incorporated into the design of subsequent survey questions and response options.

#### 3.2 Survey design and participants

To gain a more direct and comprehensive understanding of their usage patterns, needs, and perceptions of SFV products, an online survey was distributed on social media platforms (e.g., Facebook and WeChat) targeting young adult SFV product users aged between 18 and 35 years old. The survey incorporated two screening questions: one regarding the usage of any SFV products and another concerning age. Respondents indicating they do not use SFV products or those outside the target age range were automatically excluded from the survey. A total of 144 valid survey responses were collected. Among these participants, at the time they completed the survey, 51% were employed, including those freelancing; 44% were students; and 5% were unemployed. To commence the survey, we introduced the project's scope, objectives, and data handling procedures, ensuring participants were well-informed and consenting to participate voluntarily. The survey started with two background questions to assess participants' overall usage of SFV products. After this, seven questions aimed to further understand young adults' specific usage behaviours, focusing on their motivations, needs, and challenges in managing SFV product usage. The third section, integrating both emotional and perceptual inquiries, featured four questions on young adults' feelings and views towards SFV products and the quality of SFV content, alongside their self-reflections and encountered obstacles in usage management. This approach corroborated findings from our internet ethnography study and served as a foundation for formulating effective design strategies tailored to their needs. The concluding section comprised two questions to gather insights on required and favoured intervention strategies among young adults.

#### 4 RESULTS AND DISCUSSION

During the internet ethnographic investigation, the study focused on the reasons behind the excessive use of specific SFV products, measures for managing such usage, and the difficulties people encountered in trying to manage their SFV use; several insights emerged. "Feeling down" and "bored," along with the perception of the "ubiquitous presence" of SFV products and content, were frequently cited as reasons for users' continued use and excessive use of these products.

Specifically, some reported experiencing pleasure from the "mental stimulation" provided by watching SFV, which led to "unconscious overconsumption." Additionally, some mentioned that their initial intention to use SFV products for educational and productive purposes often resulted in involuntary consumption of unrelated SFV content. Among the sampled comments, various strategies were discussed to manage SFV consumption, including "uninstalling the application," "finding other hobbies," and regularly conducting "self-reflection" on SFV usage. The comments also reveal some common challenges users face when attempting to implement measures to manage their use of SFV products. For example, some expressed that reducing or stopping SFV consumption was exceptionally "mentally challenging," often leading to feelings of "restlessness" or anxiety. Others mentioned that using SFV products had become a very "effortless activity" and had already become "part of their daily routine," making it "difficult to develop interest in other activities" or shift focus. Furthermore, some commented that SFVs were "ubiquitous" in their daily lives, causing them to be "re-attracted" and "resume" using SFV products after attempting to stop.

#### 4.1 Overview of young adults' SFV consumption

The survey results reveal distinct usage patterns among young adult SFV product users. Approximately 47% of participants are frequent users (more than 3 times a day), 35% are regular users (1-3 times a

day), and the remaining 18% occasionally (3-6 times a week) or rarely use SFV applications (less than 3 times a week). As shown in Figure 1, among frequent users, 95% are current users, whereas only 5% have ceased using these products. Of regular users, 85% continue to use SFV applications, compared to 58% of occasional users still engaged with these products.



Figure 1. SFV User Categories and Composition

Frequent users predominantly watch SFV anytime and anywhere (70%), with around 12% preferring the evening or late night. Over 80% use SFV applications for relaxation or leisure, and about half for learning or socialisation. Most (83%) turn to these applications when bored, with significant numbers using them before sleep, during commutes, meals, or while waiting in queues. Regular users exhibit similar patterns, with nearly half watching SFV anytime and about one-third in the evening. Around 73% use SFV applications for relaxation and leisure, and 34% for learning or socialisation. Being bored prompts 64% of regular users towards SFV applications, and 57% use them before sleeping. Occasional users share these habits to some extent, with nearly half watching SFV anytime. Around half cite relaxation, socialisation, or leisure as their main motivations, and 58% use these applications when bored.

Regarding usage duration, nearly half of the frequent users spend over 60 minutes per session, while regular users mostly spend 10 to 30 minutes. On weekdays, about one-third of frequent users spend over 2 hours daily on SFV applications, increasing to 58% during weekends. Regular users generally spend 30 to 60 minutes daily on weekdays, with a slight increase in longer usage during weekends. Occasional users typically spend 10 to 30 minutes per session, with a minority exceeding one hour, especially on weekends. The results illustrate diverse usage patterns among young adults, highlighting the need for targeted strategies to assist them in managing excessive use of SFV applications effectively.

#### 4.2 Young adults' attempts and reflections on SFV consumption

The attempts to manage SFV usage and perceptions of these products vary among young adult users. The survey results on these aspects are analysed based on participants' different usage frequency categories, as previously identified. Among frequent users, the majority (41%) have not attempted to manage their SFV application usage and express no desire to do so. The predominant rationale is the perception of SFV products as mere entertainment, denying the need for management. Other reasons include a lack of awareness about the impact of SFV products and content, confidence in self-regulating usage, and the absence of alternative entertainment or relaxation options.

Conversely, less than half of the frequent users have tried to manage their SFV application usage, encountering challenges such as resuming usage when bored or feeling down, difficulty resisting temptation, and a dearth of alternative activities. Some users also cited reasons like entrenched daily habits of watching short videos, social engagement, and a lack of motivation to reduce viewing time.

In contrast, only 26% of regular users have not tried to manage their usage, preferring to do so, with 58% making such attempts. Among occasional users, a mere 8% have not attempted management, with 79% trying to moderate their usage. The motivations and challenges faced by regular and occasional users align closely with those identified by frequent users, indicating a trend where individuals with lesser SFV usage are more inclined to attempt managing their excessive use.

Evaluations of SFV products and content and users' attitudes towards their usage were conducted on a scale from -10 to 10, spanning from "extremely negative" to "extremely positive." Frequent users rated SFV products as high as 10 and as low as -8, with an average rating of 4.22. Regular users provided ratings ranging from 7 to -7, averaging 2.49, while occasional users' ratings varied from 9 to -7, with an average of 1.35. Results suggest that the frequent users of SFV products also tend to have a more positive evaluation of SFV products (see Figure 2).

Regarding measures for managing SFV consumption, all three user groups identified "real-life rewards" as the most effective strategy, followed by "virtual rewards," "suggesting alternative activities," and implementing "usage restrictions." Occasional users also valued "reminders to take breaks" or "limit

excessive use." Interestingly, a significant portion of participants across all usage frequencies expressed a preference for these measures to foster healthy SFV usage and consumption. "Emotional support and advice" were notably favoured among over 50% of occasional users, with about half of the frequent and regular users also acknowledging their value. The least popular measure across all groups was "distract me from watching short videos."



Figure 2. Categorising Young Adults' Personal Attitudes Towards SFV Consumption

#### 4.3 Discussion: Sustainable digital product design

The study highlights the intricate social and emotional dynamics underlying excessive SFV consumption among young adults. Findings shed light on the practical factors that contribute to this behaviour. Results suggest that boredom is the primary reason young adults excessively use SFV products. Most young adults frequently use SFV products more than three times a day without fixed schedules, alongside more extended usage on weekends. For young adults, using SFV products is the most accessible way to relax and unwind, providing continuous stimulation. However, this habitual engagement with SFV may lead to unaware overconsumption and difficult-to-regulate usage behaviours. Based on the survey results, young adults who use SFV products more frequently tend to have a more positive evaluation of both the applications and their usage behaviours. As a result, they may need more motivation to manage and reduce their unhealthy usage of these products. Many young adults face the challenge of resisting the temptation of excessive SFV consumption despite receiving advice to manage their usage through strategies such as uninstalling the applications or finding alternative activities. Those who indulge in excessive SFV usage often have difficulty controlling their habitual viewing habits effectively, leading to a fragmented attention span and further complicating their situation.

The study also assesses users' preferences and evaluates the perceived effectiveness of existing strategies for managing the use of SFV products. The aim is to identify practical and effective design interventions that can moderate excessive usage. Research indicates that products designed according to emotional design principles, such as creating a positive user experience, incorporating user-friendly interfaces, and designing for user satisfaction, tend to create positive emotional experiences for users, thus influencing their behaviour. In managing excessive SFV consumption, there is an opportunity to further apply these emotional design principles to support young adults emotionally and practically.

The 'Design for Sustainable User Emotions' recommendations are proposed to mitigate the negative impacts of undesirable digital product usage and user behaviours. This approach advocates for a responsible design ethos that prioritises users' emotions, mental health, and overall well-being, extending beyond mere usability and attractiveness.

Drawing on insights from literature and findings from this study, promising strategies identified for motivating different categories of users to regulate their SFV consumption include offering tangible and virtual rewards for progress and positive user behaviours [15], providing personalised emotional and behavioural support [12], and implementing intervention measures that offer usage analysis and feedback, and enable guided and effortless self-reflections [11,13]. These strategies could include in-app notifications that congratulate users on reduced screen time, personalised messages that encourage healthier usage habits, and features that allow users to track their usage and set limits. Furthermore, by designing interventions and products that acknowledge and address users' emotional challenges and by establishing support mechanisms, users are empowered to make more informed decisions regarding their SFV consumption.

#### **5 CONCLUSIONS**

This study employed online ethnography and surveys to explore the causes of excessive SFV consumption among young adults, finding a need for support in managing usage. Analysis revealed a connection between the frequency of SFV use and users' attitudes and perceptions towards SFV products and content, as well as the various needs and challenges they face in managing their SFV consumption. Highlighting the importance of differentiated design strategies, the research suggests employing targeted emotion-driven approaches—such as personalised reward systems, guided and effortless self-reflection exercises, and usage analytics—to help young adults manage their SFV consumption based on their current usage and user habits. It advocates for applying emotional design principles tailored to the varied needs and perspectives of different SFV user groups, aiming to foster healthier engagement and a balanced lifestyle for young adults. Plans for developing and testing a prototype application that incorporates these design strategies are underway to assess their effectiveness.

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## MATERIALITY AND THE MACHINE. MAXIMISING MATERIAL EXPERIENCES IN THE AGE OF AI

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#### ABSTRACT

Artificial Intelligence (AI) and related technologies are expected to significantly impact the future of design, but traditional design methods are still important. Material Intelligence (MI) is crucial for product designers, and a structured four-year approach to undergraduate design education centred around experiential learning through MI is presented. The approach emphasises hands-on experimentation, integrates MI into the core curriculum, and prioritises interdisciplinary collaboration to produce innovative, functional, and sustainable design solutions.

*Keywords: Studio culture, design education, material intelligence, product design, experiential learning* 

#### **1** INTRODUCTION

Artificial Intelligence and its associated technologies are set to play a significant role in the future of design [1][2]. They will emerge as powerful tools that prospective designers can harness to develop innovative artefacts[3]. However, we view AI, much like CAD and digital visualisation, as a complement to, rather than a replacement for, traditional design methodologies.

Despite the rise of AI and digital tools[4], product designers still need a deep understanding of the materials and processes they work with. This understanding, known as Material Intelligence, is crucial for designing physical objects[5]. This paper will present a structured approach to undergraduate design education that allows and enables this competency.

Similar to Emotional Intelligence, Material Intelligence requires customized educational support to develop the necessary skill set in learners. Educational interventions need the appropriate contextual groundwork to maximize success[6]. A semi-structured, investigative, and peer-supported approach that draws on real-world tasks and interactions is an integral part of this support framework [7].

As educators, we must maintain our understanding of the roles and abilities of any emerging technology and any that could lead to paradigm shifts within our field. AI has already impacted the discipline through developments such as Generative Design in CAD[8]. Still, it will become more embedded within the discipline as technologies develop[9]. As with all new tools, we see AI offering the potential to enhance the skills of the designer rather than supplant them [10].

For this reason, we must not overcorrect our approach to teaching and must take a cautious approach to adopting and integrating these tools. Their role is undoubtedly important and should lead to a reflection on our approach to education. Still, we must continue to develop competencies within our students, allowing them to function effectively as designers, no matter which tools and methods they adopt in their practice.

Material Intelligence (MI) was, for a time, a core tenant of the design of physical objects. Still, with the professionalisation of the discipline and the emergence of additional considerations, such as a greater focus on emotional intelligence [11], the role of MI within the field has lost its vogue. Furthermore, with the additional push to find cost and efficiency gains within the University Sector, it is a relatively simple accounting choice to reduce the role of the workshop and the high expense of materials and tools in favour of softer skills or adoption of digital-only representations rather than physical, and many design programmes have adopted a less hands-on approach to the design of tangible objects for this reason.

### 2 TECHNOLOGICAL EVOLUTION OF DESIGN EDUCATION

Product Design has historically been a discipline where students learn through hands-on studio and workshop practices, allowing them to engage with the physical reality of their work[11]. This

educational paradigm has roots in the Bauhaus tradition, which influenced the development of many design programmes in the latter half of the 20th century[12]. The practice-based studio approach is inherent in the way most design courses operate and speaks of the importance of practice that is seen in design education paradigms. [13]. One of the most prevalent ways of material expression in a traditional mode is through practical design activities, which involve model-making and prototyping in workshops. Recently, "FabLab" style spaces have emerged, offering accessible digital manufacturing approaches such as 3D printing and other CNC tools.

The development of these digital manufacturing approaches has led to an increased focus on the importance of digital design and manufacturing. This is often a core component of design education and has been for many years. [14]. For the most part, 3D CAD skills have replaced traditional drafting skills, with an increased emphasis on digital rendering and visualisation over more habitual marker rendering approaches to envisaging and presenting design concepts; even this has been augmented by the high adoption of graphics tablets and iPad-like tools. This digitisation of the design sketching toolset and a reduced cost of entry into this space have allowed design students to transition from the more physical proprioceptive skill to an alternative skillset augmented through digital processes[15].

Within the prototyping and modelmaking area of design education, the availability of digital manufacturing tools, such as affordable additive manufacturing equipment that many students own, through to digital plotters, laser cutters and CNC machines have provided opportunities for students to again augment their skills but often with the misplaced idea of being able to "CTRL + P" CAD work. This presents a risk that students will miss out on critical learning opportunities, fundamental to their core process through lazy and ill-considered prototyping approaches.

Education across design programmes has had to adjust to allow for a shift in expected technological interventions. As digital tools are more prevalent in early-stage education and broader society, students are taking design courses expecting to work with these ever-increasingly established toolsets. With a rigid amount of time for instruction on any programme, some traditional learning must give way to allow for their introduction. This is not necessarily bad, but implementing and integrating requires careful consideration to maintain core and necessary learnings [16].

#### **3 UNDERSTANDING MATERIAL INTELLIGENCE WITHIN CONTEXT**

Gardener posits that intelligence is not a single concept but a diverse set of abilities that allow different information types to be processed and understood [17]. Gardener suggests that individuals may combine different mixes and levels of these intelligences to contribute toward a person's cognitive ability and that educational interventions should recognise and nurture a diverse range of them.

While Material Intelligence may not fit neatly into Gardener's original multiple intelligences framework, it can be viewed as a multidimensional construct that draws on cognitive, sensory, and experiential elements gained through interactions. Emotional Intelligence also does not fit neatly into Gardener's model. Still, as educators, we are likely to be inherently more comfortable with the concept as its relationship to intrapersonal and interpersonal intelligence is often a core part of our pedagogical frameworks. As we have realised and refined our programmes to focus on the multidimensional nature of human behaviour, we have looked to educate and instruct our students in this model [11].

Designers with high Material Intelligence deeply understand different materials and their potential applications. They can visualise how various materials will look and feel in a product, enabling them to create aesthetically pleasing, tactile and visually coherent designs. By doing so, they can develop designs that are not only beautiful but also practical and efficient. This type of intelligence can only be acquired through hands-on exploration, experimentation, and manipulation of materials.

## 4 A PEDAGOGICAL FRAMEWORK FOR DEVELOPING MATERIAL INTELLIGENCE

Emphasising the unique approach, lecturers at [the program] have developed a pedagogical pathway that recognises the paramount importance of Material Intelligence as a fundamental skill for undergraduate design students. This pathway guides learners from a basic level of proficiency to a point where it becomes an indispensable and natural component of their skillset upon graduation. Integrating into the core curriculum, this multi-year approach compels students to actively engage and refine their design practice by incorporating opportunities to develop Material Intelligence.

Staff acknowledge that Material Intelligence is one of many competencies that learners are required to master. When presented to students, material-intelligence-based lessons are always a technique for exploring design practice alongside other critical aspects of the skillset, such as problem-solving, technical knowledge, and integration alongside digital tools in design and manufacture. Importantly, in a largely constructivist approach to developing learning interactions[18], students are not just encouraged but empowered to understand and engage with a range of approaches, blending these competencies as they shape their unique design identities.



Figure 1. Educational Framework for developing competencies in Material Intelligence through practice-based experiential learning

The approach to developing competency in Material Intelligence is divided into four phases, aligning with the programme's four years. In the first phase, which aims to build foundational knowledge (*principles*), learners are encouraged to understand how materials can be interacted with to express design intent and explore simple ideas. Students are provided with some taught knowledge, but the core focus is on experimentation and hands-on application (as happens across many modules in this framework). The learning outcomes for practices in these activities are designed to align with Bloom's Taxonomy, specifically focusing on the cognitive domain of gaining understanding.

The second phase of interventions aligns with two cross-module projects that run during each of the two semesters of the programme. Here, learners are encouraged to understand and build on the core competencies first explored in phase one and apply these skills in a more developed and well-rounded design practice. In this second phase, students are encouraged to examine the design space using and through practical work. The overall educational focus of this year of the programme is the importance of *process*, and the project-based application of material knowledge is critical to this learning mode. Within Bloom's Taxonomy, students are encouraged to Apply learning from lectures in taught and adjacent modules to advance and explore their responses to the design briefs. This year of the

programme also includes the most direct education into workshop practice and the "traditional" modelmaking and prototyping skillset.

During Year 3 of the program, learners are encouraged to take ownership of their design approach and develop their *practice*. This is facilitated through a series of design studio modules, which provide a scaffolded environment for exploring the design space. These modules are intentionally less structured, building on the peer-supported studio culture developed in the first two years of the degree. The Material Intelligence pathway also adopts a more hands-off approach during this phase, with teaching staff creating opportunities and a safe space for learners to analyse and experiment with materiality in their design practice. Advanced technical instruction in design and manufacturing is delivered through a hands-on approach, exploring product teardowns, and tooling design and providing students with ample opportunities to engage with materials and processes within the classroom. These classes analyse good and bad design practices by deconstructing case study examples.

The fourth year of the programme and final year of the pathway are focussed on delivering the final capstone project. This project runs for two semesters and allows learners to exhibit the culmination of their learning across the degree. Within the framework, this year provides the space to intimately explore the materiality of their practice and evaluate it within the educational studio. In other classes in this year, the learner is asked to reflect on their understanding of design and their approach and appreciation of it. To assist in delivering the Capstone Project, learners are provided with a Studio Module and teaching and material resources to help them engage with the material aspects of their design solutions. Students are encouraged to take a scientific approach to using physical and material interventions within their work to evaluate and define their design solutions' critical and technical aspects. This work is assessed separately from the Capstone Project and is focussed more on process and intent than on outcome.

## **5 CROSS MODULE PROJECTS**

A core aspect of the framework is the ability to engage in design projects that are not contained within a single module. This allows for specific skill-based learning outcomes to be realised in discreet areas while allowing students to apply their learning through a consistent output.



Figure 2. Outcomes from a Cross Module Design Project from Year 2, Project Based Application

The examples above and below illustrate how a student has participated in different graded assignments throughout the semester, each aimed at teaching distinct skills such as design research and problem framing, digital rendering, and exploration of design through modelling and prototyping.



Figure 3. Outcomes from a Cross model Design Project from Year 2, Project Based Application

This approach allows the students to explore, comprehend and apply various tools being taught while providing a scaffolded context for their work. It also offers flexibility in pedagogy for different competencies and tutors. While some assignments require a more rigid and instructional approach, such as the visualisation assignment, students can still engage in the more exploratory and accessible approach needed in the design studio and prototyping process.

The delayed opportunities for access to workshops and studios for a cohort of students due to the COVID-19 lockdown further reinforced the importance of early and phased competency development in Material Intelligence. On returning to the studios, these students initially needed more confidence in exploring design through modelling and prototyping as part of their process. It took until their capstone project to develop an appreciation and better understanding that Material Intelligence-related skills were as essential and within their grasp as their digital skills, which were not as evidently missed out on in the early stages of their development.

## **6** CONCLUSIONS

The discourse surrounding the integration of Artificial Intelligence and digital technologies within design education has underscored their potential as powerful tools for innovation, sparking optimism about the discipline's future. While AI offers unprecedented opportunities for enhancing designers' skills, educators must ensure a balanced approach that preserves the foundational principles of Material Intelligence, instilling a sense of continuity and stability and resisting a move towards an over-reliance on digital tools at the expense of tacit knowledge development.

Material Intelligence, essential for designers working with physical objects, has faced challenges amidst technological advancements and cost considerations within educational institutions. However, its significance in informing design decisions, developing valuable and significant solutions, and fostering hands-on learning experiences remains paramount.

Howard Gardner's theory of multiple intelligences recognises diverse cognitive abilities. Educators have developed pedagogical frameworks that prioritise Material Intelligence alongside other essential competencies. Through structured, multi-year approaches integrating experiential learning and studio-based practices, students are equipped with the skills and knowledge needed to navigate the complexities of the design field effectively.

Design education can empower students to develop innovative, functional, and sustainable practices that address real-world challenges by emphasising hands-on experimentation, peer-supported learning, and interdisciplinary collaboration. As educators continue to refine their approaches, it is crucial to maintain a holistic perspective that values both technological advancements and the timeless principles of Material Intelligence in shaping the next generation of designers.

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## DESIGNING TOMORROW: ADAPTING CURRICULA TO THE CHALLENGES OF A RAPIDLY CHANGING WORLD

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#### ABSTRACT

The information revolution has dramatically impacted the design field, leading to technological advancements and increased access to information. This has changed the way designers create and the concept of design itself. As a result, design practices have become faster and offer designers more resources, leading to new approaches and possibilities. This academic discussion highlights a significant shift in design practice since the early 1900s, challenging traditional curricula. It is vital to update design education to meet professional and societal needs. Design tasks today are complex and require a wide range of skills and knowledge. Therefore, curricula should be expanded to include more experiences and expertise. Designers should focus on specific goals and outcomes to develop a deep understanding of complex systems. The demands of this new era also emphasize the need for environmental action. Designers should go beyond surface-level environmental aesthetics and find tools, methods, and metrics that promote sustainable practices. The emergence of the product-service hybrid field means that design education should include expertise in physical product design and associated services and experiences. Ethical considerations should be central to design education and integrated into each discipline. The proposed framework of design curriculum encourages designers to collaborate with professionals in the field to solve real-world problems. By fostering ongoing partnerships, design education can bridge the gap between theory and practice and adapt to the changing nature of the design industry.

*Keywords: Design education, paradigm shifts, ethical integration, information revolution, curriculum transformation, Theory-Practice Gap*#

#### **1** INTRODUCTION

The 21<sup>st</sup> century has propelled design into a realm of rapid technological progress, shifting societal values, and a globally interconnected community. Design education must evolve from a conventional skill-based model to a multifaceted approach. The proposed framework equips emerging designers with modern tools, an open mindset, and an ethical compass to navigate complex opportunities and challenges. It calls for a holistic paradigm integrating interdisciplinary foundations, ethical principles, sustainability, digital fluency, human skills, global perspectives, and community engagement. The aim is to prepare students for evolving industry demands while fostering responsible contributions to a sustainable, inclusive, diverse global society. As design intersects with various disciplines and embraces technological integration, the designer's role expands, demanding new skills in problem-solving, adaptability, and technological literacy. This study proposes a forward-thinking framework, bridging the gap between traditional design education and contemporary industry needs. It suggests a shift towards innovative pedagogical methods, ethical awareness, and cross-disciplinary collaboration. The implications of this research signal a need for a transformative shift in design education, benefiting educators, practitioners, institutions, and policymakers alike. However, the proposed framework requires critical validation by organizations similar to the National Association of Schools of Art and Design (NASAD). It also may encounter challenges in implementation within current educational systems. This study embarks on a journey to reshape design education for the 21st-century world.

#### 2 REVIEW OF LITERATURE

Design education is at a critical crossroads. With the progression of digital technology, changes in human interactions and paradigm shifts; design education needs to be deconstructed and rebuilt for the

21<sup>st</sup> Century. This literature review reflects recent trends, challenges, and shifts in design education. This work includes various scholarly works. This review aims to provide an extensive picture of the discursive space of contemporary design pedagogy and chart its trajectory in the future.

**Requirement of a new framework for Curriculum:** New teaching models in design education should be adaptable and incorporate cognitive, reflexive, and heutagogic approaches [1, 2]. Synergies among design practice, education, and research drive innovation [3]. The choice-based learning pathway and flipped classroom models offer authentic, active learning [4, 5]. Curriculum transformation is vital for addressing global challenges and emphasizing real-world problem-solving while embracing diversity [6, 7]. Rapid prototyping and craft-based training integration enhance design education [8]. The Y-shaped Designer model fosters interdisciplinary problem-solving, reflecting the need for innovative curricular strategies [9].

**Desired Skills and Competencies of Designers:** Critical reflection is crucial in designing a modern Design education, addressing collaborative problem-solving for wicked problems [10]. The spectrum of student growth includes translation, creation, and articulation skills [11]. Integrating technical, analytical, and social aspects is vital [2]. Designers must navigate complexity and variability, moving beyond technocratic approaches [12, 13]. Assessing community engagement and developing new competencies like graphical representation and problem-solving are key [14–16]. The Design Competency Framework supports autonomy and creative skill development [17]. Frameworks for capability development and curriculum planning are essential [18]. The aim is to make designers commercially and internationally adept, fostering critical thinking [19].

**Critical Issues in Design Education:** The rapid evolution of technology demands continuous professional development for designers, expanding their roles and responsibilities [10, 20]. Shortened design cycles, influenced by advanced technology, reshape product and service delivery [18]. Systems theory provides insights for understanding complex scenarios and automating design through generative systems [21]. Designers must possess information-gathering and critical reasoning skills to navigate the evolving design landscape [13, 22, 23]. Ethics and sustainability are paramount in design education, preparing future designers for ethical dilemmas and responsible data use [12, 24–26]. Design must prioritize humanity's and the planet's well-being [27, 28]. Multidisciplinary collaboration is integral to design, requiring a practice-based, multidisciplinary education approach. Diverse perspectives enrich the design community, particularly from non-design professionals [14]. Interdisciplinary research opportunities connect design with psychology, social sciences, medicine, and more [18].

**Gaps in Current Design Education:** Current design education fails to prepare students for real-world challenges, lacking in-depth social understanding and business acumen [2, 11]. Ethical dimensions are often overlooked, highlighting the need for new guidelines [26]. Eurocentric biases, gaps in business competencies, and outdated educational models are noted, revealing a disconnect between theory and practice [11, 15]. Suggestions for bridging this gap include advancing creative industries and adopting student-centred pedagogies.

#### **3 RESEARCH GAP**

Significant research gaps in the existing literature focus on the evolving needs and challenges of design education in the 21st century. The gaps found are categorized into 7 different aspects:

- **Integration of Interdisciplinary Perspectives:** Existing literature emphasizes interdisciplinary perspectives as necessary in design education, yet it does not provide an integrated framework.
- Ethical Decision-Making in Design Practice: Ethics increasingly plays a major role in design education. The data sourcing and collection must be ethically done. Use of Artificial Intelligence, extended reality must have ethical boundaries. Design education, therefore, must provide value-oriented guidance for addressing ethical dilemmas in future. However, there are no effective models for integrating ethical decision-making into mainstream design.
- Emphasis on Sustainability and Environmental Awareness: With sustainable design practices now a pressing issue, it must be thought about how these principles can integrate into design education.
- **Digital Fluency and Technological Innovation:** The rapid pace of technological advancement throws up its problems, ensuring students have a reasonable degree of digital fluency for innovative design.

- Development of Human Skills for Collaborative Excellence: Human (soft) skills such as communication, teamwork and adaptability are essential to effective design practice, yet traditional curricula often neglect them.
- Global Perspectives and Cultural Awareness: Design overlaps national boundaries, yet frameworks are needed to promote cultural awareness and global perspectives.
- Adaptive Preparation for Future Challenges: Design education must prepare students for rapidly changing design landscapes. However, no model or framework prompts adaptability and resilience.

#### 4 THEORETICAL FRAMEWORK

The landscape of future design education is highly influenced by technology, society, and sustainability. As we have seen, there is a gap between traditional curricula and the demands of contemporary practice needs. Traditional design programmes need to teach adaptability, ethics, and innovation. We propose a theoretical framework that empowers budding designers to become adaptive, socially responsible, and innovative. The framework integrates collaboration, ethical decision-making, sustainability, interdisciplinarity and digital proficiency. This framework lays a foundation for the future design curriculum that equips the designers to shape the future with purpose and integrity.

The proposed framework defines 7 aspects where the research gap needs to be addressed (Figure 1). These aspects are discussed below in depth.



Figure 1. Proposed Theoretical Framework for Future Design Curriculum

#### 4.1 Integration of Interdisciplinary Perspectives

The proposed theoretical framework addresses this gap by providing a structured, immersive approach to integrating interdisciplinary perspectives into design education.

1.

2.

3.

#### **Practical Implementation Steps**

- 1. Interdisciplinary Design Studios
- Cross-disciplinary Workshops and Seminars 2.
- 3. **Collaborative Research Projects**
- Interdisciplinary Capstone Projects 4

## 4.2 Ethical Decision-Making in Design Practice

The ethical aspect of the proposed framework addresses the gap by providing a platform for embedding ethical decision-making within the curriculum.

#### **Practical implementation Steps**

- 1. Ethics workshops and Seminars
- 2. Ethical Design Projects
- 3. Guest lectures by Ethical Design Professionals
- 4. Ethical Frameworks and Guidelines

**Benefits and Outcomes** 

Environments 4. Interpersonal Growth

Better Problem-Solving Skills

Preparation for Collaborative Work

**Richer Design Solutions** 

- **Benefits and Outcomes** 1. Ethical awareness
- 2.
- Ethical Decision-making Skills Professional Integrity 3.
- Ethical Leadership 4.

#### 4.3 Emphasis on Sustainability and Environmental Consciousness

The proposed framework addresses this gap by infusing sustainability principles throughout the design curriculum, providing students with theoretical knowledge and practical skills in sustainable design.

1.

2.

3.

4.

#### **Practical Implementation Steps**

- 1. Sustainable Design Workshops
- 2. Eco-conscious Design Projects
- 3. Field Trips to Sustainable Businesses and Sites
- 4. Collaboration with Ecological Organizations

#### 4.4 Digital Proficiency and Technological Innovation

The proposed framework addresses this gap by emphasizing the development of digital fluency and fostering a culture of technological innovation among design students.

Practical implementation steps			Benefits and Outcomes		
1.	Digital Skill Workshops	1.	Enhanced Digital Proficiency		
2.	Tech-Talks and Demonstrations	2.	Innovative Design Solutions		
3.	Techathons for Innovations	3.	Cross-disciplinary Collaboration		
4.	Integration of latest technology	4.	Industry Relevance		

5. Extended Reality studios

5. Portfolio Enhancement

**Benefits and outcomes** 

Hands-on experience

Industry Alignment

Environmental consciousness

Eco-friendly innovative solutions

#### 4.5 Development of Human (soft) Skills for Collaborative Excellence

The proposed framework addresses this gap by integrating various activities and experiences that nurture the development of soft skills essential for collaborative excellence.

Practical implementation Steps			Benefits and Outcomes		
1.	Team-based Design Projects	1.	Team Collaboration		
2.	Design Thinking Workshops	2.	Effective Communication		
3.	Peer Feedback Sessions	3.	Cultural awareness		
4.	Cross-cultural Design Challenges	4.	Flexibility and adaptability		
5.	Leadership and Conflict Resolution Workshops				

#### 4.6 Global Perspectives and Cultural Awareness

This framework addresses the gap by allowing students to explore diverse cultural angles and perspectives, engage in cross-cultural design challenges, and develop a global mindset in an interconnected future world.

Pra	ctical Implementation Steps	Ber	efits and Outcomes
1.	International Design Workshops and Exchanges	1.	Cultural Sensitivity
2.	Cross-Cultural Design Challenges	2.	Global Design Fluency
3.	Guest Lectures by Global Design Practitioners	3.	Cross-Cultural Collaboration
4.	Cultural Immersion Experiences	4.	Empathy and Perspective-taking

#### 4.7 Adaptive Preparation for Future Challenges

The proposed framework addresses this gap by emphasizing adaptive preparation for future challenges, equipping students with the mindset and skills to thrive in a rapidly changing design environment.

Practical Implementation Steps	Benefits and Outcomes
1. Design Futures Seminars	1. Adaptive Mindset
2. Design Thinking for Innovation	2. Innovative Solutions
3. Scenario Planning Exercises	3. Entrepreneurial Skills
4. Industry Collaboration and Internships	4. Professional Readiness
5. Entrepreneurship and Business Skills	

In conclusion, the integrated theoretical framework equips students with interdisciplinary problemsolving skills and a proactive innovation mindset. Ethical decision-making, sustainability principles, digital proficiency, soft skills development, global perspectives, and adaptive preparation are all essential components. This comprehensive approach ensures students are prepared to navigate complex challenges, lead effectively, and drive innovation in the evolving design landscape.

#### **5 DISCUSSIONS**

The proposed design education framework navigates the field's dynamic shifts by emphasizing interdisciplinary foundations, ethical integration, and digital fluency. Recognizing design as multidisciplinary, it integrates insights from psychology, engineering, and sustainability science. Ethical considerations serve as a moral compass, guiding designers to navigate complex dilemmas responsibly. In the digital age, fluency in emerging technologies like augmented reality and data analytics is pivotal for innovation. The framework promotes experiential learning through hands-on projects and industry collaborations, bridging theory with real-world application. Additionally, it stresses developing soft skills and global perspectives, which are vital for effective communication and collaboration across diverse cultures. This holistic approach aims to equip students with the tools and mindset needed to thrive in the multifaceted challenges of 21st-century design.

## **6** CONCLUSIONS

The proposed framework for design education focuses on cultivating ethical innovators with new perspectives. Learners are equipped with cross-field foundations, principled integration, and digital acumen. Experience-driven learning, pragmatic applications, and soft abilities ensure mastery of craft and adaptability. The goal is for designers to drive improvements, not just manufacture products. Collaboration among academia, industry, and the design community is key for future progress. Recommendations include industrial counsels, sustainability plans, and cross-disciplinary projects for enriching training. This educational journey aims to redefine possibilities in design through ingenuity, ethics, and progress. However, the theoretical framework for design education has limitations. Validation across various educational contexts is needed by organizations like NASAD. The data used in the literature may not be widely applicable. Further exploration into the framework's effectiveness is necessary, along with integrating student perspectives. These limitations present opportunities for growth. Future research should focus on validation, implementation, and collaboration to shape ethical designers.

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## OLD PROCEDURE - NEW APPROACHES: QFD WITH CHATGPT - COMPREHENSIVE PRODUCT AND PROCESS UNDERSTANDING IN ENGINEERING DESIGN EDUCATION

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### ABSTRACT

Quality Function Deployment (QFD) is a well-established procedure that helps to translate customer needs and expectations into advantageous product features. A key element is the matrix-based 'House of Quality' (HoQ). Its different sections guide engineers through the process by addressing the customer's needs and expectations, defining specifications, finding how these parameters are interrelated, weighting them, evaluating and defining target values with help of a competitor analysis. But is QFD worthwhile teaching? What benefits can be seen? This article opens up new educational and engineering perspectives by presenting QFD examples, an analysis based on Artificial Intelligence (AI) using ChatGPT, and two surveys among students. The results demonstrate that QFD and the HoQ are still state-of-the-art procedures worthwhile being integrated in today's engineering education. The authors show new approaches, aspects, insights and reflections – but most of all let the users, respectively students evaluate this "old procedure with new approaches." This extension enables QFD to sustain comprehensive engineering and to support creativity – also integrating AI.

*Keywords: QFD, Quality Function Deployment, engineering products, processes in engineering design and development, AI support in QFD, AI guideline for students and scientific thesis* 

#### **1 INTRODUCTION AND RESEARCH MISSION**

Quality Function Deployment (QFD) was developed and introduced by Yoji Akao in the late 1960s [1]. In the time of strong functionally organised companies, QFD had the aim to support engineers to get a deeper understanding of customer needs and expectations – expressed by the voice of customer (VoC) and the mind of customer (MoC). QFD was also set up to support the cross-functional understanding of the customer's needs and requirements, helping to engineer beneficial products that satisfy or delight customers instead of losing the customer focus by 'over-engineering.'

Since that time, engineering has shifted from functional organisation to an 'integrated design and development.' Major aspects of this change involve interdisciplinary and cross-functional teams, simultaneous engineering and tend to integrate customers in the engineering processes.

In this context the following questions arise and define our research mission:

- Is QFD still state-of-the-art?
- Does QFD help engineers today?
- Should students be acquainted with QFD and be able to apply the method?
- If QFD still has its 'right to exist': How should students be trained to apply it?
- How can students and engineers be motivated to employ QFD?

#### **2 CONTEXTS IN ENGINEERING STUDIES**

Mechanical Engineering students typically get in contact with Engineering Design and Development from the very beginning of their studies. While learning the 'handcraft 'of designing with help of CAD they simultaneously attend lectures in mechanics, technical drawing, machine elements, material sci-

ences and production processes. At Baden-Wuerttemberg Cooperative State University (DHBW), students in the engineering design programme today already explore product development processes and models in their second year. Thus, initiation to the V-Model, VDI guideline 2221, Cooper's stage gate system or the notion of 'Time to Market' (TTM) takes place earlier than usual. The reason for preponing the corresponding lecture in the study programme was that students lacked experience when they went – according to the cooperative study model – working six months on projects in companies during the second year. During the course of these projects Engineering Design students often support experienced project managers in developing and optimising products and processes. As a result of this curricular change, students are well prepared now to apply the concepts and methods they became acquainted with in the lecture into practice.

QFD is taught in the lecture 'Quality Management' that is scheduled in the third year of the Mechanical Engineering curriculum at DHBW (which is also the prevalent instant for this lecture at most universities in Germany). As we point out later, this timeline has proved to be beneficial: engineering design lecture followed by the internship in the second year and quality management in third year. This timely order allows students to deepen their knowledge on processes and to link engineering design to quality management procedures.

### **3 QFD TEACHING CONCEPTS**

QFD and its House of Quality (HoQ), as well as subsidiary methods to accomplish the steps of the procedure more efficiently, Figure 1, have been constantly refined. As a result, QFD is a prominent tool in today's engineering world.



Figure 1. The House of Quality (HoQ)

There are even specialised institutes dedicated to QFD, offering trainings and workshops. Also, many publications about adaptions, integrating marketing and engineering methods, addressing best practise examples of applications with products, services etc. can be found [2], [3]. An overview is challenging but some publications try to summarise the milestones and refinements of QFD [4], [5]. The 'four phase model' was introduced by Sullivan, Hauser and Clausing and further developed by the American Supplier Institute (ASI), taking QFD from product, to part, to process and to production planning [4], [6], [7]. In 2015 the ISO standard 16355 was published in its first edition [8]. Today it consists of eight parts and surely is an expert standard. Also, within the domain of education a number of publications address challenges and attempts of teaching QFD. The application of QFD seems challenging. It is often exposed to criticism if only the HoQ is used as a method of implementing QFD. It is also said to be very expert related and time consuming if used as a set of adaptable matrices, as in the sense of the 'matrix of
matrices' considered by Akao and King [9] or ISO 16355 [8] with its eight parts and the diverse tools and methods being proposed therein.

#### 3.1 Traditional Teaching and Student-Centred Approach

A wide range of publications that derived an educational concept of teaching QFD, prefer a 'simple approach 'for using the HoQ: They advocate an efficient and motivating approach [10]. According to these studies, a lecture on QFD should be structured in the following steps:

- Teaching the basics, theory and philosophy of QFD and HoQ, based on an already existing engineering knowledge from other lectures (enumerated in the section before)
- Applying QFD to a daily used product, letting students work their way through an own QFD project example (either as a lecturer moderated or as a group work exercise)
- Training with other given examples (either in a lecture, working in teams and supported by the lecturer, or as e-learning exercise, possibly even in a flipped classroom concept)

In the classroom, QFD exercises often are challenging. Particularly when it comes to finding target values. This requires competitor analysis, from the 'customer's view' and from a 'technical view,' Figure 1. This step requires an in-depth study by the students. Consequently, this option is usually only effectuated by a small group of students (10 %) on a voluntary basis. The reason is simple: This step requires additional time – more time than usually available during a lecture. Lecture time spent on QFD within the frame of a 'Quality Management' lecture typically is only three to five hours. On the other hand, Schockert and Schönhofen [10] sum the needed time up to 32 hours. This, of course, allows indepth analysis. This approach surely is applicable for an elective QFD course but not within a comprehensive lecture on Quality Management that in total only spans 60 hours of lectures time.

The 'traditional' teaching concept can be characterised as a 'teacher-centred' approach where students learn theory and apply it on given, pre-defined problems. A more motivating concept is letting students choose their own QFD product. The role of educators is in assisting them by working their way through the QFD in teams. This can be classified as a more 'student-centred' approach [11].

#### 3.2 QFD product examples fostering creativity

Some of the best and most creative product examples found by students in recent lectures on QFD at DHBW are listed below:

- Thermos flask or thermos cup: (vacuum insulated)
- Catapult: mobility and competitor product to fire-fighting vehicles or aircrafts and sprinklers
- Transportable, wireless loudspeaker (waterproof)
- Beer crate (ergonomic, stackable and foldable), Figure 2



Gi weighting index, cust. req. customer requirements, Bai ratings

#### Figure 2. The core matrix of the House of Quality (HoQ) for a beer crate

Even if a beer crate seems rather simple at first sight, applying QFD generated several aha effects, Figure 2. Today's customary solution possesses integrated handles and is stackable. The design tries to optimise between stability and lightweight. All in all, a product with a high level of maturity that will be hard to challenge. Nevertheless, one student produced an innovative feature in a lecture: a foldable crate. Good

discussions evolved from the weighting of the customer requirements by applying a pairwise comparison matrix. Interestingly, the new idea of a foldable crate was rated low (=1 on a five-point scale in Figure 2) in comparison to the other customer requirements. This shows that 'out-of-the-box' product approaches often need a corrective intervention.

#### 3.3 Integrating AI in teaching QFD

The integration of Artificial Intelligence (AI), in this case of the large language model (LLM) ChatGPT, can pave the way through QFD. In our study ChatGPT was prompted with questions that QFD users would also ask in a conventional approach:

- 1. I need a good innovative product to do a QFD, Quality function deployment, in my Quality Management lecture. So please name suitable products and functions or features for the product and quality!
- 2. Which are typical Customer Needs for this product?
- 3. Now translate or derive Engineering characteristics!

ChatGPT 3.5 answered these questions as follows:

- 1. "(...) Let's consider a hypothetical innovative product a 'Smart Home Health Monitoring System.' (...) Here are some potential functions or features (...)" altogether ten aspects are listed with descriptions, e.g. from biometric and environmental sensors, data security and privacy to customisable alerts and notifications.
- 2. The second question is answered by listing twelve customer needs, some of them similar to the answer of the first question. Some are: a real-time health monitoring system, user-friendly interface, compatibility with other systems and continuous self-learning and improvement of the system.
- 3. The third question is answered respectively with detailed engineering features and refers to possible solutions, e.g. a real-time health monitoring with a high frequency sensor sampling, low-latency data transmission, compatibility with common smart home protocols, e.g. ZigBee, Z-Wave."

Students involved in the study felt that ChatGPT can support them well in gathering features for a product in a rather unknown field. In conventional lectures this objective is attained with help of creativity methods. To the educators leading the experiment the quality of the results seems adequate to the educational level. In addition, the answers were generated in only a few minutes.

#### 3.4 Understanding AI and guidelines for application

In a subsequent step of this study, a documentation of the prompts and answers of ChatGPT were analysed with help of a plagiarism software. The results of this analysis, detailed in Figure 3, were discussed in the context of scientific writing in class, taking bachelor theses as an example. It could be observed that the students were really surprised by the plagiarism test. As a result, an intense discussion engaged – both between the class and the lecturer and within the class. Unexpected at this point, the discussion added a motivating momentum to the course.

According to the documentation of the plagiarism software, documents usually exhibit a similarity index between 1 % and 2 %. Furthermore, the developers of PlagAware judge less than 1 % as no significant infringement, 1 % to 5 % as a tolerance band, and more than 5 % as significant [12]. The ChatGPT answers on QFD, listed in the first row of Figure 3, showed no match (0 % resemblance) in two different plagiarism systems (PlagAware, Copyleaks). In return, Copyleaks identified that the text was written by AI with a probability of 100 %. In order to get a feeling for reference values, the artificially generated description of customer needs and product features have been compared to four bachelor theses handed in lately. The benchmarked documents obtained a score from minimum 1,7 % to maximum 13,1 % (Pla-gAware, 20.11.23). A critical rating of 13,1 % has been attributed to a thesis that is only 44 pages long and plagiarised half a page cited literature with no literature reference. The other thesis, some of them also rated critically, proved not to be a plagiarism. References were found and literature reflected. Plagiarism software can aid but still requires in depth analysis of plagiarised suspected text. But how should scientific research deal with AI if its use can't be proved – only recognized by some means?

🔽 Date	Title of document	Project	result	preview	pages
22.11.2023	James: I need a good innovative product to do.,.	QFD	0%		5
15.10.2023	_TMK20-2_Bachelorarbeit.pdf		1.74%	i	70
15.10.2023	_TMK20-1_Bachelorarbeit.pdf		10.5%	1	106
13.10.2023	230919_T3_3300_Bachelorarbelt_S		4.61%	1 I I	50
13.10.2023	_TMK20-2_Bachelorarbeit.pdf		13.1%		44

Figure 3. Results from plagiarism tests

After having explored miscellaneous possibilities of integrating AI into QFD, students discussed guidelines for using AI. The guidelines presented hereafter are intended to prepare students for their bachelor thesis. With the fast emergence and terrific progression of AI, many universities felt compelled to establish guidelines, some even replaced examinations with orals or introduced additional colloquia. The following 'Seven rules for AI' have been setup [13] in this study:

- Use AI as a supporting tool to derive new ideas!
- Beware of prompting sensitive material which may be confidential!
- Question and reflect on results generated by AI! Be critical!
- Consult (scientific) literature in the specific field! This will help to reflect if data given, and ideas generated by AI are valid. AI may be biased!
- Document the use of AI tools! AI is not an author! [14], [15]
- Indicate precisely when data has been given and texts, codes or ideas have been generated by AI! Document prompts - if possible! Coding might be generated in a context, so document progression!
- Protect and respect the values of our society, laws, rules and human rights, such as copyright, privacy protection policy, personal rights and human equality!

#### 4 SURVEYS ON QFD AND AI

Based on the fruitful discussions in class, students were asked to share their experience with QFD in connection with AI and to describe their motivation to use it in a survey.

Two classes participated: Mechanical Engineering students in Engineering Design and Electrical Engineering students in Automation. The total number of participants was 29.

The biggest difference between the two classes manifests in a question on the use of AI: While 73 % of the Automation students state that they use AI regularly, only 17 % of the Engineering Design students do so. 72 % of the latter class declare that they are still in the phase of trying out AI so far. The cause probably lies in the different field of use: While most Engineering Design students regard AI as a support for creating ideas and as a source of information, the Automation students rather deem AI to assist them in writing and coding (programming). In comparison, only one Engineering Design student mentioned programming. Across both classes, 93 % of all students intend to use AI in the future. Potentially, this general approval rests on the positive experience from the course described in section 3.3. A gradually weaker but nonetheless clear reaction was provoked with respect to a code of conduct. Over 80 % of the students agreed on the necessity of defining such guidelines for the use of AI. Nota bene, in order to exclude bias, the guidelines mentioned in section 3.4 were presented to the students after the survey.

The survey dedicated to QFD provides the following results (quoted hereinafter in consolidated form): Over 75 % Engineering Design students think that QFD leads to innovative solutions while only 50 % Automation students do so.

Interestingly, only 47 % Engineering Design students consider QFD to procure a better product understanding while 92 % Automation students consent on this issue. This rather damped enthusiasm among the Engineering Design students seems incoherent with other results. Maybe the product example of a beer crate, the students chose, was 'too simple.' Consequently, QFD could probably not deploy its full strength: QFD particularly pays off with products revealing complex relations, e.g. in mechatronic applications. The method proved to appropriate some previously incomprehensible problems (cf. section 3.2 on the implied aha effects) very well.

Students (96 %) quasi-unanimously advocate embedding QFD and the HoQ in their curriculum. In average, the applicability of the HoQ was graded with 2.3 on a Likert-type scale reaching from 1 (very good) to 5 (very poor). Engineering Design students assigned a slightly better grade (2.1), probably

because they are more accustomed to using methods, e.g. creativity and assessment methods, than their fellow students majoring in Automation.

#### **5 CONCLUSIONS AND OUTLOOK**

The interviewed students responded very positively on QFD, although the engineering world has changed considerably since Yoji Akao developed the method in the mid-1960's. The great esteem that the students attribute to QFD suggests that the chosen student-centred learning approach, which includes the free choice of a product example, was beneficial to the learning process. In particular, the students liked the experiment of tackling the 'old' procedure QFD with a 'new' approach (AI).

Other findings from the study are: The chronological order of lectures on Engineering Design, practical experience in industry within the co-op programme and a Quality Management lecture fosters deepening knowledge on engineering processes, also recognising how Engineering Design and Quality Management procedures closely engage. Applying QFD in engineering education also trains typical engineering tasks, as determining customer needs, defining product specifications, assessing solution variants according to rating criteria and analysing competitors. Altogether, discussions of how to integrate AI into QFD lead to a comprehensive product and process understanding in Engineering Design education.

Future work will expand the focus and encourage students to apply AI to other methods. Also, the educational concept will be further refined, reinforcing learning-centred application by flipping the classroom.

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### FUN AND STRESS: INVESTIGATING STUDENTS' EXPERIENCE OF FOUNDATIONAL DESIGN COURSES

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#### ABSTRACT

Project based design courses are central to both architecture and engineering education. The objective of this study was to investigate the issues and challenges faced by students in three foundational design courses focusing on introductory design, architectural design and engineering design at the Singapore University of Technology and Design (SUTD). A survey comprising both quantitative and qualitative questions was administered in three courses. A principal component analysis conducted on the response data revealed five factors that primarily contributed to students' experience of these design courses: (1) the fun aspects of design, (2) the stressful aspects of design, (3) Course Pressures, (4) Student personality, (5) Teamwork experience. Content analysis of the two open-ended questions provided insights into the main aspects that contributed to the stress and fun factors for each course. We present initial recommendations to enhance student experience in design courses.

Keywords: Design education; architectural design; engineering design; student experience

#### **1** INTRODUCTION

Design education usually employs project-based learning, in which students learn to research, plan, design and reflect on the creation of technological projects. Students work in teams to identify the user needs, find solutions, and design and build a final product [1]. Investigations in the experience of students are crucial, as these provide insights into students' perspectives of design courses. Studies have pointed out that students are often ill-informed about design education when entering university [2]. Issues students experience may influence their design process, as well as their knowledge development. Student experience surveys can be used to drive forward changes in curriculum or pedagogy [3]. In the field of design student surveys have been used to analyse design thinking skills [4] and design literacy [5]. However, these studies are primarily used to assess knowledge and skills, not to investigate students' experiences of their design courses. Studies assessing affective variables are far fewer in number.

We present an exploratory study into student experiences, specifically the issues and challenges faced by students in three foundational design courses – an introductory design, an architectural design and an engineering design course at the Singapore University of Technology and Design (SUTD). The research questions addressed are:

- What are the major issues that negatively impact student experience in the three design courses?
- What aspects of the design courses were considered fun, and what was stressful for the students in the three design courses?

Based on our findings, we provide recommendations for improving student experience.

#### **2 BACKGROUNDS**

Design courses are central to both architecture and engineering education. Design typically consists of analysing a problem and of generating, evaluating and testing alternative solutions. Design courses primarily utilize project-based learning in which students, individually or in teams, transform a field of inquiry into a proposition or scheme. They address problems that are usually open-ended with no single, correct answer and often address real-world challenges [1]. Whereas introductory courses may be more guided and involve teaching of process and methods alongside working on the project, subsequent courses tend to use a studio setting with no or only minimal guidance on process and methods to use. Students play an important role in studio pedagogy with its learner-centred point of view. In a design

studio, groups of students have designated classrooms in which they meet regularly with their instructor(s), who guide their work on given assignments [6]. In architecture this feedback, called critiquing, is at the heart of their education. Students learn from sharing information with one another and instructors, and from their feedback [7].

Several authors investigating design education have argued that 'learning should be enjoyable' and that students should have a good time while they work [8, 9]. In Engineering design education literature, the notion of 'fun' and 'enjoyment' has been discussed in the context of design process [6], as well as design education [8]. At the same time, several studies investigated the difficulties faced by undergraduate students such as high learning pressure, heavy workload and feelings of uncertainty about the future. A related concept is learning anxiety [10]. Studies of student experiences of open-ended problems noted that students found open-ended problems both 'difficult' as well as 'fun' [11]. Chen's study with industrial design students revealed that students considered the most difficult design tasks to be concept generation, design presentation, and design research [12].

#### 3 METHOD

#### 3.1 Foundational design courses at SUTD

All three analysed design courses involved studio-based projects that covered task clarification, concept generation, evaluation and refinement, detailed design of preferred concepts, and communication of results. The first-year foundational Introductory Design course (ID) is specifically developed for all the university's first-year students to introduce the concepts of design, design related skills, mindset of innovation, entrepreneurship, and methodologies in design. This course is the foundation for the other two courses that we analysed. The Xth-year foundational architectural design course (AD) establishes foundations for architectural design through a series of projects that build in scope and complexity to have students engage issues of 3-dimensional geometry and drawing, space and component aggregation, ordering systems, structure, circulation and narrative, and tectonics. The Xth-year foundational Engineering Design course (ED) helps students develop a holistic view and competency in the combined interactions of engineering design and engineering project management. Students learn design, analysis, prototyping, testing, and project management methods to effectively plan, organize, and execute an engineering project.

#### 3.2 Survey design and administration

The survey comprised 25 questions: two open-ended questions and 23 closed questions. The closed questions were used to survey students' experience of instruction mode (8 questions, semantic differential scale), class content (8 questions, semantic differential scale) and challenges affecting performance (7 questions, Likert scale). The semantic differential questions measured two aspects: (a) the fun aspect that ranged from *Lot of fun* (2) to *Very boring* (-2), and (b) the stress aspect, that ranged from *Very stressful* (-2) to *Very relaxed* (2). The 23 items were chosen from literature and then refined further with research team members, a selection of students and ex-students. Face validity was conducted with PhD students and Teaching Assistants on the course, who went through the questionnaire and provided input on the terminology used. The questionnaire was then pilot tested with a subset of students (n=10). The survey was conducted in the three foundational design courses, in both online and paper format nearing the end of the term. With the help of the course coordinators, 15 minutes of class time was allotted to the students to do the survey.

#### 3.3 Data analysis

We employed a principal component analysis (PCA) on the closed questions to reveal factors that primarily contributed to students' experience of foundational design courses: (1) the fun aspects of design, (2) the stressful aspects of design, (3) course pressures, (4) student personality, (5) teamwork experience. The open questions were analysed using a content analysis synthesising strategy aimed at investigating the reasons for student responses in rating questions. Themes emerged from the data using an inductive approach. Descriptive coding followed by topic coding was used [13]. From the review of the data, 10 patterns were identified, coding was reviewed, discussed, and refined by researchers.

#### 4 **RESULTS**

Respondents consisted of 246 students from the ID course (93 female, 153 male; 56% of students attending this course) 48 students from the AD course (27 female, 21 male; 61%) and 71 students from the ED course (27 female, 44 male; 59%).

#### 4.1 Principal Component analysis

A PCA was conducted on the 23 items with orthogonal rotation (varimax). The Kaiser–Meyer–Olkin (KMO) measure verified the sampling adequacy for the analysis (KMO = .837 and all KMO values for individual items > .77, which is well above the acceptable limit of .5). Bartlett's test of sphericity ( $\chi^2$  (253) = 2935.032, p < .001) indicated that correlations between items were sufficiently large for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. On the basis of the results from the first round, we reduced the number of items in the exploratory factor analysis. The revised version had 20 items, and five components. Two items had cross-loadings to two factors. Figure 1(a) shows the factor loadings after rotation, and 1(b) shows the interpretation of factors that contribute to students' experience of design courses.



Figure 1(a) Principal component analysis, (b) interpretation of factors that contribute to students' experience of the analysed design courses (\*"DesStg"= Design Stage; "IndWork"=Individual Work)

#### 4.2 Average factor scores for each course

Average factor scores for each course measured by means of factor scores (obtained by multiplying the standard scores for the original variables by the factor score coefficients). These scores were normalized to facilitate interpretation. Figure 2 shows quite different trends for the courses with regards to stress and fun of designing.

The ID course does not stand out, apart from being the only course for which the design-related stress factor was very low. The AD course was the course most enjoyed by its students and having the lowest course pressure. Nevertheless, the students experienced a fair amount of design-related stress and teamwork issues, but the fun scores are higher than the stress and teamwork scores. The ED course was experienced as very stressful, with a lot of pressure (both scored highest for the three courses), and a low score for fun. Student personality was found to play a relatively small role in the experience of the design courses.

#### 4.3 Content analysis

The content analysis of the two open-ended questions provided the following insights into the main aspects that contributed to the stress and fun factors for each course.

#### Stressful aspects of design

The most frequently occurring themes in a course in terms of percentage of answers of the respondent of that course, are the following:

- Subjectivity (ID 19% of students): For the first year ID students the most frequently occurring theme in the category stress was the issue of subjectivity in design---that different people would have different opinions on the same design, which led to confusion. As pointed out by on student, "...the professors constantly said things that contradicted each other or even themselves... we never know who and when to listen, which made it difficult..."
- Uncertainty and vagueness (ID- 14.3%): Students seemed to be struggling with the vagueness that is inherent in design problems. This ranged from being unsure of ideas and getting stuck while designing, as voiced by a student "(*I dislike*) Uncertainty if ideas will materialise...'. Another student had issues with "getting stuck at other dead ends that cannot be solved that easily".
- Rules and restrictions (ID 9.5%): The first-year students complained about the restrictions in design briefs that "...shut down avenues [students] can explore..." (ID-01).
- Self-learning issues (ID- 9.5%): The first-year students reported difficulties in self-learning and articulated the need for greater guidance from professors.
- Lack of foundational/ technical knowledge (AD 8.3% and ED 17.1%): In ED, Design related stress in students was also due to student unpreparedness, lack of prior knowledge, and lack of technical ability. As expressed by one ED student: "*The theme is way beyond our league until we are forced to come up with ideas that has to be innovative and novel, but we have barely the technical ability or knowledge to execute them (sic).*

#### Fun aspects of design

The most frequently occurring themes in a course in terms of percentage of answers of the respondent of that course, are the following:

- Freedom, imagination and Experimentation (ID 28.6%, AD 20.8% and ED 10%): Students from all three courses mentioned that they liked to have 'freedom' in design, *especially* the 'freedom to choose their topics of interest' and experiment with 'impossible or silly concepts' (AD). They liked that 'the course provided an avenue for us to be as innovative and creative with our ideas,' (ID).
- Learning new skills (ID 14.3%, AD 16.7% and ED 10%) Students in all three courses mentioned enjoying learning new skills, such as technical and software skills, and '*learning about new technology*' (ED). AD Students enjoyed learning skills such as '*making presentations*' (AD) and '*learning how to communicate ideas clearly*' (AD).
- Hands on (ID 14.3% and ED 12.9%): Students in ED and ID especially enjoyed hands-on work and liked '*exploring methods of fabrication*'. One student pointed out that they particularly liked the course as "*it is not content heavy, more hands-on work*" (ID).
- Enjoy the design process (ID 14.3% and ED 7.1%): Students in all three courses mentioned that they enjoyed the design process including 'conceptualization', 'thinking critically about design' and the 'exposure to a variety of design problems' (AD).
- **Multi-disciplinarity (ID 4.8%)**: Students liked that their design course was multidisciplinary and "allowed them to showcase their multiple talents" (ID).
- **Design thinking (ID 4.8%)**: Students in ID mentioned they liked using design thinking ideas and methods for streamlining ideas, as well as learning about user empathy and user centric design.



Figure 2. Mean factor scores for each course for Introductory Design (ID), Architectural Design (AD), and Engineering Design (ED) courses

#### 5 DISCUSSION AND CONCLUSION

The objective of this study was to investigate the issues and challenges faced by students in projectbased foundational design courses as a basis for improving their experiences. We conducted a survey in three project-based design courses at the Singapore University of Technology and Design to gain insight into student experiences. While previous studies have investigated 'fun' and 'enjoyment' in the context of the design process [6] and found open-ended problems were perceived as both 'difficult' and 'fun' [11], in this study we provide insights into students experience of the "fun" and "stress" aspects of design projects. The experiences differed considerably between the courses. The first-year introductory design course was not experienced as stressful, but not particularly fun either. A possible reason, based on comments about rules and restrictions, is that in this course students are guided through the process while learning various design concepts and skills. A further possible reason is that this course is taken by all first-year students at the university: their design experience and hence expectations may vary and not all of them may be equally interested in design. The foundational engineering design course scored highest in design-related stress, with low scores for fun and high scores for course pressures. A possible explanation is the amount of technical knowledge that novel solutions in engineering can require which students probably have not encountered yet.

The foundational architectural design course was considered very enjoyable, despite a fair level of design-related stress and team issues. A possible explanation is the very low level of course pressure the students experienced, and the fact that in comparison to ID, this course focuses on their area of interest, architecture (although this did not seem to have played a role for ED students), and the very visual and interactive nature of architecture courses. The design-related stress in AD may have been caused by an inner drive to perform and come up with novel solutions, or by the team-issues they experienced to a higher degree than the other courses. Overall, students liked design when it allowed them to '*push limits*' and challenge them, but in a good way, i.e. without them feeling overwhelmed. Based on our results, in Table 1 we provide some initial recommendations to enhance student experience in design courses.

Instruction mode	• Greater interactive and visual content delivery.	
	• Content delivery through seminars or workshops rather than	
	lectures.	
	<ul> <li>More studio time and guidance from instructors.</li> </ul>	
Course structure	• Better connection between design and other courses.	
	<ul> <li>Integrating assignments of other courses into design projects</li> </ul>	
	Customizable deadlines, no-deadline 'dream projects'	
Knowledge provision	• A list of high-quality online sources suitable for students to acquire	
	the necessary knowledge within the time constraints of the design project and their level of competency.	
	• Learning resources, training in technologies and processes that include AI	

Table 1. Recommendations for improving student experiences of design courses

Design dispositions &	•	Preparing students to deal with uncertainty and subjectivity as main
attitudes		characteristics of design problems.

This study primarily focused on investigating students' experience of design course instruction and content. Other components that affect student experience, such as presentations and assessments, were outside the scope of this study. The survey being anonymous allowed students to express their opinions more freely but did not allow us to link their responses to their actual performance. Future research includes a more comprehensive understanding to examine variables such as assignments and assessments.

This study addresses a very fundamental issue in design education: how do students experience their design courses? Recent advances in Artificial Intelligence have specially made it important for instructors and researchers to understand how it impacts students learning in design education. While this study uses data from one university, the issues reported here are probably generic and relevant for instructors developing design courses in other countries. We look forward to conducting comparative studies to understand students' experiences of design education in different parts of the world.

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# FAB THESIS: A UNIVERSITY MASTER'S PROGRAMME

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#### ABSTRACT

Fab Labs are educating people in digital fabrication relevant to many areas of life. Often, education in Fab Lab context is non-formal. The existing examples of the formal educational programmes of the Academany educational initiative, such as the Fab Academy distributed educational programme, are provided through Fab Labs for people to learn the possibilities of digital fabrication, with Fab Academy being recognized in several universities around the globe. There is a need for continuum for this education within Fab Lab network, as well as it would support the appreciation of this continuum throughout the world if it would be possible to recognize it even partly in any university. Here, we study pilot "Grow with Fab", run in the network and propose a model of formal education for digital fabrication, Fab Thesis, and a possible method of sharing it to the network as well. This is a methodological development that bridges the Fab Lab educational paradigm with academic education. Findings of the Grow with Fab pilot contribute to the framework presented in this paper, for Fab City created prosumers in higher education. There is an educational path utilizing digital fabrication from pre-school to elementary school, high school, and university in Oulu area. In Fab City Oulu, we connected sustainability goals to this education. We will produce new kinds of prosumers to working life with new needs and values to empower their productivity. Still, we do not currently have a master's programme for these people with future skills and future values. This paper contributes to this goal.

Keywords: Fab Lab; higher and education; recognition of non-formal education, Fab City

#### **1** INTRODUCTION

Fab Lab is a small-scale digital fabrication and innovation platform, derived from MIT [1]. Fab Labs are defined by four rules: public access to the Fab Lab is essential, Fab Labs subscribe to the Fab Lab charter [2], Fab Labs share a common set of tools and processes, and Fab Labs must participate in the larger, global Fab Lab network [3]. Common core tools are a laser cutter, a sign cutter, a precision CNCmilling machine, a large-scale router type milling machine, a 3D-printer, an electronics workstation, and communication devices for video conferences. Common processes utilize also for example composites, casting, programmeming, etc. Having common processes is a tool for developing distributed manufacturing and enabling knowledge sharing network. There are over two thousand Fab Labs in the world. The contribution of this paper is towards the definition of form and purpose of Fab Labs [4]. One of the most important focus areas of the Fab Lab network is education [5]. The biggest programme, Fab Academy [6], is a six-month distributed learning process for the principles and practices of digital fabrication, based on MIT's 18 study credit point course "How to Make (almost) Anything". Fab labs need to have an educated instructor and a full inventory to participate in this programme. The diploma is granted by Fab Foundation. It recognizes skills to work and found a Fab Lab and ability to integrate those skills into a functional prototype presented for a final project. There is no global academic recognition for Fab Academy. However, many universities recognize the Fab Academy at some level. Fab Labs' role in education is of high importance [7]-[9]; For instance, the Fab Lab approach is significant for students to effectively bridge the gap between product design and electronics in an accessible way [9]. University teaching, along any education and digitalization, is in a change. Some universities are planning to sell the courses on the web and some, more than 250 institutions including MIT, share their materials for free [10]. Still, there is no distributed, master's level education for the

digital fabrication. Nor there is a programme for digital fabrication and rapid prototyping in Finnish universities. In this paper, we propose a partial solution for this problem.

#### 1.1 Fab Thesis Pilot

Fab Thesis was piloted under a name "Grow with Fab". It was a nine-month education programme pilot, started in October 2017, and followed Fab Academy completion. Fab Thesis was open for registration in 14 Fab Labs. It further developed the distinct role of Fab Academy within education [11]. It was designed to be a project incubation programme and the next step after Fab Academy or Bio Academy [12] ("How to Grow Almost Anything", a programmeme on the intersection of biology, biotechnology, and digital fabrication). Bio Academy used the latest personal digital fabrication processes to enable biological experiments outside expensive high-level laboratories. Additionally, Textile Academy [13] (a programmeme on the intersection of textiles, fashion, and digital fabrication technology) was piloted, to tackle issues of fast fashion with personal digital fabrication, at the time. The student applying to the Fab Thesis was recommended to have one or preferably two of the Fab educations. The student proposed a project. It would have been beneficial to continue the final project of Fab Academy if the funding (15 000 €) were achievable. This pilot blended elements of design challenge addressing a specific design problem, an acceleration programme (that helps early-stage startups grow and scale), engineering, design, and digital fabrication. Fab Academy is a programme of weekly workshops and a short final project to present the skills gained during the weekly workshops. This leads to a situation where numerous innovative projects are prototyped but remain unfinished. Fab Thesis aims to help these projects to reach a productive state [14]. There are already commercial or otherwise successful projects continued after Academany educational initiative offering distributed educational programmes focused on digital fabrication (e.g., Aquapioneers [11], Smart Citizen Kit [14], Open Source Beehive [15]). Cherry picking the best projects to the pilot would also help labs to keep talented people around. Especially if they would get a partial grant for working in the lab part-time during the Fab Thesis. In the larger scale, Fab Lab networks promise a positive impact on society, fostering innovations and new product development.

#### 1.2 Open Questions

While there are differences as well, Fab Academy and Fab Thesis pilot both share common elements with formal education. Class, professor, teaching assistant and evaluation, all have their equivalents in both settings. It is of high importance to recognize key differences and similarities, to take advantage of agile development of non-formal education programmes in the Fab Lab network in formal setting. The proposal of Fab Thesis in the context of higher education rises the questions of its recognition as a part of higher education. In particular, the main issues are: (1) How to integrate the elements of Fab Thesis into the higher education degree, and (2) How to preserve the inherent characteristics of making and learning processes in Fab Lab in the context of such integration. In this paper, we discuss the example solutions of these issues.

#### 2 METHOD

The Fab Thesis students built the next version of their project or given subject for approximately nine months. The schedule started with defining the nodes and the committee in April 2017. Application was launched for students June 29<sup>th</sup> with the deadline of July 31<sup>st</sup>. Projects were selected by the committee and local labs in August at FAB13 conference. The study programme started at October 16<sup>th</sup>. The progress was reviewed in December and mid-term review was in March. Thesis presentations were in July followed by project exhibition or presenting a paper at FAB14 conference.

The project had to be documented weekly. The programme offered top-tier, globally acclaimed lectures held by CEOs of leading companies or known scientists. Table 1 presents information about Fab Labs that took part in the Fab Thesis Pilot programme, including Fab Labs' names, locations, students starting in the programme, the subjects of their thesis, and their mentors. Two students accepted to the programme did not start. Students are considered as the primary authors in the Fab Thesis, providing approximately 10-page conference papers. The authorship is shared between local labs and Academany. The cost is predicted to be shared by students, labs, and/or companies. Utilization of the project is determined on a case-by-case basis. One of the targets of the pilot year was to develop a business model for each Fab Thesis. Labs offering the programme must have sufficient expertise to guide students' daily activities and the capability to grant access to the machines for 20 hours per week. The Academany

coordination provides global supervision and guidance for the students through a group of experts from both within and outside of the Fab Lab network. Students' progress is documented and shared online. Finally, certification is granted to the students by the evaluation committee. To graduate, two primary objectives should be met: (1) a conference paper of ten pages presented in the FAB conference, and (2) a landing page. The landing page is a web page set in a dedicated domain to present the design project. It serves the purpose of rapidly presenting the idea or product to external parties, such as companies or external visiting mentors with subject-specific expertise.

The research and project development for producing a conference paper are documented in the GitLab repository. These documentations are useful for instructors and supervisors to follow the development of the project. An instructor is equivalent to a teaching assistant and a supervisor to a professor in formal education. Communications and feedback happen through issues and milestones set in the GitLab repository. Furthermore, attending midterm presentations is compulsory for the students to remain in the programme. The final presentations of the pilot took place at FAB14 conference, with the alternative option of presenting via video. The certificate of completion was granted by Academany.

Location	Student	Subject	Mentors
Peru, Lima,	Jose Lazarte, Website:	Cocoa	Local mentor: Roberto Delgado
Fab Lab	https://growwithfab2018.	fermenter	Supervisor: Francisco Camacho
TECSUP	fabcloud.io/JoseLazarte		
Ecuador,	Roberto Gallo, Website:	Bits and	Local mentor: Isaac Robles
Quito, Fab	https://growwithfab2018.	Atoms Pen	Supervisor: Jani Ylioja
Lab ZOI	fabcloud.io/RobertoGallo/		Advisor from the network: Fiore
and Yachay			Basile
Finland,	Jari Pakarinen, Website:	PCB THP	Local mentor: Jani Ylioja
Oulu: Fab	https://jarifablaboulu.	Automation	Advisor outside the network: Adj.
Lab Oulu	wixsite.com/modular		Professor Georgi Georgiev
Spain:	Student N.N., Website: no	Ecotron	Local mentor: Santiago
Fab Lab	longer available.		Fuentemilla
Barcelona	_		Supervisor: Tomás Diez
Switzerland,	Student N.N., Website:	fabkit	Local mentor: independent
Geneva	https://www.fabkit.org/		Supervisor: Jani Ylioja

Table 1. Fab Labs and students accepted into the Fab Thesis Pilot programme

#### 2.1 Impact of the pilot

Three out of the seven applicants completed the programme, and two of them received certificates upon graduation. The third applicant, who completed the programme, missed the deadline for the conference paper, although the manuscript was almost ready. Cocoa fermenter project (see Table 1) was continued after the graduation and is currently patented. Figure 1 presents the PCB THT Automation, which was a study project and never meant to be continued after the graduation. It enabled the automation of a machine with labour-intensive two-hour process, freeing the operator for other tasks and reducing their workload. Bits and Atoms pen was continued after the pilot and mass manufacturing was designed in collaboration with a Chinese producer. Unfortunately, there was no follow up on the concept as a Kickstarter project and marketed solution.



Figure 1. Left: a pushbutton on the left and a rocker switch on the right automated with modules. Up right: a button pusher module uncovered. Down right: A printed circuit board through hole plating machine automated with the modules. The entire automation system can be removed from the machine in one piece

#### 2.2 Findings from the pilot

One of the aims of the pilot was to start a network capable of offering distributed education based on the Fab Thesis pilot. However, only one graduate in Peru was available to serve as a node since the student in Finland left the Fab Lab for an industrial position. In this initial pilot, the roles were reversed: while normally students come to teacher(s), we sent a teacher to each student for a week to address the most challenging aspects in design/creativity, engineering, and hardware acceleration/impact. Data was collected through close observation of students' progress during week-long visits to each student, facilitating discussions on the subject matter and obtaining feedback. While the outcome and impact of the pilot are obvious, we do not consider it to be in alignment with the required resources. Initiating the programme locally and subsequently sharing the suitable parts for the network appears to be more feasible.

We identified essential elements for impacting formal education, such as integrating creativity practices to fight the design fixation, emphasis on processes, and engineering, as well as active searching for impact in the hardware acceleration process. These elements address a major challenge in formal education, where students struggle to design and prototype fully functional devices quickly.

#### **3 PROPOSED COMBINATIONS**

The Fab Thesis contributes by bridging Fab Labs as alternative educational and innovation platforms [16] to a form of education that complements conventional methods. In this paper, we outline the recognition of Fab Thesis elements and compare them with the last year of ITEE (the Faculty of Information Technology and Electrical Engineering) study guide's master's programme for a bottom-up approach. As for a top-down model, we develop a framework for a master's programme in a university to be shared to the Fab Lab network later.

# 3.1 Master's programmeme in study guide for computer science at the University of N.

In the University of Oulu's ITEE faculty, the fourth academic year entails courses totalling 60 ECTS (European Credit Transfer and Accumulation System; 1 ECTS is approximately equivalent to 27 hours of effective work) credits in 2024. The fifth academic year is divided into two parts. The first part consists of regular courses, and complementary and supplementary studies, as well as 5 ECTS credits of practical internship in the field of student's major studies. The 5 ECTS credits could be gained for two months of training and report submission. The first part is worth of 30 ECTS credits. The second part involves completing the master's thesis for 30 ECTS credits.

#### 3.2 Building a master's programmeme on findings of the Fab Thesis pilot

For a bottom-up model, we suggest aligning the first part of the academic year with five or six subdivided diary-style project documents for the Fab Thesis. Each document would receive accreditation for approximately 5 points. Accreditation can also be extended to the landing page and internship in the Fab Lab. The Fab Academany Thesis paper would be extended to master's thesis.

If the programme adopted the top-down approach, resembling a master's programmeme, then it would be crucial to initially have Fab Academy or 5 university courses, which are equivalent to Fab Academy. This would enable students to fully utilize the capabilities and resources of a Fab Lab as a learning environment, amounting to 25 ECTS credits. Next, students would have the option to choose two modules from a range of established courses offered by the university from fields such as computer science, information technology, or environmental subjects. Each module would contribute 25 ECTS credits towards the programme. The field of computer science encompasses design and creativity. A special course designed to teach students on Super Fab Lab processes (Fab Labs capable of making Fab Labs), along with a seminar series covering a range of topics would be developed, each contributing 5 ECTS credits. Subjects for the seminar series would be Super Fab Labs, Fab City (a network of cities empowering their inhabitants to circular economy via Fab Labs), sustainability, safety, value creation (Merriam-Webster, value added: "of, relating to, or being a product, whose value has been increased

especially by special manufacturing, marketing, or processing "), and impact. Internship would provide 5 ECTS credits. Master's thesis would be 30 ECTS credits. Areas to investigate in master's thesis would include a product developed beyond the proof of concept, enhancing its functionalities through Super Fab Lab processes, and considering frugal approaches to production.

#### **4** RESULTS, DISCUSSION, AND IMPLICATIONS

In this paper, we acknowledge the similarities between the status of the pilot's programme and the potential for the academic accreditation at the University of Oulu. [17]. From our empirical observations of the Fab Thesis pilot two findings emerged. Firstly, while effective hardware acceleration and product-to-market process would benefit from expertise in design, engineering, and marketing, mastering all these areas or even maintaining interest in all of them was not easily achievable for an individual. While boundaries between subjects overlap and engineering shares similarities with design processes, students faced difficulty in mastering subjects outside their personal backgrounds. [18], [19] Secondly, the students who completed the course were in countries, where it is not customary for students to pay the necessary fees for the business model to be viable. In Finland, education is free, while in Peru and Ecuador, the cost of Fab thesis at a large scale exceeds the standard of living.

Several design educations have taken advantage of Fab Labs [20], [21]. Mosted-Van Der Sar & al. utilized a specific course developed to be executed within Fab Labs to explore design education in such an environment. [9] They acknowledged the shift in skill sets and design practices required after the third industrial revolution. Similar to our pilot, they noted that students were empowered in rapid prototyping and participatory design. Moreover, aligned with our findings, they observed their Fab Lab transforming into an interface to the city, thereby impacting their environment using educational elements. Also, in their course, the students' backgrounds determined whether they found certain subjects irrelevant or complex. These observations resulted in alternations to the course. Informed by our empirical experience and research findings, we refined our educational framework. While the bottom-up approach to integrate the Fab Thesis into the formal education would preserve the characteristics of the Fab Thesis, it was too different to local educational norms to gain local acceptance and lacked financial sustainability.

During the development and execution of this programme, the primary focus was on addressing the needs of the Fab Lab network. Due to the distinct business model and Fab City Oulu initiative, which aims to attract digital fabricators to study at the university, there is a need and opportunity to establish a local master's programme. The suitable components of this programme could be shared with the Fab Lab network through a top-down approach. We consider this a more feasible approach to link Fab Thesis with a master's programme. The method for documentation resembles the one used in Fab Academy. In addition, the processes utilized are often derived from Fab Academy. It will connect novel educational processes crafted for digital fabrication into academic setting. Our proposed framework will enable the recognition of the content and the learning goals of Fab Thesis to align closely with master's degree studies according to the Bologna process [22]. The framework will serve to bridge the cutting-edge research in the new field to both local and global economy and environment. The framework presented in this paper is expected to lead to a new degree programme focusing on emerging digital fabrication techniques.

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## DESIGNING FOR UNSEEN USERS: ENHANCING NON-EXPERT RESCUERS' EMOTIONAL EXPERIENCE IN CARDIAC ARREST EMERGENCIES

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#### ABSTRACT

Global ageing is leading to an increase in cardiac arrest incidents among senior citizens, posing a significant societal challenge. Most out-of-hospital cardiac arrest (OHCA) incidents occur at home, limiting patients' immediate access to professional help and Automated External Defibrillators (AEDs). In such instances, Cardiopulmonary Resuscitation (CPR) by caregivers, often the patient's family with no expert knowledge of emergency care, becomes crucial. Compared to professional rescuers, caregivers could face challenges in executing effective CPR due to skill gaps and emotional barriers in performing such procedures on family members. This study investigates the emotional experience of caregivers in cardiac arrest scenarios, a critical but often overlooked aspect in the design of emergency care devices. We aim to understand 1) how emotions affect caregivers' performance and experience during domestic cardiac arrest incidents, and 2) how design can support their practical and emotional needs, enhancing their performance. Semi-structured interviews with professional rescuers and non-expert caregivers reveal the emotional challenges that caregivers might confront before, during, and after cardiac arrest incidents, such as fear of approaching a collapsed person, anxiety about causing harm, lack of confidence, and moral pressure from social ties. These challenges can lead to adverse reactions that further hinder their CPR performance. The study highlights the importance of including emotional support for non-expert rescuers in OHCA incidents. By incorporating human-centred design principles, we propose an inclusive design guideline for emergency care devices and practical design strategies to mitigate emotional barriers and assist operational performance for non-expert rescuers.

*Keywords: User emotions, inclusive design, emergency equipment, human-centred design, human performance* 

#### **1** INTRODUCTION

The global rise in ageing has led to an increased incidence of out-of-hospital cardiac arrest (OHCA) among the elderly, primarily due to the higher prevalence of cardiovascular diseases in this demographic [1]. Notably, 85% of these emergencies occur at home [2], where immediate access to professional medical support and essential life-saving devices, such as Automated External Defibrillators (AEDs), are often limited. In these critical scenarios, the ability of caregivers and family members to perform cardiopulmonary resuscitation (CPR) becomes crucial [3]. However, the effectiveness of such interventions is frequently compromised by the caregivers' lack of formal training and the overwhelming emotional pressures faced in these emergencies. Addressing these gaps is essential for the design of home-use emergency care devices.

We explored the emotional and practical challenges non-expert users of emergency care devices might face during OHCA incidents at home. Semi-structured interviews with cardiac emergency professionals and non-expert caregivers of the elderly provided an in-depth understanding of these dynamics. The findings reveal discrepancies between the ideal responses in cardiac emergencies and caregivers' perceptions and experiences, primarily influenced by their emotional states and lack of professional training. Results highlight the importance of integrating emotional support with practical functionality in the design of such devices, aiming to empower the 'unseen' users during emergencies. Drawing on human-centred design principles, we propose an inclusive design guideline for home-use emergency care devices that focuses on emotional support and intuitive design for non-expert users, enhancing their performance and overall experience in such high-stress situations.

#### 2 HUMAN-CENTRED EMERGENCY CARE DEVICE DESIGN

Design can drive societal change and promote equity by challenging conventional norms through integrative approaches, utilising diverse perspectives to foster thoughtful design that enhances inclusion [4]. Human-centred design (HCD) is a methodology focused on developing interactive systems that prioritise the user's needs by leveraging human factors (e.g., attention, emotions, memory, and physical capabilities) and usability principles to enhance the human experience. The stakeholders of such interactive systems are individuals or organisations invested in the system's ability to meet their needs and expectations [5]. Particularly in the design of home-use emergency care devices, the patient is often highlighted as the primary stakeholder. Applying HCD principles, we acknowledge the significant role emergency care devices play for both patients and rescuers, especially non-expert rescuers. As shown in Figure 1, we also identify the non-expert rescuers as another crucial yet often overlooked stakeholder, stressing the importance of considering their experience and challenges in the design of emergency care devices.



Figure 1. Human-centred emergency care device design for OHCA incidents

Specifically, in the context of OHCA incidents, non-experts may experience overwhelming stress, fear, and confusion, which can impede their ability to effectively use emergency care devices. This issue is particularly pronounced in home settings, where the rescuers are often the patient's family members or caregivers. The emotional bonds in these situations can further complicate the social dynamics involved. This study seeks to explore the experiences and challenges faced by non-expert rescuers in home OHCA incidents, with the goal of guiding the design of more inclusive emergency care devices and systems.

#### **3 CHALLENGES FOR NON-EXPERT RESCUERS**

This section discusses the skill-related and emotion-related challenges caregivers of patients might encounter during OHCA incidents in home settings, where CPR execution by non-expert rescuers is required. Considering this group of 'unseen' users highlights the necessity of human-centred design for emergency care devices.

#### 3.1 Skill-related challenges

In OHCA incidents, it is recommended that non-expert rescuers perform the early stages of "The Chain of Survival", which includes calling for professional rescue, performing high-quality CPR promptly, and rapid defibrillation [6]. Among these stages, high-quality CPR is identified as the crucial early rescue operation that poses a skill-related challenge to non-expert rescuers. Studies suggest that highquality CPR necessitates rescuers perform continuous chest compressions, maintain a stable chest compression rate with correct hand placement, achieve appropriate depth for chest compressions, and require minimal training [7]. For non-expert rescuers to perform high-quality CPR, the skill barrier could include lack of formal training, skill retention, common mistakes in operation, and the discrepancy between training and real emergency incidents. For example, common mistakes in CPR execution include failing to maintain an open airway for the patient and improper responses to the patient's physical feedback. Research also suggests that CPR skills can deteriorate within 3-6 months without ongoing practice or review [8]. Compared to training, real-life emergencies often present more complex challenges than those simulated during training. These include overlooking or misinterpreting physical signs from the patient, experiencing differences in the tactile sensation of performing compressions on a human versus a manikin and facing added environmental distractions. Identifying specific conditions, such as agonal gasps or assessing the patient's condition based on skin colour and breathing, can be particularly challenging in stressful and complex situations [9].

Several factors contribute to the skill-related barriers: the cost of CPR training can be prohibitive; training opportunities may be limited in certain communities; and some caregivers may feel physically incapable of performing CPR or may not prioritise CPR training due to perceived irrelevance [10].

#### 3.2 Emotion-related challenges

Besides CPR skills training, research also indicates that non-expert rescuers require psychological preparation to cope with emergencies, such as envisioning possible emotional reactions during the procedure [11]. This subsection maps the user journey of non-expert rescuers to explore potential emotional-related challenges they encounter at various stages of delivering CPR to their family members, namely the indication, performance, and post-rescue stages.

- Indication Stage: Studies suggest that the fear of encountering a collapsed person, a lack of confidence in rescue skills, and apprehension about causing further injury to the patient are identified as potential emotional challenges at this stage. These factors contribute to the reluctance of non-expert rescuers to perform CPR in domestic OHCA incidents [12]. Without prior rescue experience, non-expert rescuers are required to process complex and unfamiliar information, leading to "cognitive paralysis" or the enactment of inappropriate actions due to their struggle to "generate new appropriate behaviours" [13]. Reactions such as "freezing", panic, and a refusal to intervene can emerge when confronted with a family patient, with these responses also likely persisting into the performance stage [14].
- Performance Stage: At this stage, emotions such as lack of confidence and fear of causing injury continue to affect non-expert rescuers, leaving them feeling aimless and helpless during the procedure. These feelings lead to conservative actions, often resulting in insufficient chest compression depth [14]. Additionally, decision-making while performing CPR on a family member can be compromised by emotional attachments and bonds, which may cloud the caregiver's objectivity and adversely affect their judgment regarding the patient's physical condition [15].
- Post-rescue Stage: Following the rescue of a domestic OHCA incident, non-expert rescuers, often family caregivers acting as first responders, may also experience post-traumatic stress disorder (PTSD). Engaging directly in CPR and confronting what appears as a chaotic and distressing situation can leave them grappling with trauma-related emotions, such as "fear and helplessness", long after the incident [16]. Non-expert rescuers might also think they could have significantly helped the patient but failed to achieve the desired outcome or performed inadequately during the rescue. In that case, they may be plagued by "shame, guilt, or embarrassment" [17].

#### 4 METHOD

We conducted semi-structured interviews with both medical professionals and caregivers for senior patients to further understand the emotional and skill-related challenges faced by non-expert rescuers when performing CPR during domestic OHCA incidents. Three professionals were interviewed to gain insights into these challenges, especially those related to skills. Professional participants (P1-P3) are seasoned professionals with more than 20 years of experience in medicine and have also served as CPR training instructors. Four non-expert caregivers (NP1-NP4) of senior patients in domestic settings were interviewed to examine their perceptions of performing CPR on their family members. NP1 and NP3 have phased caregiving experience, whereas NP2 and NP4 possess intensive caregiving experience.

#### 5 INTERVIEW RESULTS AND DISCUSSION

Interview results from both professionals and caregivers reveal a range of practical and emotional challenges that non-expert rescuers may encounter during early cardiac arrest rescue. This section summarises these key challenges, framing them as user needs that must be addressed in the design of domestic emergency care devices. Following this, the discussion turns to design recommendations for human-centred emergency care devices, based on these identified user needs.

#### 5.1 Challenges in performing high-quality CPR by non-expert

Professionals highlighted several key points to enhance the quality of early cardiac arrest rescue for nonexpert rescuers: quickly and accurately identifying cardiac arrest, immediately calling for professional assistance and enlisting the help of others nearby for co-rescue, relocating patients to an appropriate rescue environment, clearing the trachea, searching for AEDs if possible, and performing high-quality CPR in time. Professionals also suggested two main skill-related challenges for non-experts performing high-quality CPR: physical strain and technical errors. To be specific, CPR is a physically demanding task that, without proper technique (e.g., using body weight to assist compression), may not be manageable for one non-expert alone to sustain over the necessary duration (approximately 6 minutes) before professional help arrives. Non-experts may also be unable to recognise the decline in the quality of their CPR performance due to fatigue, underscoring the importance of real-time monitoring and corescue in OHCA incidents. Furthermore, high-quality CPR execution requires professional techniques such as specific hand placement, compression depth and rate. Professionals (P2, P3) noted that while "these skills can be quickly learned," it is not recommended for completely untrained individuals to attempt CPR alone. Moreover, professionals advised against non-experts considering the physiological factors of the patient (e.g., body composition) during compressions. According to professionals, effective CPR typically results in clear physical feedback from the patient, suggesting the importance of focusing on the technique rather than outer factors.



Figure 2. Emotional challenges faced by non-expert rescuers - reported by professionals

As summarised in Figure 2, professionals suggest that potential emotional challenges for non-experts in performing effective early rescue include a primal fear of interacting with and approaching the patient, loss of concentration due to anxiety, lack of confidence in CPR skills and knowledge, apprehension about causing further harm, and fear of facing criticism from the patient's relatives and friends. These factors can lead to an ineffective and overly cautious approach to the patient.

#### 5.2 Results from non-expert participants

Despite having a basic understanding of cardiac arrest, non-expert caregiver participants are alarmingly unprepared for OHCA incidents occurring in domestic settings, highlighting the importance of preparation for such events. Essential preparations for non-expert caregivers include knowing the locations of nearby AEDs, understanding how to summon professional rescue, and being aware of the estimated time until their arrival.

From a skill-related perspective, non-expert caregivers' knowledge of CPR and early rescue primarily derives from less formal platforms, such as television programs and social media video clips. The skills that non-expert caregiver participants claimed they had or would have difficulty mastering include identifying cardiac arrest, evaluating whether patients have other injuries, determining the correct hand placement for compressions, and managing the force and frequency of compressions.

Non-expert caregivers also acknowledged the emotional challenges they would face when dealing with OHCA incidents involving their family members. They were asked to imagine the cardiac arrest of the family member they were caring for and then discuss their concerns and emotions surrounding the entire process of such events.

At the indication stage, non-expert participants described feelings of anxiety and terror, which could affect their early rescue responses and subsequent performance. Participants explained that their concerns leading to such feelings include a lack of confidence in their rescue skills. Another factor affecting their responses at this stage is their reaction to emergencies, as NP1 commented, "In such a situation, it may become impossible for me to respond." Non-expert caregivers described their reactions to emergencies as "trembling" (NP1), "crying" (NP2), and "mentally blank" (NP4). Echoing professionals' comments, fear of the collapsed family member and the potential for causing further harm could impact non-expert rescuers' responses at this stage. As some participants remarked, "He is family, and I am afraid it would cause more damage" (NP1) and "I have only performed (CPR) on mannequins...for a real person, I would be scared" (NP2).

Non-expert caregivers suggest that fear and lack of confidence would persist into the rescue performance stage. Alongside the fear of causing further harm to the patient, they anticipated experiencing performance anxiety and self-doubt during CPR execution. For example, NP2 said, "And then every time I press... if you don't press properly...his (the patient's) ribs are easily crushed, aren't they?" Non-expert participants also stated that such negative emotions during the operation could intensify if they did not receive positive validation or feedback.

Participants indicated that they would experience traumatic stress if the rescue outcome was unfavourable. They would tend to blame their own performance, believing they could have done a better job during the rescue. This could result in self-doubt and self-condemning emotions such as regret and guilt. As NP4 expressed, "If I had studied CPR a little more correctly, I might have been able to save him... I may blame myself." Participants also mentioned that they could face criticism from other family members if they were involved in the early rescue and the outcome was not ideal. In such a situation, some participants thought they would face the criticism and accept it; others said they would need professional support.

#### **OHCA** Incident Rescue



Figure 3. Self-reported emotional challenges faced by non-expert rescuers

In summary, self-reported emotional challenges from the non-expert rescuers in domestic OHCA incidents align with those reported by the professional participants, with a few nuanced emotions shown in Figure 3. These challenges could significantly affect the non-expert rescuers' experience, performance, and mental wellbeing during as well as after the incidents. Hence, the design of domestic emergency care devices should consider supporting them accordingly.

#### 5.3 Discussion: Human-centred design recommendations

At the indication stage, primary emotional barriers for non-expert rescuers in OHCA incidents include fear, lack of confidence, and stress due to information overload, leading to suboptimal responses. Adopting human-centred design approaches, such as creating personalised emergency plans that consider the patient's condition and information on rescue services and facilities, can enhance rescuers' confidence, and reduce stress by minimising the need for additional information processing during emergencies. Furthermore, providing clear guidance and support and opportunities for mental rehearsal and practical exercises can improve non-expert rescuers' emotional and practical readiness.

Throughout the performance stage, non-expert rescuers contend with obstacles, including apprehension, self-doubt, and the challenge of focusing during physically intensive rescues. Regular reviews of skills can elevate their confidence and ensure skill mastery. Alongside encouragement and clear instructions on actions, real-time feedback on the patient's condition or rescuer actions allows for quick adjustment of techniques, thus avoiding undue distraction by patient monitoring. Collaborative CPR is also recommended to mitigate this strain. Using technological aids that promote team rescue efforts and provide positive reinforcement for proper CPR techniques can reduce self-doubt and lessen emotional repercussions during the rescue.

After the rescue, mitigating self-regret or external criticism can be achieved by providing validation and emotional support. In other words, offering comprehensive reviews and recognition of the rescuer's efforts in the design of emergency care devices plays a critical role, reinforcing the importance of their contributions and confirming the efficacy of their actions.

#### **6** CONCLUSIONS

This study harnesses human-centred design principles to cater to the overlooked emotional demands of non-expert rescuers in situations of out-of-hospital cardiac arrest (OHCA), specifically targeting caregivers of senior patients in domestic cardiac arrest contexts. By breaking down the rescue endeavour into three stages—identification, performance, and post-rescue—this research highlights significant barriers related to skills and emotions. In response to these challenges, it introduces targeted human-centred design interventions: personalised rescue plan, combined emotional and skill rehearsals, unambiguous guidance coupled with encouragement, instantaneous feedback during CPR procedures, and post-rescue emotional reinforcement along with validation of performance. Future works will focus on implementing and evaluating the design strategies through the design and testing of a home-based CPR assistance device.

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# A TRANSDISCIPLINARY STEAM X D WORKSHOP ON AI RESCUE ROBOTICS FOR PRE-UNIVERSITY STUDENTS

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#### ABSTRACT

We apply the STEAMxD (STEAM = Science, Technology, Engineering, Arts and Mathematics, and D = Design Thinking) transdisciplinary framework to a different set of disciplines (i.e. Humanities, Artificial Intelligence (A.I.) and engineering), in a 5-day workshop which was carried out for a total of 95 participating high school students (16-18 years old) with the intention to validate our transdisciplinary training approach by applying a STEAMxD framework [1]. The students worked in teams of 5 students along 9 faculty instructors from different disciplines, and 10 undergraduate helpers, to solve a design challenge using a systems approach complemented with human-centric, design thinking, and A.I. elements. In general, survey feedback showed high levels of student engagement, awareness of using A.I., engineering, and design thinking to address real-life problems. Overall, the students found the workshop useful and insightful, validating the STEAMxD framework as an approach using design thinking to bridge the social-ethical context of real-world problems to engineering and technological solutions through transdisciplinary design and a systems approach. Specifically, we were able to construct a socio-ethical context for robotics through a human-machine interaction scenario and A.I. image recognition training that was showcased through a design competition comprised of a storyboard pitch and an AI-equipped rescue robot challenge. This work will benefit those interested in transdisciplinary education, engineering design education, and those interested in forming strong faculty teams from different disciplines to work together into meaningful and impactful projects that prepare students in transdisciplinary design.

*Keywords: STEAM, STEAMxD, design education, transdisciplinary education, human-centric, artificial intelligence* 

#### **1 WORKSHOP BACKGROUND**

Since we had developed a transdisciplinary design training workshop successfully for pre-university students in areas of *Medical Supplies* and *Drones*, we set forth to determine if the *STEAMxD* framework can be also applied to the topics of *Artificial Intelligence* and *Rescue Robotics*. As a result, a *STEAMxD* workshop (STEAM = Science, Technology, Engineering, Arts, and Mathematics, with D = Design Thinking) was organized as a designette [2-3], wherein students employed a design systems approach, incorporating a human-centric context, A.I. (STEM), and design thinking [2]. The narrative for the workshop, emphasizing the ethical aspect of the design challenge, was created with the help of social science. The A.I. component facilitated the transfer of skills through a series of workshop sessions, enabling participants to prototype suitable solutions. Design thinking, crucially, provided tools and methods to drive potential solutions and bridged the other two components, guiding the workshop towards a collaborative outcome [2-8], see Fig. 1 (left).

#### 2 WORKSHOP METHODOLOGY

The use of design thinking methodologies has been receiving significant attention in education as a powerful framework for fostering creativity, collaboration, and problem-solving skills among students [9]. Design thinking helps students develop a deep understanding of complex problems and generate innovative solutions and is particularly valuable in education as it prepares students to tackle real-world

challenges, adapt to change, and think critically and creatively across disciplines. Unlike traditional problem-solving, which follows a linear and structured approach, design thinking revolves around a human-centric innovation process, leading to enhanced solutions.



Figure 1. STEAMxD lies at the interface of the human-centric context, Artificial Intelligence (Science & Technology), and design thinking (left). Daily programme timetable (right)

The workshop is created in a socio-ethical context, driven by Design Thinking, and implemented through STEM. This concept aligns well with transdisciplinary education as design thinking can integrate arts, sciences, technology, engineering into a larger whole from its components, enhancing learning outcomes in these fields [10]. It has been argued that the engagement of STEM to youth should be before university [11]. Thus, a pre-university (16-18 years ago) collaborative *STEAMxD* workshop was formulated and conducted in January 2023 and January 2024 for a total of 95 students. As shown in Fig. 1 (right), each day was separated into 2 sessions (AM and PM) wherein the students were introduced to a design brief titled "Rescue Operation at a Disaster Area Using Robots Equipped with A.I. Image Recognition Technology" and to a *workshop scenario* where they seized the role of SUTD entrepreneurs (TECH NGO) undergoing a series of training sessions to rapidly acquire competencies needed to deploy search-and-rescue teams at a disaster site. Finally, students received information on the workshop deliverables for day 5: (1) A.I. Rescue Operation challenge with its metrics, and (2) a storyboard 3-min pitch with its rubrics.

#### **3 WORKSHOP PROGRAMME**

#### 3.1 Day 1 AM Session 1: Socio-ethical context

The deployment of rescue robots, especially during an emergency, requires ethical deliberations. Ethical decisions to be made before the deployment of rescue robots are who to prioritize and who or what to deprioritize, and in a multi-site disaster setting, which site to focus on first and which site to focus on later. Different choices or strategies of rescue entail different risks to the victims and the robot and accompanying human rescuers. The stakes are real. In this session, students tackled a thought experiment, titled: 'The Prioritization Problem', which mirrors the design brief. The primary aim of this thought experiment is to prime the students for more advanced ethical reasoning during the A.I. rescue operation challenge in day 5, such that they can 'transfer' the learning from this ethics session to inform their subsequent deliberations. In this thought experiment, a landslide has occurred and there are multiple casualties, which are unevenly distributed across the disaster zone, each characterized by a different risk profile. In the thought experiment, the first responder is an autonomous rescue robot that has been programmed to make hard choices on site: should the robot focus on the four kids huddled around an unconscious adult potentially hazardous boulder and fallen trees, or seek to map out the main site of the landslide, which is likely to have trapped many more people? Should the robot abide by the rule of helping the most vulnerable, the riskiest, or the most likely number of victims near the main site of the landslide? Importantly, every movement the rescue robot makes across the disaster area renders the site even more unstable, and recommending an optimal course to help different groups of victims is paramount. Students are then asked to justify why they have selected certain courses for the robot. In rendering their ethical deliberation explicit, students are then primed to undertake a similar line of reasoning throughout the duration of the workshop.

#### 3.2 Day 1 PM Session 2: Design Thinking Methods and Tools

After introducing the students to ethical considerations, students were introduced to the *Double Diamond Design Thinking Framework* [12]. Afterwards, students were guided to complete 3 activities in the remaining 2 hours. In activity 1, each team was tasked to create 2 to 3 victim *personas* in a

disaster area described in the design brief. In activity 2, each team was to choose one of the *personas* and generate a *problem scenario* and a corresponding *activity scenario*. A *problem scenario* is a narrative of current practice and user experience while an *activity scenario* describes how the *problem scenario* can be transformed with the use of social robotics technology. Each team went on to develop the *information scenario* and corresponding *interaction scenario*. The "Scenario-Based Design for Human-Robot Interaction" was developed by Y. Wang, inspired by the Scenario-Based Design framework proposed by John M. Carroll and Mary B. Rosson for Human-Computer Interaction projects [13]. This activity allowed students to evaluate user needs and to generate useful functions and properties to be designed for the A.I. robot for the rescue mission. In activity 3, each team was given the freedom to build a low-fi prototype using Lego bricks, Playdoh, and craft materials such as pipe cleaners, ice cream sticks, aluminium foil and craft eyes, see Fig. 2 (left, middle). Low-fi prototyping permitted for students to easily take apart their prototype, reiterate the design thinking process and iterate when needed. At the end of activity 3, students were presented with several examples of storyboarding and were given time to draft their own storyboard to prepare for the storyboard pitch on Day 5.



Figure 2. Students ideating (left), prototyping (middle), and camera links (right)

#### 3.3 Day 2 AM Session 3 and PM Session 4: Computer-Aided Design (CAD) for Additive Manufacturing (Space-age Fabrication Technologies)

In this session, we introduced students to computer-aided design (CAD) and 3D printing as tools at the Develop phase of Double Diamand Design Thinking framework. Students were presented with the challenge to fabricate a structural arm to mount the camera onto the robot. To accomplish this task, students were required to create drawings and 3D print two camera connectors (Link 1 and Link 2) of different lengths as shown in Fig. 2 (right). We leveraged this opportunity in the morning session to introduce Fusion360, a CAD software to create 3D sketches of the connectors. Students experienced a typical workflow of modelling in Fusion360 and learned a variety of basic functions, such as creating sketches on different planes, extrude, evolve, mirror symmetry, constraints, and fillet. We also emphasized parametric modelling as it provided flexibility for design modification and subsequent improvements. Subsequently, students employed PrusaSlicer, a slicer software to convert a .stl format 3D file to a g-code file for 3D printing in the afternoon session wherein students made use of Prusa i3 MK3S and MK3S+ 3D Printers in our own Dyson-SUTD Innovation Studio to print the camera arms. We also arranged a lab tour to the SUTD Fabrication Lab and the SUTD Digital Manufacturing and Design (DManD) Centre to broaden students' horizons on various cutting edge additive manufacturing technologies that open up numerous possibilities of 3D printing in industry and research, for various applications, manufacturing processes and fast prototyping.

#### 3.4 Day 3 AM Session 5: Robot Assembly and Driving

The Makeblock *mBot Ranger* model was used for the A.I. design challenge. The *mBot Ranger* comes with treads for locomotion, with separate light, sound, and ultrasonic sensors, attached to a modular mainboard which is compatible with Arduino and Raspberry Pi packages [14]. The components are mounted to a configurable aluminium alloy frame to form a moving robot. Students assembled the robot in its tracked configuration while a customized 3D printed arm was then attached to the robot using a specialized attachment plate. The other end of the 3D printed arm was then connected to the Logitech C310 camera that would be used as the visual implement for object detection in the design challenge.

#### 3.5 Day 3 PM Session 6: Introduction to A.I. Principles

In this session, we set up a software pipeline that is not only powerful but also cost-effective. This included YOLOv5 [15], an advanced computer vision model that the students learned to train, fine-tune, and execute an object detection model.

At its core is a convolutional neural network. The students learned to train this model using a Jupyter Notebook with a Python script that was easy to tweak. The script utilized the complimentary storage capabilities of Google Drive to keep their materials and work safe while the training was performed online using the Google Colab [16] environment, an online service that let us use a virtual computer to execute our script. For the crucial step of image labelling, we used the Roboflow [17] online platform, a user-friendly website for image annotation. The labelled images were then exported from Roboflow and uploaded to Google Colab. Once they had the trained weights, they uploaded the weights onto a Raspberry Pi via MS Remote Desktop, hence allowing our students to perform model inference using the robot's camera remotely. This software pipeline effectively demonstrated the end-to-end process of developing an AI model to students, see Fig. 3 (left) for the overall process. We provided figurines for students to take pictures or videos (see Step 1), then these pictures are loaded into Roboflow, which we leveraged to annotate the taken pictures; see Step 2. A key challenge is the exact, consistent, and comprehensive labelling of objects using tight boxes. Overall, we instructed and guided the students to aim for a large and diverse data set to achieve the best results in model training. Steps 3 to 5 represent the actual training and evaluation performed in the Google Colab environment. In the augmentation, the students can apply general transformations to the dataset. For example, if the resolution differs between the camera on the robot and the camera used to collect the training data, the students can adjust to this before starting the model training process. The first AI session aimed to produce a baseline model and provide the students with the tools and techniques to optimize it further.



Figure 3. A.I. training workflow (left) and an A.I detection illustration (right)

#### 3.6 Day 4 AM Session 7: A.I. Image Recognition Training

This session introduced the *model deployment and inference*. The robot was equipped with a Raspberry Pi, which via remote access from their laptops, the students could copy the machine learning model (i.e., only its parameters) to the Raspberry Pi and place it in the already prepared folder structure. A ready-to-use Python script allows the students to take pictures with the onboard camera and observe how the model automatically annotates the objects in the picture, see Fig. 3 (right). After evaluating their first model, the students must identify deficiencies of their model by testing it on several scenarios. For example, they might observe that an object is undetected or misclassified. Therefore, it was essential to extend the training dataset. For instance, their initial data needed to be more representative of a particular class of interest, or they needed to take pictures from additional angles under different lighting conditions. This experience not only solidified their theoretical knowledge but also provided a foundation for critical thinking and problem-solving skills in A.I. applications.

#### 3.7 Day 4 PM Session 8 and Day 5 AM Session 9: Self-Immersion Design

In these sessions, students had the flexibility to organize their time and efforts according to their priorities and needs, such as CAD printing, A.I. object recognition training and optimization, robot piloting and camera feed.

#### 3.8 Day 5 PM Session 10: A.I. Rescue Robot and Storyboard Pitch Challenges

The A.I. rescue robot challenge required all teams to integrate and combine all of the competencies learnt throughout the workshop. The challenge scenario consisted of a populated area hit by a landslide wherein students undertook the role of rescue robot operators to overcome the complicated terrain displaying potential risks to human rescuers [18, 19]. The modified Makeblock robots were piloted by the students to navigate through the terrain using both direct sight and the camera feed. Teams detected a set of figurines placed within the arena and scored points based on number of accurate and successful detection of selected objects, and whether they could complete their journey through the arena within the allocated time. The arena was split into two terrain zones, the outdoor disaster zone at a populated urban area, and an indoor disaster zone set within a hospital site context. At specific locations, the robots,

piloted by the student teams, had to choose their paths based on ethical considerations, such as choosing to save a VIP vs a larger group of injured civilians. The teams would score points based on the quantity of objects detected with their trained object detection model, and whether they fall into the correct object class categories, human (5 pts) or pet animals (3 pts). Points for obtaining bonus objectives were also awarded to teams. Furthermore, each student team were given 3 minutes to give a storyboard pitch to convince the judges that they had the best systems-approach solution to deploying A.I-equipped rescue robots to the disaster area. Each team was assessed based on their ethical sensitivity, geographic considerations, understanding of A.I., systems design, clarity of message, and their unique selling point (USP). There were 4 judges, each with a different background (academic and industry) and varied disciplines (Social science, Physics, and Engineering).

#### 4 WORKSHOP RESULTS

The student self-perception of the workshop is summarized in Fig 4 below.



Figure 4. Student feedback on usefulness of skills acquired (left), and usefulness of daily workshops in achieving the deliverables on day 5 (right)

All respondents (40 students) agreed that the day 5 design challenge competition allowed them to experience, learn, and apply human-centric design, technology, and engineering to solve real-world issues. 90% of the respondents declared that they are more likely to consider undergraduate studies in engineering or technological design (not shown), and the activity students enjoyed the most were *Hands-on learning, Teamwork* and the *Socio-ethical context* discussion of the workshop (not shown). All skills imparted were found to be valuable, especially the CAD 3D printing prototyping session on day 2 and the A.I. training on days 3 and 4. In addition, 70% of the respondents found the pace and depth of the workshop "just right." Finally, 68% of respondents at the end of the workshop recollected the theme of ethics, and when combined with the two key words repeated the most, *ethics* and *decision*, it implies that students did not see the topic of robotics in isolation, but rather as an intricate design component within a larger system – as a transdisciplinary design exercise.

#### 5 WORKSHOP DISCUSSION AND SUMMARY

Taken together, and after 2 consecutive years, we believe that this unique 5-day collaborative workshop programme offers a unique opportunity to equip students with 21<sup>st</sup> century competencies required to practice, within a university setting, transdisciplinary design, wherein students are expected to problemsolve in contextual settings beyond the classroom. The *storyboard challenge* with its rubrics to allow students to showcase their systems understanding of the problem and potential solutions, and the *design challenge* with its metrics to allow students to display their technical skills, proved to be an integrated, intricate, and strong component of the workshop. In summary, this *A.I. Rescue Robotics* workshop validated via positive student self-perception feedback our transdisciplinary design training approach, which was previously used successfully to another workshop based on *Medical Supplies* and *Drones* [1], by applying the *STEAMxD* framework of bringing faculty from different disciplines (Humanities, Design, Physics, Engineering, A.I.) to work together to create an integrated designette (product) that is larger than its comprising units. Finally, this work provides valuable insights on how transdisciplinary design education can be delivered within the classroom using social science/humanities, technology, engineering, and design thinking for solving real-world problems.

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## POTENTIAL OF THE VISION MODEL WITH REGARD TO THE SUSTAINABILITY ORIENTATION OF A DEVELOPMENT PROJECT

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#### ABSTRACT

During product development (PD), the vision model method is used as a guide to ensure that development is progressing in the desired direction and that the results meet the original goals and expectations. Among other things, the method can also be used to collect feedback from stakeholders and, if necessary, to adapt visions and goals that are recorded and visualised in the vision model accordingly.

In addition, the literature suggests methods and tools for the strategic alignment of the project with sustainability aspects at the start of development projects. The Ten Golden Rules and the design-for-sustainability strategies are important guidelines for a development project in pd. The Ten Golden Rules represent a method for improving product quality and performance, while the design-for-sustainability strategies aim to minimise the environmental impact of products by means of guidelines. Both methods help to focus on the product life cycle and the impact of a product in it. In order to apply these guidelines in practice, they should be integrated into the development process from the outset.

This can be done by training developers and through targeted use in alignment meetings. This can be useful to ensure that the guidelines are adhered to throughout the development process.

Both alignment methods and the vision model are sometimes used independently or either one or the other. This article presents a concept for the active inclusion of sustainability requirements for a product in the vision model. The focus here is on the clear visualisation of the goals to be achieved for the long-term orientation of development towards sustainability.

Keywords: Sustainability, target visualisation, product development

#### **1** INTRODUCTION

During the PD phase, the vision model method serves as a critical navigational tool, ensuring that the development process is moving in the intended direction and is not only a guide but also a means to gather feedback. In addition to the vision model method, literature recommends various strategies and tools for the strategic alignment of projects with sustainability aspects at the inception of development projects. Among these are the Ten Golden Rules [1] and the design-for-sustainability strategies [1], [2] both of which provide valuable guidelines for a development project in PD. The integration of sustainability goals into the vision model will be used in the teaching of sustainability aspects in practical projects and will have a supportive effect in order to fulfil the development goals as well as to promote the resulting dissemination of knowledge in the economy. This will have a long-term effect on society by raising awareness and specialisation. For example, this can help to ensure that sustainability is an integral part of product design and PD and not just an afterthought. This can also help to improve the company's long-term competitiveness by ensuring that its products meet changing customer needs and regulatory requirements.

#### **2** THEORETICAL FOUNDATIONS

This chapter gives an overview over the theoretical foundations of the vision model and The Ten Golden Rules as well as their potentials for improvement through a combination of the two methods.

#### 2.1 The Vision Model

The vision model (VM) is used to show the end goal of a project development project in a concise and easy to understand manner [3]. In contrast to functional specifications documents [4], [5] and requirement lists [6] the vision model centres around finding the balance between clarity and granularity. The vision model describes goals and results of a project as well as the necessary steps to reach them.

It's a tool that helps defining as well as communicating goals and expectations of all stakeholders, making it an essential part of project management and product development.

The vision model is usually presented as an illustration or at least some sort of text visualisation and transports information about the general mission, underlying goals, target audience, environment and technology needed for the project or product. Figure 1 depicts an example of a vision model for a mechanical lemon press, with a general vision describing the overall goal (drinking juice straight from the fruit), fundamental goals underlying the overall vision (producing pressed juice fast and easily with a mechanical press) and detailed instrumental goals that describe the actual steps that need to be taken to develop such a product.

The VM can also visualise assumptions and restrictions that are relevant to the product or project, as well as measures to reach the vision. This enables the team to keep an overview over their shared goals throughout the whole project.

The overall goal or vision needs to be open to an array of different results or solutions and work as a motivator for the team. It does not have to be technically reachable, but rather convey a slogan or mantra. It is important for companies or teams to be able to identify with the overall goal, so everyone can stand behind the idea and work towards a common goal [3].

The fundamental goal specifies the concrete job the team has to achieve within one short sentence, while the detailed instrumental goals can be used as a collection of the most important characteristics of the project or product. The detailed goals are ideally grouped under themes like function, design or comfort (or any other group that was deemed relevant to each use case) and consist of three to four points at most.

VISION Ideal conception / Overriding objective	from the fruit directly into the glass			
FUNDAMENTAL OBJECTIVE Concrete realisation of the vision	quick and easy processing of oranges into 100% fruit juice in a mechanical orange squeezer			
	Function	Design/Gestalt	Use	
INSTRUMENTAL OBJECTIVES Detailed objectives of the vision	<ul> <li>Gain of 60-70% juice per fruit</li> <li>Maintenance-free</li> <li>Mechanical juice extraction with minimum effort</li> </ul>	Compliance with the company Cl Self-explanatory Prevention of operating errors	<ul> <li>Ergonomic use of the press</li> <li>Max. 3 handles to release the machine</li> <li>Dishwasher safe</li> </ul>	

Figure 1. Example of a Vision Model [3]

The point of the VM is not to give a comprehensive overview like a requirement list but rather a focused visualisation of an overall goal. The detailed goals can never list everything that is relevant and serves a different purpose than a requirement list – which can still be useful in addition depending on the project or product [3].

#### Potentials

While the vision model is a great tool to visualise overall goals that are easy to communicate, there still is some untapped potential to support its use.

- Prioritisation: One challenge is the prioritisation of goals in order to build such a concise overview without becoming too vague. The VM can never be as detailed as a requirement list and therefore should not be used instead of one but in addition to. It is impossible to fit all relevant points into the VM, but only the most important.
- Adaptability: The VM as it is designed currently can be used completely independently, no bias or direction is added into the concept. It can be used to frame a product development project and as a strong communication tool it can be adapted to help teams focus on sustainability in addition to

other relevant aspects.

• Fit for sustainability: By expanding the VM by aspects of sustainability, it can be used to further promote the sustainability of products and communicating with stakeholders. Thus, this contribution proposes an approach that specifically integrates the ten golden rules into the VM.

#### 2.2 The Ten Golden Rules

The Ten Golden Rules can be used to improve a product's sustainability [7] and help making a product longer lasting, efficient and environmentally friendly. It consists of ten rules or guidelines that can be adapted to each project according to its goals. As a result of its deliberate adaptability, the concept has been successfully applied in companies [1].

The "Ten Golden Rules" are structured according to the life cycle of a product. Each rule is assigned a picture that visualises the respective focus of the rule.

Example of the generic version:

- 1. Use of closed loops for necessary toxins or complete avoidance of toxins.
- 2. Minimising energy and resource consumption in the production phase and during transport through improved housekeeping.
- 3. Using structural features and high-quality materials to minimise product weight without compromising required flexibility, strength or other functional priorities.
- 4. Minimising energy and resource consumption in the use phase, especially for products with the most important aspects in this phase.
- 5. Promoting repairs, maintenance and upgrades, especially for system-dependent products (e.g. cell phones).
- 6. Promoting a long service life, especially for products with significant environmental aspects outside the use phase.
- 7. Investing in better materials, surface treatments or structural precautions to protect products from contamination, corrosion and wear and tear to ensure lower maintenance and longer life.
- 8. Provide for upgrade, repair and recycling through accessibility, labelling, modules, predetermined breaking points and manuals.
- 9. Promote upgrading, repair and recycling by using fewer, simple, recycled, non-mixed materials and no alloys.
- 10. Use as few fasteners as possible and use screws, adhesives, welded joints, snap-fits, geometric locks, etc. according to the life cycle scenario. [1]

The ten rules are kept general so that they can be adapted, concretised or further developed depending on the context. For example, rule 2 can help to ensure that a product is manufactured with fewer materials, which leads to a reduction in waste and environmental impact. Rule 6 can help ensure that a product lasts longer and therefore needs to be replaced less often, which in turn leads to a reduction in waste and environmental impact. Therefore, the Ten Golden Rules can be applied as part of a comprehensive approach to improving the sustainability of a product.

#### Potentials

- Adaptability: The rules could be further developed so that they can be applied flexibly to different contexts and rapidly changing environments. This would ensure that the rules remain relevant even in dynamic and agile working environments.
- Measurability: Establishing customised rules can help to evaluate the development and measure the progress of the implementation of sustainability.
- Collaboration and sharing of best practices: The experiences and insights related to the "Ten Golden Rules" serve to share and could lead to an improved understanding and cross-industry innovation of the sustainability of products.

#### 2.3 Possible adaptation of the vision model

Combining the vision model with the Ten Golden Rules can be a powerful tool for PD, helping to ensure that the final product meets the original goals and expectations while taking sustainability aspects into account.

One way to combine the vision model with the Ten Golden Rules is to use the rules as the basis for developing the vision model. For example, each rule can be seen as an important aspect to be implemented that must be harmonised in the vision model. By developing the vision model in this way, the Ten Golden Rules are reflected in the development task, and it can be ensured that product

development is built on a solid sustainable foundation based on best practices from the outset. Another way to combine the vision model with the Ten Golden Rules is to use the vision model as a framework for applying the rules in the PD process. For example, each rule can be seen as an important milestone to be achieved in the PD process and the vision model can be used to measure and monitor progress in achieving these milestones. By using the vision model in this way, it can be ensured that the Ten Golden Rules are not only applied in theory, but that they are actually put into PD practice.

Finally, the vision model could also be used to visualise and communicate the impact of the Ten Golden Rules on product development. For example, the rules can be presented as part of the vision model to show how they impact different aspects of product development, such as product quality, usability, environmental impact, etc. This can make the vision model a powerful communication tool to help all stakeholders develop a shared understanding of how PD efforts align with the organisation's goals and expectations. In addition, the D4S strategy approach can also be used here, where the rules are used to orientate the project at the beginning of a development task and the rules are used within a spider matrix during the course of development to evaluate the sustainability of the development.

#### **3 A SUSTAINABILITY VISION MODEL**

As both methods are used to align projects and represent an overarching guideline, this contribution proposes a combination of both methods to form the sustainability vision model – sVsion model – (sVM).

One possible approach suggested here is;

- 1. Identify the rules: Firstly, the Ten Golden Rules should be identified and understood. This involves carefully analysing the rules to ensure that they are fully understood and that their meaning and relevance to product development is clear.
- 2. Selection and adaptation: The rules are then adapted according to the development task or removed from the list so that any unsuitable rules no longer need to be considered.
  - a. It is also suggested that the rules be expanded to include the aspects of holistic utilisation;
    - i. Consideration of social and good working conditions in the pre-use phase.
    - ii. Promoting a collaborative, barrier-free and intergenerational solution; ensuring satisfactory functioning even after the use phase.
- 3. Integration of the rules into the vision model: Next, the rules should be integrated into the vision model. This involves considering each selected and customised rule as an important aspect of the vision model and ensuring that it is appropriately reflected in the model. For example, each rule could be represented as a separate element in the vision model or considered in combination with other elements of the model.
- 4. Development of the vision model: Once the rules have been integrated into the vision model, the model can be further developed to ensure that it covers all relevant aspects of product development. Other factors such as customer requirements, technical requirements, market trends, etc. can be considered.
- 5. Validation of the vision model: Finally, the vision model should be validated to ensure that it meets the requirements and expectations of the stakeholders. Feedback loops can be conducted with stakeholders to ensure that the model is accurate and meaningful and that it can serve as a basis for product development.
- 6. Development evaluation: The customised rules can also be used in the course of the project to evaluate and compare the development and/or product concepts. The rules can be visualised in a spider matrix and evaluated by the development team on the basis of a score. The evaluation thus represents a good visualisation of the status in order to communicate the results and to be able to make decisions in relation to the development task in a targeted manner.

By incorporating the Ten Golden Rules into the vision model as shown in Figure 2, it can be ensured that product development is built on a solid foundation based on proven procedures and practices. This supports product development to become more effective, efficient and successful and that the end product meets the original goals and expectations as well as the sustainability goals.



Figure 2: Example of an sVsion Model

The sVM provides predefined space for the respective Golden Rules that have been deemed most appropriate for each level of the model. By not forcing developers to use all ten rules, the implementation becomes more realistic for the actual development project, as not all rules may be applicable in a meaningful way and therefore delay the application rather than empower the team. The free space serves as an orientation for the inclusion of the sustainability aspects from the Ten Golden Rules in the development goals of the sVM. These can be reflected on during the first step of the proposed approach and successively categorised in the second to third step in the vision model. The objectives can be differentiated between very tangible instrumental objectives and almost unattainable visions and localised in the sVM. The Ten Golden Rules are woven into the sVM at all levels to have relevance in all phases of the PD project. The vision is guided by the rules as well as the fundamental and instrumental goals. The developer must decide which objectives apply to which level and where they have the greatest impact.

In the future, this approach will be used in case studies with students in order to test the sVM for suitability for use and ease of application and to be able to address any adaptation requirements that may arise. The focus of dissemination is increasingly on small and medium-sized companies (SME), as they often lack the capacity to apply more complex methods and are therefore dependent on methods that are easy to understand and apply [8], [9], [10], [11]. Among other things, this is a major hurdle for integrating methods with the focus on sustainability into SMEs approaches. Better communication of the results of a technique [12] thus represents a great potential for better integration of sustainability aspects into the product development (PD) of SMEs.

#### **4 SUMMARIES**

The Vision Model is used to show the end goal of a project development project in a concise and easy to understand manner [3], while the Ten Golden Rules are used to improve a product's sustainability [7] and help making a product longer lasting, efficient and environmentally friendly. By combining the two,

this contribution seeks to support the early phases of product development, when the potential to influence the sustainability of the product is highest.

Within this contribution, the Vision Model and The Ten Golden rules are transformed into the Sustainability Vision Model, a new approach to a more effective, efficient and successful product development that incorporates sustainability from the beginning. It helps to visualise the objectives of a product development and the sustainable objectives in one organised form. The combination of the strengths of the two methods is advantageous in view of the overarching social trend and also in the teaching of sustainable product development.

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# CHAT-GPT: A CLEVER SEARCH ENGINE OR A CREATIVE DESIGN ASSISTANT FOR STUDENTS AND INDUSTRY?

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#### ABSTRACT

The intelligent design assistant has been an enduring interest for design research and industry. ChatGPT is an AI chatbot released in 2022 providing text-based responses to user queries, generating content, able to converse and improve; this different to finding static content like a search engine. ChatGPT has created a landmark surge in popular interest in Generative Artificial Intelligence, and given its nonprescriptive nature, it is timely to take a snapshot of its use in industry and design education. This paper presents survey results from industry and from undergraduate product design students. 61-65% of both groups utilise ChatGPT for project work, sometimes daily, but most commonly a weekly basis, indicating growing utility in industry and education. Tasks most commonly begin with ChatGPT and refined by users. Industry respondents commonly check human work too. The most common application was research, with free text responses highlighting idea generation, and coding as more creative endeavours. Industry commonly use it for refinement of written communication, while students employ it for CV and letter drafting, even potentially design folio content (less likely). Higher numbers of respondents agree that ChatGPT could enhance work scope, quality, and creativity, with potential need for training in industry and in embedding in university education. Daily or weekly use of ChatGPT for research tasks reminiscent of what one respondent termed a "clever search engine," yet new applications are emerging. Universities have the opportunity to prepare graduates for evolving industry practices, and indeed to influence those practices.

Keywords: Chat-GPT, text-based AI, language-based AI

#### **1** INTRODUCTION

This paper reports on 2 complementary surveys on ChatGPT use. In August 2023 58% of industrial respondents (n=83) agreed ChatGPT should be integrated into university courses prompting a second product design engineering student focused survey. Within our industrial network snapshot, practicing engineers are not using ChatGPT to the systematic ends suggested by some (see Lausanne project described below). Early discussions with / observations of students have determined that some are using ChatGPT like industry, and potentially more creatively too. With the student survey we aimed to uncover the extent of the differences between industry and student ChatGPT use with implications for project-based learning and teaching in future curriculum. After setting the scene with a brief review, the paper will present and discuss results.

#### 1.1 Generative AI

Artificial Intelligence (AI) is an enduring driver for design research and practice [1, 2]; the massive potential offset with concern for the future [3]. The ultimate Artificial Intelligence will be realised when human intelligence is replicated or exceeded by computer-based models. In the meantime, AI has trickled into many of the systems that designers and engineers use without significant concern e.g. generative CAD systems and suggestive web searching.

Increasingly sophisticated web search engines, such as Googlebot, improve at interpreting user prompts linking to complex metadata mined from the deepest parts of the internet including text, image and video content. The new Generative AI systems are also capable of understanding user supplied text/queries

and outputting text, image and video responses, but these are not retrieved from pre-generated content, rather these are uniquely developed in response to the user prompt and did not exist in advance.

At this level of description, it is difficult to appreciate the significance of these systems over what search engines like google have provided us for quite some time. Designers and design students have been using search engines like Googlebot to find critical specification data as well as descriptive and visual inspiration for ideation in their projects. The engines now even push information to users based on their online footprints and have arguably become more 'conversational'. Some search engines are now incorporating explicit "chatbots" moving users into a very similar environment as the famed ChatGPT. Language/text understanding/generation models which are able to train themselves are here; the first General Pre-Trained Transformer (GPT) models from 2018 and a new reality has dawned for practice and higher education with advent of ChatGPT in November 2022 [4]. Integrity in learning and assessment is an issue if generative AI is promoted in education. However, there is undoubtedly a need to consider how this technology will be productively used in practice.

The Q3 2023 Engineering Designer magazine (IED) reports 'How Artificial Intelligence is Transforming Engineering Design: Beyond CAD'. Distinct from research agendas for Generative Design [5] and image-based AI [6], the article highlights the 'world's first Chat-GPT designed robot'; Lausanne researchers are developing design specifications and concepts using a text-only chatbot. In the nascence of Chat-GPT, we want to understand the extent and differences between how our industrial networks and students have usefully leveraged text-only AI.

#### **2 METHODOLOGIES**

The initial study undertaken in July and August 2023 by a cross engineering faculty team, including a student intern, aimed to understand how engineering employers were using ChatGPT so as to inform teaching and learning practice. Following ethics approval, an anonymous, 18 question, Qualtrics questionnaire was distributed through an online networking platform aiming to sample across the 8 disciplinary networks of our engineering faculty, including Product Design and Manufacturing.

To understand our students' experience of ChatGPT an extended/modified version of the survey was approved for distribution to students of the Department of Design Manufacturing and Engineering Management (DMEM). The survey was distributed by email and classroom announcements 5 months after the original industry survey. We targeted early (1 and 2) and senior years (4 and 5) of 3 undergraduate product design courses.

#### **3 RESULTS AND ANALYSIS**

This section of the paper aims to convey the structure of the questionnaire design as well as present and contrast the results obtained from the separate industry and student distributions. The results are organised around: frequency of use; nature of tasks; types of tasks; enabled improvements; concerns and looking to the future.



Figure 1. Key highlights of the Industry Sample
## 3.1 Response Profiles

Figure 1 shows the distribution of engineering disciplines in the industry sample. 'Other' includes low response rates from naval architecture, biomedical engineering and computer engineering. 'Design' includes product design, engineering design and architecture. Manufacturing has clustered technology and operations management with manufacturing engineers. Civil and environmental engineering was the most active network. Potential significance for "design" is highlighted in this paper where possible but given the sample size have mostly looked at all disciplines together as an "industry snapshot".



Figure 2. Key highlights of the Student Sample

Figures 1 and 2 show similar response rates for both distributions. It was perhaps surprising that so many respondents have not been active ChatGPT users but still motivated to participate. Non-users answered fewer questions and given it may also be a means to accelerate completion of the survey, we focused mainly on the responses of the 65% of industrialists and 61% of students who indicated they have used ChatGPT for project work. Table 1 shows results for an additional question that was asked to students showing some reasoning for not using ChatGPT in this way. Current plagiarism policy in our institution explicitly states AI is not allowed in assessed work, so may play a role in general abstinence, but it seems some students do not yet see a benefit of the tool to their efficacy.

Table	1.	Student	Survey	Q8
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Why you have not used ChatGPT for engineering or design	
work/project purposes: (select all that apply)	/29
I don't use ChatGPT for any purpose.	37.9%
I don't really know what ChatGPT is.	17.2%
I have never considered it a useful thing to try.	37.9%
I don't trust ChatGPT.	27.6%
I don't believe I am allowed to use ChatGPT for these purposes.	26%

#### 3.1.1 Gender

It was not expected that gender would play role in the ways ChatGPT is used and seemed unlikely any such patterns would be evident in the sample size/balance. The pie chart in figure 2 shows the gender distribution across the 4 years of study highlighting users (solid colour) and non-users (dotted colour).

## 3.2 Frequency of ChatGPT Use

The early year student group is bigger but has more respondents claiming to "rarely" use the tools. Overall, approximately "weekly" is the most common frequency for the students and for industry (Figure 4). However, there are more "daily" and "not intend to use it again users" and less "rarely" industry users. There are 9 more industry users in the study than student which may explain increases in any type of user, but the lower number of occasional users may be indicative of a difference between industry and student adoption levels.



Figure 3. Frequency of ChatGPT use by students across years of study

29% of industry users do not think that their employers know they use ChatGPT at work. 3/7 students claiming to have used ChatGPT in employment (Q14), believed their employer was unaware (Q13).



Figure 4. Frequency of ChatGPT across role levels (Q4) and business size (Q3)

# 3.3 Nature of the task

In table 2, students and industrialists are similar in most often using ChatGPT to start a task but finish as human endeavour. Industry respondents may be slightly more likely than students to do the reverse; review human work using ChatGPT. It is reassuring to see low figures for using ChatGPT verbatim. Fewer students offered insights into "other" applications, but interestingly were 'rearranging equations' and developing research interview questions. Industry respondents included uses classified under one of: "As a clever search engine for research and translations"; writing or rewriting communications/text; debugging and/or suggesting coding and idea generation.

Table 2.	Industry	Q12,	Student	Q16
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I use ChatGPT to (select all that apply);	Industry	Students
provide a broad view of the landscape to assist task completion by a human.	68.5 %	62.2%
complete the task, then undertake a brief ~ballpark" check.	13%	24.4%
check / review work already completed by a human- did I miss something.	29.6%	17.8%
complete the task alone without modification.	13 %	11.1%
other purpose not stated in options.	22%	11.1%

## 3.4 Task Types

In reflection the wording of the first option in table 3 is quite ambiguous for the student and may have been difficult to interpret in a study context. Research is unanimously the most common task type. 6 industrial respondents (11%) included other uses, some of which are arguably within the scope of the pre-defined answers, but also included: Automation of spreadsheet or word processing tasks, writing personal performance reviews, presentation structuring and support for using software packages. 2 students expanded AI use to image generation for folios (not ChatGPT) and similar to industry responses highlighted opportunities for coding development.

Table 3. Industry Q13, Student Q17

I use ChatGPT for (select all that apply):	Industry	Students
Core engineering tasks relating to my profession	33.3%	8.9%

Research purposes to support tasks	57.4%	77.8%
Communication between clients and colleagues	33.3%	11.1%
Organisation, prioritisation, or scheduling of tasks	16.7%	11.1%
other purpose not stated in options.	11%	4.4%

## 3.5 Use for Employment Application

Additional questions (Q12 and 13) were included for students. 40% (18) of the student users had used ChatGPT when applying for employment. Table 4 shows responses in this context, where it is perhaps not surprising there is less strong agreement that ChatGPT is useful for folio development.

Table 4. Student Survey Q13

Please indicate your agreement with the following statements: ChatGPT is useful for the purpose of:	strongly dis. %	somewhat dis. %	neither %	agree %	strongly agree %
developing CV contents.	0	0	16.7	55.6	27.8
ChatGPT is useful for the purpose of developing cover letter contents.	0	0	11.1	33.3	55.6
ChatGPT is useful for the purpose of developing portfolio contents.	16.6	16.7	22.2	33.3	11.1

Table 5. Student Survey Q19, industry Q13

What improvements do you see ChatGPT enabling in your work?	Industry	Students
Improved efficiency (more work completed in the same amount of time)	16.7%	6.7%
Improved scope (larger area of knowledge & easier access to information)	35.2%	53.3%
Improved quality (higher quality outputs completed at the same time)	37.0%	46.7%
Improved creativity (higher quality & quantity of ideas)	35.2%	28.9%
Other, not stated	3%	2%

# 3.6 Impact on work

From table 5 scope, quality and creativity impact divide the majority of responses. A number of respondents did select both "quality" and "creativity" but with no statistical correlation. "improved creativity" is one of more obvious interests for designers, but none of the industry respondents from the "product design"/Design discipline did select this option, and the student response is quite low.

# 3.7 Concerns

Industry users were more concerned (63% vs 53%) about mistrust/misuse of ChatGPT than students, and significantly more concern about Intellectual Property leaks (51.9% vs 15.6%). Student users were more concerned about diminished job satisfaction (37.8% vs 9.3%); perhaps those working are more reassured by seeing the impact of ChatGPT and less pessimistic about how these jobs will evolve?

## 3.8 The future

Table 6 shows the largest and final section for the survey. There seems relatively good alignment of student and industry responses on most points; generally, less "strong disagreement" on most items. More notable areas of variance have been highlighted in bold red outline. There is a relatively high level of agreement that training is required within organisations but less students feel strongly about that. Students may feel slightly less strongly that ChatGPT is going increase in capability over the next 2 years. Students seem to agree a bit more that ChatGPT could be purposed towards meeting UN SDGs; awareness of SDGs is quite high in universities and may be more variable in industry.

There is some variance in agreement over whether ChatGPT should be incorporated into engineering programme's learning and assessment practices. In reflection, including AI in assessment is quite different to using it in learning and perhaps challenging to give a single answer to both.

I = Industry, S = Students. Select the option which best describes your position on following statements:	Strongly dis %	Somewhat dis %	Neither %	agree %	Strongly agree %	
UK engineering employers are under-utilising ChatGPT.	Ι	3.7	13.0	37.0	35.2	11.1
	S	2.2	4.4	55.6	37.8	4.4
ChatGPT can provide value to an engineering	Ι	1.9	5.6	9.3	46.3	37.0
organisation/engineering employers.	S	2.2	6.7	6.7	64.4	24.4
Training is required to best use ChatGPT in engineering	Ι	3.7	5.6	9.3	37.0	44.4
organisations.	S	4.4	13.3	28.9	42.2	15.6
ChatGPT is currently capable of producing useful outputs.	Ι	5.6	3.7	18.5	42.6	29.6
	S	4.4	4.4	4.4	60.0	31.1
The capabilities of ChatGPT will substantially increase in	Ι	3.7	1.9	18.5	22.2	53.7
the next 24 months.	S	2.2	6.7	11.1	46.7	37.8
ChatGPT will prove useful in achieving the UN	Ι	5.6	9.3	42.6	29.6	13.0
Sustainable Development Goals.	S	6.7	6.7	40.0	42.2	8.9
UK undergraduate engineering programmes should	Ι	14.8	9.3	14.8	27.8	31.5
incorporate ChatGPT into learning & assessment practice.	S	6.7	17.8	22.2	40.0	17.8

Table 6. Student Survey Q18

# **4** CONCLUSIONS

The study was limited in the small respondent numbers within some industry disciplines (not least design) and some course groups. However, survey perhaps does not have the resolution to unpick disciplinary rationale for the responses made. Focus groups are planned as a follow on.

Industry may be using the tool more frequently and finding more uses for language-based AI within their roles than the design students do in their day-to-day activities. Both students and industrial participants have mentioned coding as a significant application, and there are significant coding projects in years 3 and 4 of the courses where ChatGPT could have impact if it is not already. Our design teaching places a lot of emphasis of Product Design Specification, and it would be interesting to look deeper into the role of language-based AI for that. "A clever search engine or an intelligent design assistant"? There is certainly immediate evidence of search engine like activity and there is mention of idea and content generation which is arguably moving towards something more assistive and generative.

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# SUPERVISION OF DESIGN PHD STUDENTS IN AN ERA OF GENERATIVE ARTIFICIAL INTELLIGENCE

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# ABSTRACT

Supervising a PhD candidate towards acquiring the requisite skills and competencies throughout their PhD journey is a fundamental aspect of PhD supervision. The emergence of various Generative Artificial Intelligence (GenAI) tools, such as ChatGPT, could be a potential paradigm shift for academic design research. Given the context, the consequences of the incorporation of GenAI in the supervision process need to be carefully explored to reap the benefits of such a modified approach in a transparent and ethical manner. This paper presents an exploratory study of PhD supervision activities influenced by GenAI, outlining the affected skills and competencies of PhD supervisors. The study involved conducting 11 semi-structured interviews with PhD supervisors from the engineering design community, which were subjected to a detailed analysis. Preliminary findings are presented, accompanied by a set of recommendations to navigate this emerging interface between GenAI and PhD supervision.

Keywords: Supervisor skills, PhD supervision, generative artificial intelligence

# **1** INTRODUCTION

Upon completion of their PhD study, PhD students should become autonomous researchers capable of independent research problem-solving and thinking. To do so, they should possess a wide range of skills and competencies to proficiently employ general research methods and tools for collecting, analysing, interpreting and communicating research data [1]. They must develop their abilities to propose novel insights and develop research contributions, aligned with the research methodologies utilised in their respective academic communities. Furthermore, they are expected to communicate their findings through scholarly papers and presentations proficiently. Throughout this PhD process, a PhD supervisor has a central role by being responsible for providing domain knowledge and expertise, guiding students through research/professional development initiatives and ensuring adherence to the highest ethical and quality standards [1].

The incorporation of Generative Artificial Intelligence (GenAI), such as ChatGPT [2], into research practices could potentially open a new dimension to PhD supervision (e.g. [3]), necessitating a reevaluation of how supervisors guide their students through the complexities of PhD study within the engineering design context. In that sense, PhD supervisors should serve as role models by actively engaging in their professional growth [4] and leading the way towards well-educated and responsible integration of GenAI into design research practices. To do so, possibilities of GenAI as part of the research and PhD supervision process need to be carefully explored to better understand and reap the benefits of such a modified approach. Therefore, the primary objective of this paper is to conduct an exploratory investigation into the current effect of GenAI technologies on PhD supervision activities within the engineering design domain, with a particular emphasis on identifying the impacted skills and competencies of PhD supervisors.

# 2 RESEARCH METHODOLOGY

In the context of this exploratory research, we employ a qualitative methodology, centrally featuring interviews that will allow delving into the complexities of the influence of GenAI on PhD supervision within the context of engineering design research. A semi-structured interview was selected as a suitable

research method due to the exploratory nature of this study and the possibility of obtaining an in-depth understanding of the GenAI effect on PhD supervision with a limited number of participants.

The interviews covered key topics such as experience in PhD supervision, familiarity and use of GenAI tools in research, challenges and benefits, potential shifts in supervisory due to GenAI, necessary competencies for GenAI integration, and awareness of PhD students' GenAI usage.

The selection of interviewees was strategically made from the Design Society community, alongside the authors' direct professional networks. Precise inclusion criteria were set to ensure the relevance and depth of our data: only individuals with prior experience in supervising PhD students and who were actively overseeing PhD candidates at the time of the interview were considered. This approach resulted in a diverse group of participants, with academic ranks ranging from Assistant Professor to Full Professor. In total, we interviewed 11 scholars located in five countries: France, Sweden, Italy, Slovenia, and Croatia.

Given the rapid evolution of AI tools, we opted to conduct a series of interviews within a limited timeframe, aligning with the submission deadline for the full paper at this conference (March 11th, 2024). The duration of the semi-structured interviews varied, ranging from a minimum of 15 minutes to a maximum of 53 minutes.

The interviews were uniformly conducted in English via Microsoft Teams, recorded, and transcribed using Teams' automatic feature or Windows Stream when IT restrictions applied. Subsequent refinements were made to ensure the transcripts accurately mirrored the audio recordings.

The analysis of the results was conducted through reflexive thematic analysis [6], which allows the identification and interpretation of patterns within the collected qualitative data. This approach emphasises the integral role of the researcher's personal experiences and existing knowledge base, requiring a rigorous and introspective examination of the data [6]. Given that both authors are themselves experienced in PhD supervision, reflexive thematic analysis was deemed suitable for this study. The approach steps include, in a broader sense, familiarisation with the data, coding the data, and theme development [7].

#### 3 RESULTS

The findings are organised around two central themes that were identified from the conducted interviews. To enrich the presentation of these results, selected quotations are directly extracted from the interview transcripts, providing tangible illustrations of the key points.

#### 3.1 Effect of GenAl on different research activities

In general, the interviewees expressed many potential benefits of using GenAI for different research activities and discussed how these tools are used or could be used. Each interviewee had some level of experience experimenting with GenAI technologies; however, many indicated that their practical application of these tools across various research activities remained somewhat constrained. Their previous experience using GenAI allowed them to reflect on the related advantages and challenges, and they stated the need to spend more time testing and evaluating these tools to provide stronger claims. Interviewees identified several research activities for which GenAI could provide support.

#### 3.1.1 Finding relevant papers and supporting literature review

Interviewees listed and commented on this activity among the first, indicating that they had several trials for this type of effort. They stated that GenAI (e.g. ChatGPT and associated tools such as Scholar AI) could be helpful in terms of conducting some preliminary checks of the research background (initial familiarisation with the topic) and searching for the most prominent work for a given research topic. In addition, AI tools could indicate connections between disciplines and different research viewpoints that were maybe not considered from the beginning (this can help with the formulation of research problem). Considering the interdisciplinary of engineering design, this ability is very important.

However, interviewees raised several concerns related to the balance between the comprehensiveness and depth of the literature review offered by these tools. A subset of interviewees cautioned against treating GenAI as a mere "search engine" and expressed their doubts regarding the quality of output for literature review, attributing their concerns to the quality of the sources employed in training the GenAI and the potential for "hallucinatory" content. Also, most respondents haven't used specialised AI tools for literature review (e.g. Research Rabbit or Scite), and their claims are predominantly based on experiences with ChatGPT.

#### 3.1.2 Summarising and synthesising

Summarising and synthesising findings from different research contributions was frequently highlighted during the interviews. As often mentioned by interviewees, a researcher has to provide the initial structure of the research idea, methodology, etc., in order to easily navigate the prompting process used as input for GenAI tools. The interviewees commented that researchers should still not over-rely on structuring suggested by GenAI tools, as achieving the desired outputs can be challenging. The current capabilities offered by GenAI allow for the summation of various research findings and speed up the process in that sense (*"It's quicker, it's faster, it gives us the extract, the essence of the papers."*). Additionally, one respondent suggested that these summaries could be perceived as a *"new blank page"* for e.g. literature review sections. To be more precise, this respondent believes that this allows the creation of the very first draft of this manuscript section.

Moreover, by inputting a range of documents and informational sources into GenAI tools, some interviewees reported the ability to extract key concepts from the document and gain initial insights for the following analysis. Still, the reliability of outputs remains an issue, and the underlying rationale for provided outputs is often hard to understand.

#### 3.1.3 Analysing data and coding

Few interviewees pointed out that the emergence of these GenAI tools has democratised access to sophisticated data analytics capabilities, altering the way they approach data analysis. These tools have enabled a shift away from labour-intensive, manual programming tasks towards the automation of analytic processes through GenAI, streamlining their workflow.

Furthermore, GenAI tools are perceived as suitable for the rapid development of code, which is instrumental in creating software prototypes. Such prototypes play a crucial role in testing and validating various research contributions, a practice becoming increasingly prevalent in PhD studies within the engineering design research domain. While a certain level of knowledge is necessary to generate and repurpose the developed code, these tools offer substantial support to those who may not possess extensive expertise in computer science.

#### 3.1.4 Improving research methodology

The opportunity to obtain early feedback from GenAI throughout the research process is perceived as the main strength by several interviewees. In this way, researchers can accelerate their learning curve and engage with GenAI in a collaborative manner, being challenged and questioned about the underlying rationale of different aspects of research methodology. For instance, one interviewee suggested asking for feedback on the preliminary design of experiments. The common perception is that GenAI often cannot offer detailed insights into every aspect of the research process, but it can trigger further reflections. However, these rapid feedback loops could be associated with agile ways of working in comparison to more conventional approaches based on the Design Research Methodology [8].

As an interesting use case of GenAI, two interviewees proposed generating datasets that could enable researchers to trial their methods and contributions prior to formal validation or application in real-world design contexts. This would allow pilot demonstrators in earlier research phases to obtain feedback and subsequently refine proposed contributions and/or approaches. Given the challenges often associated with acquiring data from industrial settings, GenAI can provide datasets that, while potentially not fully accurate or relevant, can still serve to validate preliminary concepts.

#### 3.1.5 Writing activities

All interviewees reported prior utilisation of GenAI tools for a variety of administrative and routine tasks, demonstrating a comprehensive understanding of their potential to assist in generating textual content for diverse purposes. Specifically, for research activities, interviewees frequently acknowledged the support they got to enhance written communication.

GenAI tools strongly support activities such as translating, writing, proofreading, and editing, and this was recognised by all interviewees. This allows for a significant increase in writing quality (flow, readability), which is particularly beneficial for non-native English speakers in articulating their research findings more effectively.

### 3.2 Effect on PhD supervision

This section describes the main insights obtained from the interviews regarding the different aspects of supervising PhD students, considering these new emergent technologies.

#### 3.2.1 Are supervisors familiar with GenAI practices of PhD students?

Half of the interviewees acknowledged a lack of close oversight regarding their PhD students' use of GenAI tools. Although they encourage students to use these tools and get familiarised with prompt engineering and GenAI skills, in general there is no specific supervision on this aspect of PhD study. Interviewees mentioned several reasons for this behaviour, such as the recent emergence of these tools (and lack of perceived need as it is still early), the desire to keep the same level of autonomy of PhD students, students' hesitation to use GenAI tools and prevailing supervision culture within certain academic institutions. Also, some interviewees admitted their own limited understanding of these tools, which hampers their ability to detect potential misuse. On the other hand, the impossibility of easily identifying improper use of GenAI was also highlighted as a concern (*"one of the difficulties is to check what was written by the students and what was written by the AI"*).

Two interviewees stated that they have high-level discussions with their PhD students about integrating and using GenAI in their research activities. Their practices involved some GenAI assignments, followed by a phase of experiential learning through trial and error ("*let them fail*"). In this way, students became familiar with the importance of precise prompting and current tool limitations. Afterwards, the following discussions were based on the generated output, fostering reflection on its quality and reliability.

In general, the observed lack of awareness and insights into the working routines of PhD students raises questions of trust and confidence (*"it has already changed everything in terms of confidence that a supervisor might have with his PhD student"*).

#### 3.2.2 Upskilling of PhD supervisors

These emerging supervision issues indicate the necessity for upskilling supervisors to become familiar with these technologies, ensuring they can provide proper feedback on the generated outputs. All interviewees perceive the same necessity and are aware of a need to tailor their supervision practices. The common perception by interviewees is that the upskilling of supervisors should cover understanding the basic GenAI technologies and prompt engineering. Several interviewees acknowledged the need to start exploring these GenAI tools for research purposes. They expressed their willingness to learn more about their use and gain a deeper understanding of their reliability. This would allow them to evaluate the value and limitations of these technologies critically.

As the capabilities of these technologies evolve very fast, there was a comment by one interviewee that supervisors should be informed about the latest AI developments and understand their potential implications for research. Two interviewees pointed out that students might soon surpass their supervisors in knowledge of these tools, if they haven't already, indicating a pressing need to keep pace. Furthermore, one interviewee stated that it is crucial to learn how to measure and evaluate the quality of the GenAI output, while almost all of them referred to a need to educate themselves regarding the ethical use of these tools.

It is important to emphasise that one interviewee stated that higher education institutions should offer supplementary educational workshops for their faculty and staff, as opposed to relying on external private online courses on these teaching topics. Despite the absence of formal additional education among the interviewees, it is noteworthy that four of them supervise PhD students engaged in projects that explore the support provided by AI and GenAI in various engineering design tasks.

#### 3.2.3 Will GenAl influence the ethical aspect of supervision?

As ethics and integrity are part of PhD programmes, all interviewees agree that these aspects should be carefully transferred to this GenAI usage context as well.

As one interviewee stated, "the presence of AI tools in research projects does bring new dimensions to consider, such as data ethics, algorithmic transparency, and the interpretability of AI-generated results. These aspects should be part of the conversations with students. However, these discussions should be integrated into the broader context of research integrity and rigor, rather than prompting a fundamental change in supervisory approach."

Interviewees agree that GenAI-produced output needs to be used responsibly for research activities, as PhD students are ethically responsible for their use of GenAI. However, as many institutions do not provide clear guidelines and regulations on the acceptable and proper use of GenAI, some interviewees are left uncertain about the best course of action.

#### 3.2.4 Will GenAl change the PhD supervision?

The responses predominantly indicate the PhD supervisors think supervision will change, but they do not specify precisely how deep this change will be. However, some interviewees claim that change will be radical (*"I think that in PhDs there will be - before ChatGPT and after ChatGPT"*) due to the possibilities that these tools will offer, while others view this development as merely the addition of a new instrument to the existing toolkit (*"it's just adding a new tool"*).

In general, there is a consensus among the interviewees that the integration of GenAI tools should be encouraged but coupled with consistent scrutiny and critical evaluation of the quality of outputs. Most interviewees are not convinced that the impact of these technologies will be only positive, raising some major concerns such as overreliance on the generated outputs, losing sight of human-centric skills, a false impression of doing "thorough exploration", etc. Together with the aforementioned trust issues, most interviewees stated that institutional regulations and clear guidelines for the proper and ethically acceptable use of GenAI are necessary. Such measures would then allow the structured introduction of GenAI into PhD education, setting the boundaries for further use. However, a prerequisite for its introduction, as highlighted by interviewees, is the upskilling of PhD supervisors.

Even though interviewees believe that students and supervisors are together in this new emerging situation, opinions diverge on "leadership" roles (depending on the supervisor type [1]). Some interviewees advocate for supervisors to lead this endeavour, whereas others suggest that students might inherently possess a more intuitive grasp of these technologies.

#### **4 DISCUSSIONS**

The primary advantage of utilising GenAI tools lies in their capacity to speed up the discovery of pertinent literature, the extraction of its core concepts, and the acquisition of feedback. As such, these tools provide a basis for further improvement of technology-enabled supervision, potentially changing the interaction between supervisors and PhD students. To explore it, this study builds upon the previous work (e.g., [3]) and further extends it by exploring the perspectives of supervisors.

Before going into the specificities of the supervision process, interviewees expressed their doubts about the quality of outputs, and many of them were not aware of GenAI's potential for research. Still, there is a consensus among interviewees that these technologies should support the activities of PhD students. However, a PhD study requires considerable introspection and cognitive consolidation, or as one interviewee named it "internal maturity process", crucial for organising the knowledge acquired on the PhD topic. This should be reflected in a change of supervisory role and help them focus on the wider intellectual growth of PhD students, which cannot be replicated by GenAI tools [3]. Our findings suggest that GenAI tools hold the potential to support a reflexive approach to research activities [9], offering initial proposals that can serve as drafts for further validation and expansion by the PhD students. A "peer role" of GenAI is emphasised even more through the possibility of providing continuous and timely feedback. When appropriately utilised, GenAI can complement the supervisory role [1], addressing potential delays in feedback and contributing to a potentially more agile approach to PhD projects (in comparison to traditional approaches [8]). As such, the introduction of GenAI could enhance the efficiency of research projects and elevate the quality of written communication. This improvement should not aim to increase publication volume or shorten the duration of doctoral studies but rather to enhance the substance of the research output.

The obtained responses emphasise the role of critical thinking [10] even more throughout the whole PhD research process (problem formulation, literature review, definition of research methodology, data collection etc.), and a supervisor should carefully facilitate the development of related skills of PhD students. A supervisor should ensure that students fulfil the required PhD learning outcomes [1], irrespective of methods and tools employed during the PhD journey (which was perceived as a concern by interviewees). To do so, supervisors need to have enough knowledge of GenAI tools and prompt engineering (in addition to design domain expertise), to ensure that the outcomes derived from these tools are carefully developed and critically evaluated by the PhD students. Integrating GenAI could create a working environment where PhD students are empowered to concentrate on generating novel

ideas, validating them, and disseminating the results. Consequently, the role of the PhD supervisor may shift more towards reinforcing the foundations of research, such as source validation, critical thinking, methodological rigour, clarity of contributions, verification of new knowledge, and understanding the specificities of the design research community.

Emphasising an ethical approach, PhD supervisors should not solely depend on formal ethics education within the doctoral programme but should act as role models for responsible GenAI usage. These insights could inform the integration of GenAI into design research methodologies in a structured and systematic manner. By laying out individual research activities and related GenAI-support use cases, the role of supervisors extends beyond teaching PhD students to use them; they must also prepare them to master forthcoming GenAI tools that will soon become integral to the design research landscape.

# **5 CONCLUSIONS**

The primary findings from this exploratory investigation indicate that the majority of interviewed PhD supervisors are primarily experimenting with GenAI tools like ChatGPT for personal/administrative rather than research-related applications. There is a notable lack of awareness among supervisors regarding their PhD students' use of GenAI tools and a significant gap in their understanding of specialised tools designed for research purposes.

Furthermore, findings suggest that, rather than seeking to prevent PhD students from utilising such tools, supervisors should equip them with the knowledge to utilise these new GenAI resources effectively and ethically. However, as a prerequisite, supervisors themselves must become familiar with the diverse functionalities offered by GenAI research tools and attain proficiency in their application. This knowledge is essential for critically assessing the outputs generated by these tools and ensuring their responsible and ethical utilisation in research. Moreover, findings highlight the critical importance of fostering analytical skills throughout the PhD journey, with supervisors playing a key role in guiding students to meet academic outcomes, underscoring the need for supervisors to encourage but critically assess the usage of GenAI technologies.

This exploratory study reinforces the pertinence of the topic at hand. A main insight is that the emergence of GenAI tools is compelling the research community to reassess the aspects of necessary PhD supervision and redefine the essential skills required of both PhD students and their supervisors. One of the future works will be to propose a dynamic list of GenAI tools efficient for research activities.

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# **'IMPOSTER DESIGNER': SETBACKS AND SELF-DOUBTS ON A JOURNEY TOWARD IMPACT**

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## ABSTRACT

This conference paper empirically reports the setbacks and self-doubts that confront design students, academics and practitioners as they journey forward in their professional lives in search of impact. Results from thirteen (13) iterative design workshops with 258 participants point to a critical need to elevate well-being as core capacity for complex problem solving in design education, practice and research. This is especially important, given the systemic expansion of design scope and subsequent desire for increased impact. This conference paper further disseminates the emerging concept of 'designer resilience' as a new approach to design pedagogy that acknowledges the inherent difficulties of pioneering systemic change.

Keywords: Resilience, complexity, setbacks, self-doubt

# **1 SCENE SETTING: A PHONE CALL**

I've been working on student well-being and improving design education since 2020. As part of this my work, I keep close contact with Alumni/Alumni to hear their stories, experiences and wisdoms.

I take a phone call with an Alumna of the Master of Strategic Product Design program at Faculty of Industrial Design Engineering, TU Delft. They are now a Co-Director at a design agency working on systemic problems related to healthcare reform, the future of work and climate-resilient cities. The conversation proceeds like this:

Alumna: "We design across all these systemic problem spaces, with people who have so much knowledge and expertise. Who am I to advise design directions to people with 30 years' experience in their industry, you know?!"

Author: [... listening...]

Alumna: "We do all this work, but I am struggling to see our impact... or what role design has to play." I hypothesise that these questions and concerns confront many more designers. These questions stay with me in the days that follow. I continue to think about them as I work to improve design pedagogy through my own research on designer resilience.

## 2 SYSTEMIC DESIGNS BUT WHAT IMPACT?

The tangible benefits of a new designed service or product can be isolated through various scores and measures – customer satisfaction, sales, memberships, usability and ergonomics. Comparatively, conducting systemic design to realise transitions (in renewable energy transitions or universal healthcare, for example), requires time to muddle through complexity [1], build, test, implement and observe the impact of design interventions longitudinally [2]. At the end of the design project, a system lives on, evolving potentially well beyond the designer's imagination or best intentions [3]. For this reason, isolating design impact within systemic framing, however desired, is fraught with difficulty. For emerging designers in the first decade of their careers, the need to visibly see/feel their contribution to present-crises is essential confidence building during early and critical learning on the job. In a time of existential threats and ever-powerful technologies, feeling like an "imposter designer" is no place to linger.<sup>1</sup> Design educators must be sensitive too, to striking a balance in learning environments. The

<sup>&</sup>lt;sup>1</sup> The imposter designer continually questions their capabilities and knowledge, even though they are accomplished and bring value to society when they design. The term is appropriated from 'imposter syndrome'; which is a behavioural health phenomenon described as self-doubt of intellect, skills, or accomplishments among

balance is fine at times. Educators must train design students in a way that acknowledges the limitations of the design and thus promotes transdisciplinary appreciation, without disaffecting hope or underlying drivers to study design in the first instance [4].

## **3 DESIGNER RESILIENCE**

Even with good and just ideas, designing the world that ought to be is a difficult journey that opens individuals to critique and prejudice [5]. However urgent and necessary change is, processes of reform bring designers into inherent resistance. Designer resilience is defined as a meta-cognitive capacity and adaptability to be drawn upon when designing gets difficult [6]. Designer resilience consists of ten essential principles and associated practices that initiate critical reflection, reflexivity between designer and context and emotional self-awareness [7]. At its core, designer resilience provides students, practitioners and researchers with the tools to elevate their well-being during design work and build community.

There are different layers of designer resilience as indicated in Figure 1. At the most central layer, each designer requires resilience to deal with the inherent challenges of the design process and of design collaborations. The next layer of resilience is aimed at shaping an uncertain future design career and accompanying design identity. Finally, a contextual layer of resilience towards a feeling of responsibility towards people, society, and the planet wraps around the inner spheres. This paper explores the setbacks and self-doubts that persist across these layers, and are of subsequent reason therefore, to promote designer resilience in design education, practice and culture more generally.



Figure 1. Three layers of designer resilience

### **4 RESEARCH DESIGN**

Over the last twenty- four (24) months, together with a dedicated research team<sup>2</sup>, we have undertaken a collaborative research-through-design approach to elevate well-being and resilience as a topic across our community. Through iterative workshops with Master of Science students at Faculty of Industrial Design Engineering, TU Delft, we have engaged 187 MSc design students in designer resilience work. We have also engaged twenty-five (25) global design teachers and forty-six (46) senior design practitioners to ensure that the project receives broader perspectives of practice and research. In total, we have conducted thirteen (13) workshops. These workshops range in duration from 45 minutes to full day sessions.

Workshops can be as simple as working through a particular setback within a design project and identifying subsequent transformative learning – to – specific sessions that work with design educators

high-achieving individuals (National Library of Medicine, 2023, URL:

https://www.ncbi.nlm.nih.gov/books/NBK585058/).

<sup>&</sup>lt;sup>2</sup> See acknowledgements

on ways to reform what is a higher education system focused on student performance, enrolment growth, and rankings. In addition to gaining HREC approval for our project, the planning and execution of workshops has received guidance from Faculty Academic Counsellors' who are trained clinical psychologists.

Data analyses consisted of a thematic analysis of workshop materials, reviewing our own workshop notes, reflecting on our own experiences as educators/students and recalling participant anecdotes that left a major impression on us. As with previous research, limitations of the approach are accepted in order to prioritise student safety and engagement, which we view as a vital precursor to working on topics of well-being and resilience [6]. In Figure 2, we show a few impressions from our workshops.



Figure 2. Workshop Impressions. Top right, two images: Feed your students a nice lunch, then take them on a walk in the sun to discuss how their design education is progressing

# 5 RESULTS: IDENTIFIED SETBACKS AND SELF-DOUBTS

Provided below, are a list of setbacks and self-doubts expressed during workshops. These setbacks and self-doubts promote ongoing existential conflict within the designer. For clarity, I opt to present these in dot point format associated with each layer of designer resilience.

#### Setbacks and self-doubts at the level of designing:

- Harsh or prejudicial criticism of work can have a profound effect on an individual's confidence to openly share creative work. Creative work by nature is always open to critique. There is no deducible or correct answer in design and thus the designer must negotiate critique and brave criticism.
- Paralysis within the design process due to a lack of confidence can accumulate due to negative

events. Designers may feel they intuitively know what to do but lack the confidence to try. Many design students in particular report feeling despair when stuck within a process or project.

- Having to work on projects that create interpersonal conflict with team members. Working in teams is an inevitable aspect of design due to the social nature of problem solving. Conflicts flow openly when people disagree on what the problem is, what needs to be designed, and how it should be designed. Pluralism creates tensions that lead to conflict.
- Not knowing what to do next in projects. When a designer tasked with solving problem does not know how to proceed, a wave of existential self-doubt follows "am I an imposter designer?".
- Having to present a project outcome that you know needs another iteration. This often occurs in design education where students work within projects with tight deadlines and with limited design management experience. Standing in front of design work and presenting it, the designer is hypervigilant to the flaws of their project.
- Not being proud of a project outcome feeling embarrassed. Often this was the result of a problematic design process where prior setbacks mentioned were encountered.

#### Setbacks and self-doubts on the way to becoming a designer:

- Not knowing what kind of designer to become. Graphic, communication industrial, interaction, strategic, service, social designer and more?! As the design field expands in scope, it is natural that those within it question where they 'fit'.
- Lacking the courage to share a learning journey with others. Designer resilience workshops provided a 'safe' environment in which personal stories were shared. Design curriculum must make more space for guided reflection. This is ironic, given design requires reflection as a source of learning.
- Being driven by grades and performance rather than learning. Good grades were described as a gateway to better job prospects and other professional opportunities.
- Failing a course then losing scholarships. Many of the international students in coursework carrying scholarships need to pass in order to receive funding.
- Being rejected by design schools during the enrolment process. One student we met with described how attempts to enrol in design education had been rejected due to flaws in their portfolio. This was a terrible experience, yet this individual bounced back and tried again with success.
- Feeling like you don't fit in anywhere. This more existential feeling can also be reframed as an indication of uniqueness or distinctiveness. Yet feeling alone or not fitting in is known to be socially and developmentally damaging.

#### Setbacks and self-doubts at the level of generating impact:

- Not seeing good and just ideas realised in society. Why design when the outcomes of the process remain on paper? This setback relates to the purpose and greater ambitions of designers.
- Coping with the pressure to create positive impact. Many students and practitioners spoke about struggling to sleep under the pressure to create impact in a project.
- Working for unethical clients but needing the work anyway. Much of this work comes as a result of productivity of outdated, unsustainable yet profitable industrial activity. Designers will always have to decide what kind of work they accept and decline.
- Thoughts of imposter syndrome. Questioning expertise was a pattern of our workshops. This relates back to confidence noted earlier in setbacks and self-doubts at the level of designing.
- Doubting the bigger legacy of a career. When working with practitioners and academics, we observed questions about legacy.
- Sacrificing time with loved ones to pursue positive impact. Commitment to creating impact posed a challenge for participants who made clear sacrifices relating to social and family relationships.
- Feeling that whatever work you do, it will not be enough to avert [xyz] crisis anyway. A wave of pessimism was observable in many participants who felt powerless when talking about grand and wicked challenges facing society and the real role design could play.

## 6 DISCUSSION AND CONCLUSION

Design is profession where practitioners challenge the status quo in quest for impactful improvements to society. Where the designer adopts systemic framing of projects, identifying impact from subsequent design interventions is fraught with difficulty. Yet identifying one's impact is important for developing confidence and learning on the job – in plain terms, for knowing what works and what doesn't.

The results of this paper demonstrate that design students, practitioners and educators alike harbour deep self-doubts and insecurities about designing, becoming a designer and generating impact. These self-doubts and setbacks are persistent regardless of expertise. As I write in the early pages of this paper, feeling like an "imposter designer" in a world awash with existential problems and ever-powerful technologies is no place to linger. The results also show our design community is resilient, overcoming difficult setbacks and remaining dedicated to their craft no matter the burden of self-doubt they internally harbour.

The results of this conference paper have implications for design education. How we communicate the scale of world problems to our students and develop design capabilities must be carefully approached. As educators we must be careful not to launch naïve designers into society, who believe in the endless or superior power of design. We must be mindful also, of training designers riddled with self-doubts who will be prone to feeling like "imposters", even though they are capable and responsible.

Moving forward, design education must acknowledge and address setbacks and self-doubts of their community openly in order to unlock our collective authenticity, reflexivity and resilience. I propose designer resilience as a set of essential principles and practices capable of this reform. Future research will work to implement the approach in higher education curriculum and investigate the subsequent outcomes.

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# GENERATIVE AI IN DESIGN EDUCATION: BUSINESS AS USUAL, A TROUBLEMAKER, OR A GAME CHANGER?

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# ABSTRACT

Higher education institutions (HEI) are facing fundamental questions regarding students' use of artificial intelligence (AI) tools in the form of large language model (LLM) based chatbots. Students are already using AI tools to respond to written assignments and exams. Our research question is: What is educators' standpoint about students' use of generative AI in higher education? A mixed methods approach was applied for the present study. First, a qualitative investigation was conducted, centred around interviews that revolved around potential consequences (i.e., opportunities, threats, challenges, etc.) and factors related to the educators' views on AI. Based on the qualitative approach, three propositions were postulated for a narrower quantitative approach, including a larger sample of educators from industrial design (ID) educations at HEIs' in Europe. The quantitative data was collected through a questionnaire and analysed using a fuzzy-set qualitative comparative analysis (fsQCA). The findings from the questionnaire supported our proposition about (1) Knowledge about AI leads to seeing opportunities rather than challenges, but not our propositions of (2) Emphasizing skill-focused learning outcomes leads to seeing opportunities rather than challenges. This study emphasizes the importance of knowledge about AI for educators' not emphasizing challenges. This study emphasizes the importance of knowledge about AI for educators.

*Keywords:* Generative AI, artificial intelligence, higher education practices, assessment, AI knowledge

# **1** INTRODUCTION

Higher education institutions (HEI) are facing fundamental questions regarding students' use of artificial intelligence (AI) tools in the form of large language model (LLM) based chatbots, image generators [1]. Students are already using AI tools to respond to written assignments and exams. Support from generative AI solutions such as ChatGPT may mean that yesterday's well-established proxies for doing, reflecting, and learning must be rethought [2]. For instance, writing an essay must mean that the students learn the literature needed for the essay. Thus, continuing many of our current ways of giving students assignments may neglect that writing skills, literary knowledge, and reflective insight are not required to deliver a seemingly sound response to an assignment or an exam. Hence, students may use AI in a way that does not facilitate in-depth understanding and provide the desired and required learning outcomes. Furthermore, it is known that AI services may also generate incorrect information, and previous research found that students are less inclined to critical thinking when using AI tools [3], which could result in significant misconceptions. Students' use of AI is relatively new, and higher education institutions (HEI) do not have sufficient guidelines and knowledge on how to use AI in education and also lack experience in dealing with the challenges that might occur [4]. Though generative AI presents some challenges, there are also opportunities. Generative AI tools can be powerful to automate repetitive tasks and can aid students with the writing of text [2]. Nevertheless, the development and availability of generative AI has prompted a need for new learning outcomes, including knowledge about AI, more focus on critical thinking and reasoning, digital literacy, and generic skills [5]. Educators are now facing the challenges AI brings to assessment methods in HEI, but do not necessarily have solutions readily at hand. In this paper, we wish to explore what influences educators' viewpoints on students' use of generative AI in higher education.

# 2 BACKGROUNDS

#### 2.1 AI in higher education

Generative AI tools can provide opportunities in education, but also have some limitations. AI tools, such as ChatGPT, can increase access to information, facilitate personalized and complex learning, and decrease teaching workload [6]. Chatbots can be used for brainstorming, writing assistance, and individualized learning [2]. In a review from 2020 [7], researchers found that AI has been adopted in education and used to perform administrative functions to reduce time use. Furthermore, AI has been used to aid learning processes by helping customize content. AI tools such as writing assistants and revision assistants are made to aid students and can benefit learning. Adaption for students using AI tools can foster retention and uptake, ultimately improving the students' learning. On the other side, AI may encourage dishonesty by students using AI platforms and tools to write or do tasks for them [7]. AI tools such as ChatGPT also has a lack of understanding, difficulty in evaluating the quality of responses, risk of bias and discrimination, and lack of higher order thinking skills [6].

Though the use of AI for students can be a tool for learning, some students may be tempted to take shortcuts. In a study by Farazouli et al. [8], educators assessed home examinations blindly, where some were written by students and some generated by ChatGPT at three levels of complexity. The teachers were not successful in identifying the texts written by ChatGPT, and only correctly suspected ChatGPT 14% to 23 % of the time. The teachers with more experience with ChatGPT were more successful in suspecting the AI-written texts. Thus, AI creates new challenges for educators regarding assessment. A literature review on using chatbots in education found that the research is still in an early stage, with little consensus and knowledge about effective learning design or learning strategies with chatbots [9].

## 2.2 Al in design education

AI can be a useful tool in design education both for the students and educators. In design education, AI has been used as product testers for design students [10]. The AI tools were shown to be useful in participating in student design activities. Two educators explored using ChatGPT as a virtual colleague [11]. ChatGPT helped save time, structure textual content and documentation, and was used as a brainstorming tool in creating design course content and materials. The chatbot had some limitations as it often generated generic and vague content, and human prompting and editing were required to produce the desired outcome. Assessment that requires product design are moderately affected by generative AI [12].

Technology and AI impact designers, for example, in industrial design where technology is an integrated part of the product [13]. Integrating the rapidly developing technology in design education is valuable. Developing technologies and AI can provide innovative opportunities for the design of new products, and by disseminating knowledge about AI and emerging technologies to the design students, they will become better at implementing and using the technology in their designs and products.

#### 2.3 Adopting new technologies

The technology acceptance model (TAM) presents factors influencing teachers' adoption of technology, such as perceived usefulness, perceived ease of use, attitudes toward technology, and self-efficacy [14]. A study applying TAM found that perceived usefulness and perceived ease of use positively impacted students' attitudes toward behavioural intentions and actual use of AI-based systems [15]. As AI is a new technology, according to the TAM teachers' perceptions and attitudes towards AI will influence both their adoption of the tool, and possibly students' attitude and use.

A significant factor for teachers to change behaviour and adopt technologies is knowledge [16]. For teachers to use technology in a way to facilitate learning, they need knowledge of the technology itself, knowledge of pedagogical practices appropriate for the technology, pedagogical methods for student learning and how technology can support the learning.

## 3 METHOD

A mixed methods approach was applied for the present study. This gave us a more comprehensive view of AI in design education and yielded richer and multifaceted insights. First, a qualitative investigation was conducted, centred around eight semi-structured interviews with educators from industrial design

(n=3), architecture (n=1), entrepreneurship (n=2), electronic engineering (n=1), and industrial engineering (n=1) about potential consequences of AI in design education (that is, for instance, opportunities, threats, challenges, etc.) and factors related to the educators' views. A pilot of the interview was conducted. A thematic analysis [17] was done on the interview transcripts. After getting familiarized with the data, initial codes were identified and eventually sorted into clusters that emerged as different themes. The themes were then reviewed and named. The resulting themes were used to postulate propositions for a narrower quantitative approach in the form of a questionnaire that was distributed to 14 universities in Norway, Sweden, Denmark, Finland, Netherland, Germany, England, and Italy, which offers industrial design courses. Therefore, a limitation of the study is that it is only conducted within a (mainly northern) European context. The questionnaire consisted of 24 questions distributed across four themes: knowledge about AI, use of authentic cases in education, skills-focused courses, and perception of challenges and opportunities with AI. Answers were rated using a sevenpoint Likert scale, where I = Strongly disagree and 7 = Strongly agree. The measures were: Knowledge of AI, Use of authentic cases, Skill-based course, AI is an opportunity, AI is a challenge, AI is more of an opportunity than a challenge. Questions about knowledge about AI is inspired by TPACK-deep [18]. The questionnaire was piloted with four Norwegian educators completing the questionnaire and giving detailed feedback. A potential limitation in the questionnaire design is that the respondents must themselves evaluate how "case-based" and "skill-based" should be interpreted in their educational context.

The quantitative data was collected through a questionnaire and analysed using two approaches: Fuzzyset qualitative comparative analysis (fsQCA) and multivariate linear regression. We received 47 complete responses to the questionnaire. FsQCA is a set-theoretical approach that, unlike more traditional statistical methods such as multivariate regression, allows for investigating how combinations of several factors may explain an outcome [19]. Thus, our analysis is strengthened by using two independent approaches to assess the propositions from the qualitative part of this study. Both quantitative analyses were conducted using STATA/MP version 17.0 and fsQCA using the package 'fuzzy' by Longest and Vaisey [20]. Values for fsQCA should have a value between 0 and 1, where 0 represents "full non-membership" of a certain condition, such as the absence of knowledge about AI, and 1 represents "full membership" of a certain condition, such as the presence of knowledge about AI. Preparation of the dataset through data calibration is therefore necessary, and we used the direct approach proposed by Ragin [21]. The calibration should result in three values for each variable: (1) A crossover-point (CP), which is the point of maximum ambiguity whether it represents membership or non-membership, (2) a full non-membership threshold (FNT), where it is certain that a value represents the absence of a factor, and (3) a full membership threshold (FMT), where it is certain that a value represents the presence of a factor. We used a combination of theoretical anchors and empirical anchors (distribution of values of each variable) to define the three calibration values, which are presented in Table 1. Since we used a seven-point Likert scale, a value of 4 is the theoretical crossoverpoint. Empirically, a starting point for the crossover point could be the median value for the measured variable. We chose a 75% weighting on the theoretical perspective, except for the skill-based course variable, where the distribution of values was biased towards higher values, which is expected in industrial design courses.

Variable	Mean	SD	Median	Min	Max	FNT	СР	FMT
Knowledge about AI	4.43	0.63	4.43	3.14	6.00	3.71	4.07	4.86
Case-based course	4.93	1.28	5.20	1.20	6.60	3.90	4.21	6.00
Skill-based course	6.11	0.73	6.00	3.25	7.00	5.50	6.00	6.75
AI opportunities	4.65	1.22	5.00	2.00	7.00	3.33	4.20	5.60
AI challenges	3.89	1.34	4.00	1.33	7.00	2.60	3.92	5.00

Table 1. Descriptive statistics and calibration values

FNT and FMT were set empirically at 20 percentiles and 80 percentiles, respectively. A minimum significance level of p<0.05 and a consistency threshold of 0.8 was defined for the fsQCA, in line with recommendations by Ragin [22]. The results from fsQCA were reduced to a minimum reduction set using the Quine-McCluskey algorithm [20].

# **4 FINDINGS**

#### 4.1 Qualitative thematic analysis

The thematic analysis of the eight interviews identified the following themes:

- 1. AI is an opportunity: The educators viewed generative AI as an opportunity for the students to learn to use a new tool and to work more effectively.
- 2. AI does not hinder learning: The educators were not worried that generative AI would hinder students learning and argued that the courses was based on experiential learning and therefore the students would learn, no matter if they used generative AI or not. For example, the students still had to do their own considerations and choices based on the information they had.
- 3. AI is not a challenge: Specificity and practical work in the courses were emphasized, where the educators meant AI could not do this work for the students. For example, physical models must be built, and specific information and context must be included in their project. The educators therefore meant that AI was not a challenge in their courses.

The interviewed educators had not yet implemented specific AI tools in the courses but considered possibilities for it in the future. Based on the qualitative approach, the following three propositions were postulated for a narrower quantitative approach: (1) Knowledge about AI leads to seeing opportunities rather than challenges, (2) Emphasizing skill-focused learning outcomes leads to seeing opportunities rather than challenges, and (3) Use of authentic cases leads to educators' not emphasizing challenges.

#### 4.2 Quantitative analysis

47 educators answered the questionnaire (15,7 % response rate). The results from fsQCA are presented in Table 2 below, and the results from multivariate linear regression are presented in Table 3 below. Two sets representing paths to seeing AI opportunities were found (sets 1 and 2 in Table 2). From sets 1 and 2, we see that knowledge about AI must be either combined with a skill-based but not case-based course (set 1) or with a case-based but not skill-based course (set 2). Set 3 represents the one path to seeing AI challenges, where a combination of absence of AI knowledge and absence of a case-based course is necessary. Thus, AI knowledge is necessary, but not sufficient, to explain AI opportunities. The absence of AI knowledge is necessary, but not sufficient, to explain AI challenges.

Set	Knowl.	Case	Skill	AI opp.	AI chall.	R.cov	U.cov	S.con
1	1	0	1	1		0.235	0.154	0.865
2	1	1	0	1		0.293	0.212	0.857
3	0	0	-		1	0.275	0.275	0.881

 Table 2. Results from fsQCA

 (R.cov=raw coverage, U.cov=unique coverage, S.con=solution consistency)

The results from multivariate linear regression are in line with the fsQCA. From Table 3, we see a strong and significant positive impact from knowledge about AI and AI opportunities and a substantial and significant negative impact from knowledge about AI and AI challenges. Significant influences from the other variables were not found.

 Table 3. Results from multiple linear regression analysis

 (standardized coefficients, standard deviations in parentheses, \*\*\* p<0.01, \* p<0.1)</td>

	Model 1: AI opportunities	Model 2: AI challenges
Knowledge about AI	0.458*** (0.263)	-0.294* (0.308)
Case-based course	0.066 (0.131)	-0.102 (0.154)
Skill-based course	0.056 (0.234)	-0.102 (0.274)
Adjusted R <sup>2</sup>	0.169	0.056
Sample size	N=47	N=47

Interestingly, there is no significant correlation between AI opportunities and AI challenges (b=-0.126, p=0.389). Hence, AI opportunities and AI challenges represent independent dimensions and are not opposites of each other. This interdependency was confirmed using factor analysis. Overall, the quantitative analysis supports the first proposition from the qualitative analysis, namely that "Knowledge about AI leads to seeing opportunities rather than challenges". The analysis was unfortunately not able to successfully assess the two other propositions. A few respondents also used

the opportunity to leave a comment at the end of the questionnaire. Thoughts about using AI in their courses in the future were mentioned, although not yet implemented.

#### **5 DISCUSSIONS**

First and foremost, our results show how knowledge about AI is essential. Hwang & Chang [9] state that there is little research on the knowledge about how chatbots can be used to facilitate learning. Our results show a need for knowledge about AI to be able, as educators, to see opportunities for AI use in higher education. According to the study by Farazouli et al. [8], educators struggle with detecting assignments where students have used ChatGPT, though educators with more experience with ChatGPT were more successful. Atlas [2] argues that we must re-think current practices. The result of our study shows that if educators have more knowledge about AI in education, they also have a more optimistic and opportunity-seeking approach. This could be solved with more research on how AI influences assessment methods in HEI, but also that HEIs' create courses for educators to enlighten and increase competence on the topic. Opportunities from chatbots, image generators, and other tools available to students are powerful tools to automate repetitive tasks, can help with writing, save time, structure text content and documentation, as well as aid brainstorming [11].

According to TAM [14][15] perceived usefulness is important for the adoption of new technologies, which means that by increasing educators' knowledge about AI, they have a higher chance of perceiving the opportunities that lies withing the tools and therefore also be more inclined to use the tools. Having educators who understand the usage of AI tools might be essential to educating future designers who are capable of appropriate use and implementing these tools into their work and products [13]. Knowledge about the specific technology and how to use the technology in specific ways is important to increase students learning [16]. Our results also show that not having knowledge about AI leads to seeing challenges, which might lead to avoidance of the AI tools. Increasing knowledge about AI is therefore important for educating the designers of the future. The results also show that knowledge about AI together with either case-based but not skill-based course, or not case-based but skills-based course, lead to seeing opportunities for AI. These findings point towards some characteristics of courses that also need to be present, in addition to knowledge about AI, for educators to see opportunities. These findings somewhat align with the propositions postulated, though the relationships are more complicated. Though these findings are difficult to make sense of, the main takeaway is the importance of knowledge about AI in seeing opportunities, both for courses with a high degree of skill focus and courses with a high use of authentic cases.

## **6** CONCLUSIONS

Knowledge about AI is essential to see opportunities and a lack of this knowledge can lead to seeing challenges. To strengthen industrial design education, increasing educators' knowledge about AI is crucial, both for educators to be able to use AI in an appropriate and constructive way and to educate the designers of the future who can use AI, understand its limitations, and implement the technology into their designs in a suitable manner. Students' use of AI is already common practice. Therefore, educators must be able to guide students towards the appropriate and ethical use of these new and powerful tools.

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# A BLENDED APPROACH OF ONLINE TOOLS TO ENHANCE COLLABORATION ABILITY IN DESIGN EDUCATION

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# ABSTRACT

Collaboration is essential to design and is a learned skill that needs to be integrated deeply into educational processes. Teamwork enables students to look beyond their own space, time, and culture, preparing them for collaborative work in their future design practice. This study tested a blended approach of online tools in the design education process, demonstrating improved student engagement in collaboration. The online tools discussed in this study include Slack, Figma, Miro, and a card-based online workshop tool designed by the team.

The study followed a design course at a college from 2019 to 2022, discussing how online tools affect the design education process in a graduate-level studio course. The main objective was to evaluate how online tools impacted students' learning and collaboration performance. Firstly, we focused on the cocreation and the competencies developed in the collaboration process. Then, we examined the quality of the design projects and correlated it to the effectiveness of communication within the teams. Data were collected through surveys and self-reflective writings at the end of each semester, and comparative studies were conducted on intercultural collaborative project outcomes versus traditional in-house team projects.

The results revealed that the blended approach generated promising statistics regarding learning and collaboration inclination and teamwork engagement. The advantages and values created are summarised in the conclusion.

Keywords: Design education, collaboration ability, online education tools

# **1** INTRODUCTION

Design education serves as a cornerstone for preparing future designers to navigate the complexities of the modern world. Central to this preparation is the cultivation of collaboration, a fundamental skill that transcends individual capabilities and fosters collective creativity and innovation. Collaboration in design education is not merely about working together; it's about embracing diverse perspectives, leveraging collective expertise, and co-creating solutions that address real-world challenges.

In recent years, advancements in technology have reshaped the landscape of design education, offering new opportunities to enhance collaboration through the integration of online tools. The rationale for integrating these tools into design education is grounded in their capacity to overcome traditional constraints, such as geographical distance and time limitations, while fostering a culture of connectivity and collaboration among students. By leveraging online tools, educators can create immersive learning experiences that transcend the boundaries of the physical classroom, empowering students to collaborate seamlessly and engage in meaningful dialogue regardless of their location.

The present study aims to explore the transformative potential of online tools in augmenting collaboration ability within the context of design education. By examining the impact of a blended approach that incorporates online tools such as Slack, Figma, Miro, and a card-based workshop tool, the study seeks to elucidate how technology-enhanced collaboration influences students' learning outcomes and collaboration performance. Through a longitudinal analysis spanning from 2019 to 2022, the study evaluates the effectiveness of online tools in promoting co-creation, developing collaborative competencies, and enhancing project quality in a graduate-level design course.

# 2 LITERATURE REVIEW

## 2.1 The Importance of Collaboration in Design Education

In the field of design practices, cultivating collaboration is foundational, fostering an environment where creativity and innovation thrive to address the increasingly complex problems designers face (Nielsen et al., 2019). Design education aims to "serve environmental, technological, and societal changes and challenges" (Wu et al., 2021). Currently, design education has moved towards a collaborative practice, where designers work in teams and collaborate with other disciplines to solve unstructured problems. In this process, designers need relevant collaboration skills, including cognition, teamwork, information sharing, negotiating common ground, and reaching consensus (Kiernan et al., 2017).

Furthermore, collaboration in design education reflects the interdisciplinary nature of professional design practice and mirrors the collaborative processes prevalent in the industry. However, it is less so in education where the curricular structure and requirement for assessment make implementation difficult (Kiernan & Ledwith, 2014). Therefore, there is a call for more related research on design collaboration within the design education community.

It is now common in contemporary graduate design education for co-design, speculative, and futuresfocused approaches to be embedded into curricula to support critical exploration (McAra & Ross, 2020). Traditional individual design skills cannot meet these emerging design methods. Brainstorming, facilitation, choreography, empathy, and translation are collaborative skills that support this new practical field of design education (Örnekoğlu-Selçuk et al., 2023), which are also key transferable skills for design students entering the industry in the future.

## 2.2 Emerging Online Tools' Potential in Design Education

While collaboration and communication tools have developed with new computer technologies, there appear to be fewer digital/online creative design methods compared to physical creative methods (Brisco et al., 2021). Online tools combined with specific or integrated design methods can better allow the occurrence of design ideation to support future-oriented complex and varied design activities. For example, a tool developed by Wenzel et al. (2016) called 'Tele-Board' supports design thinking through remote collaboration.

Currently, one of the most common online tools is the digital whiteboard, where many users can share ideas, brainstorm, and conduct specific design collaboration activities on a virtual whiteboard (Brisco et al., 2021). This form aligns with the thinking patterns of designers starting from scratch in real scenarios. Many developments of shared whiteboards have appeared and are commonly used by design teams, including Miro, Figma, and Butter. These collaborative whiteboards can provide necessary design methods and process templates for design activities to support users in better collaboration. At the same time, other online tools for design collaboration have also attracted attention, such as the card-based brainstorming tool (Liu et al., 2023) and the prototyping tool 'Designy' (Ramos & Wallace, 2019). However, there is little research on how different online tools work together to affect design students' collaboration abilities in design education environments.

## **3 METHODOLOGIES**

The study was conducted within the framework of a graduate-level design course spanning three academic years, from 2019 to 2022. The course aimed to provide students with comprehensive training in various aspects of design, including conceptualisation, prototyping, and project management, while emphasising the importance of collaboration in the design process. Throughout the course, students engaged in a series of collaborative projects designed to simulate real-world design scenarios and encourage teamwork and interdisciplinary collaboration.

Description of the Design Course:

**Contact Hours:** 55 hours

Major: Environmental Design, Interaction Design

Assessment: course work and assignments

Prerequisite: Design Basics

Students: maximum 16(divide into 3-4groups)

The course is structured in three modules:

1. Lectures and Seminars 1 (8 hours)

Based on the selected topic, the course will have selected lectures, mainly to introduce the relevant theory, research and design skills, and expertise related to the subject and so on.

- 2. Workshop (41 hours) (group work) Project in the real world with real community users and needs such as small-scale community renew. With complex context and stakeholders to communicate and research, students will need to use more broad knowledge and skills to solve problem. Throughout the workshop, students will apply broad-ranging knowledge and skills to tackle complex problems. From conducting field research and analysing users to crafting strategies and conceptual designs, to developing prototypes and gathering feedback, this workshop offers a comprehensive exploration of the project process.
- 3. Exhibition and Presentation (6 hours) Concluding the course, an exhibition and seminar will be orchestrated to facilitate the exchange and sharing of experiences among participants.

## 3.1 Overview of the Online Tools Utilised

- 1. Slack: A messaging and communication platform that enabled real-time communication, file sharing, and collaboration among team members. Slack serves as a dynamic messaging and communication platform, fostering real-time interaction, seamless file sharing, and effective collaboration among team members. Through its versatile features, students engage in swift exchanges, share resources effortlessly, and collectively refine their creative endeavours within the studio environment.
- 2. Figma: A cloud-based design tool that allowed students to collaborate on design projects in realtime, providing features for prototyping, wireframing, and design iteration. Within the Design Studio Course, Figma emerges as a pivotal asset, offering a cloud-based design platform that empowers students to collaborate seamlessly on design projects in real-time. Equipped with robust features for prototyping, wireframing, and iterative design processes, Figma provides a versatile canvas for students to bring their ideas to life collectively, fostering innovation and iteration within the collaborative studio environment.
- 3. Miro: Similar to Figma, Miro is an online whiteboarding platform that facilitated visual collaboration, brainstorming, and ideation sessions among distributed teams. By providing an intuitive virtual workspace, Miro enables students to ideate, organise thoughts, and co-create visually, fostering a dynamic and inclusive creative process that transcends physical boundaries.
- 4. Zoom: Video conferencing tool for remote meetings, critiques, and workshops.
- 5. A card-based workshop tool designed by our team is used in the brainstorming phase of the design workshop. Drawing on metaphor design methods in interaction design, this tool is designed with multiple interactions and four adapted desktop modes. Students can improve communication, creativity, and engagement among team members through this card-based workshop tool (Liu et al., 2023). The tool helps students output content in the form of text, pictures, and videos from specific thinking perspectives. This interaction promotes students' online participatory discussions and information exchanges, and the diverse desktop modes give students a higher sense of presence when participating in online workshops. This research focuses on the tool's impact on communication, creativity, and engagement in students' collaborative abilities.



Figure 1. Card-based Online Workshop Tool

#### 3.2 Data Collection Methods

1. Surveys: Designing surveys to gather quantitative data from students regarding their perceptions of collaboration effectiveness, and their learning outcomes.

- Self-reflection writings: Asking students to write reflective essays at the end of each semester to 2. gather qualitative insights into their learning experiences, collaboration processes, and perceived impact on their design projects.
- Observational studies: Observing students' interactions and behaviours during collaborative 3. activities. This can provide valuable qualitative data on communication effectiveness, and engagement levels.
- Interviews: Conducting semi-structured interviews with students and instructors to gather in-depth 4. insights into their experiences.

These data collection methods can provide a comprehensive understanding of how the online tools impact students' learning and collaboration performance in the design education process.

## 3.3 Comparative Study Design between Online Learning and Traditional In-House Team

The research team conducted comparative study to analyse and compare the outcomes of two tests of design education process: those using online collaborative platforms and those executed by traditional in-house teams. The study aims to assess the impact of online tools on collaboration effectiveness, project quality, and learning outcomes in the context of design education.

1. Participant Selection:

> The grouping method was primarily based on students' voluntary selection. In 2019, all students opted for offline groupings and exclusively utilised offline tools. In contrast, in 2021, all students chose a combination of online and offline tools. However, due to the pandemic in 2020, some students attended classes online while others attended offline, naturally forming two control groups.

year	Course scale	Students' info	Online tools	Offline tools*	Notes
2019 autumn semester	9 students	All offline		Whiteboards	All students attended classes offline and utilised offline supplementary tools.
				Pin-up kits	
				Storyboard templates	
				Design Critique Cards	
				Design Workshop Kits	
2020 autumn semester	10 students	Group A		Whiteboards	Due to the pandemic, for the 2020 academic year, students of this course attended classes partially online and partially offline.
				Pin-up kits	
		4 offline		Storyboard templates	
				Design Critique Cards	
				Design Workshop Kits	
		Group B	Slack	Design Critique Cards	
		6 online	Figma/Miro	Design Workshop Kits	
			Zoom		
2021 autumn semester	16 students	All offline	Slack	Whiteboards	Students voluntarily grouped themselves and choose between using online tools or offline tools. However, all students opted to utilise online tools to supplement their course learning.
			Figma/Miro	Pin-up kits	
			Card-based	Storyboard templates	
			Workshop Tool	Design Critique Cards	
			zoom	Design Workshop Kits	

Table 1. Participants and the comparison of online/offline tools

\* The offline tools listed in this table exclusively comprise those geared towards teamwork and collaboration. Data Analysis: 2.

- Quantitative analysis: Quantitative analysis will involve statistical analysis of scores provided by the same group of teachers to compare differences between the two groups.
- Qualitative analysis: Thematic analysis will be conducted on self-reflection writings and interview transcripts to identify common themes and patterns related to collaboration effectiveness and project quality.

Outcome Measures: 3.

Collaboration effectiveness: Assessing factors such as communication clarity, teamwork cohesion, and task coordination.

- Project quality: Evaluating the creativity, functionality, and innovation demonstrated in the final design outcomes. (Figure 2)
- Learning outcomes: Examining the development of collaborative skills, cross-cultural competencies, and design proficiency. (Figure 3)



Figure 2. Project quality analysis

Figure 3. Learning outcomes analysis

## 4 FINDINGS

#### 1. Collaboration effectiveness

After analysing the results of the questionnaires and interviews, the findings reveal that online learning platforms enhance collaboration by providing tools for "real-time communication," "document sharing," and "collaborative editing." On the other hand, traditional in-house teams may excel in collaboration due to face-to-face interactions, non-verbal cues, and immediate problem-solving. The following points summarise arguments cited from the interviews:

- (1) Knowledge Sharing: "Slack facilitates asynchronous communication, allowing us to share insights, resources, and experiences across diverse time zones and locations." "Slack enables us to access resources at our own pace and convenience," while traditional teams may face constraints related to fixed schedules and physical presence.
- (2) Conflict Resolution: Online platforms may "provide structured channels for resolving conflicts, such as anonymous voting mechanisms in the Card-based Workshop Tool". In contrast, traditional teams may rely on face-to-face meetings and interpersonal skills to address conflicts in real-time.
- (3) Adaptability to Change: When facing the changes such as project requirements, deadlines, or external factors, "online platforms may enable rapid adaptation through agile methodologies, such as Zoom virtual meetings, and remote collaboration tools Figma or Miro". In contrast, traditional teams may "face challenges in adjusting to change due to established workflows, work breakdown structures, and communication norms".
- 2. Project quality

Through the statistical analysis of scores provided by the same group of teachers to compare differences between the two groups (Figure 1, 2), the results indicate that the group combining online learning and in-house working in 2021 exhibited the highest level of project quality. This finding suggests that integrating elements of both online learning platforms and traditional in-house collaboration methodologies leads to optimal project outcomes. By leveraging the advantages of online tools for asynchronous communication, remote collaboration, and access to diverse perspectives, while also harnessing the strengths of face-to-face interactions, immediate feedback, and established workflows inherent in traditional in-house teams, this hybrid approach maximises project quality. The synergy between online and in-house working environments creates a dynamic and adaptable project environment that fosters innovation, thorough problem-solving, and effective coordination, ultimately resulting in superior project deliverables.

#### 3. Learning outcomes

Findings could demonstrate differences in learning outcomes across the different collaboration modes.

(1) Collaborative Skills: The findings indicate that the online group and the combined group demonstrated notable advancements in collaborative skills. Through the utilisation of online platforms and in-person interactions, team members honed their ability to communicate effectively, collaborate with diverse team members, and navigate complex project dynamics.

- (2) Cross-cultural Competencies: The integration of online learning platforms facilitated interactions among team members from diverse cultural backgrounds, leading to enhanced cross-cultural competencies. Through virtual collaboration and asynchronous communication, students gained exposure to diverse viewpoints, enriched the learning experience, broadened their cultural awareness, and equipped them with the skills necessary to collaborate effectively in multicultural environments.
- (3) Design Proficiency: Analysis of learning outcomes also revealed improvements in design proficiency among students engaged in the combined working model. By leveraging online design tools, accessing educational resources, and participating in hands-on design projects, students developed technical skills, creativity, and critical thinking abilities essential for success in designrelated fields. Additionally, the integration of traditional in-house collaboration methods facilitated mentorship, peer feedback, and practical skill development, further enhancing students' design proficiency and readiness for professional practice.

# **5 DISCUSSIONS**

This study remains ongoing, as the limited number of students in each semester and the inherent variability in student characteristics pose challenges to drawing definitive conclusions from the comparative research. The findings of this study should therefore be considered as indicative rather than conclusive. The research team acknowledges the need for continued investigation into this topic, recognising the importance of further tracking and analysis to deepen our understanding of the dynamics at play. Moving forward, the research team is committed to ongoing monitoring and evaluation, aiming to elucidate the nuanced relationships between collaboration modes and learning outcomes over time.

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# FOSTERING ARTIFICIAL INTELLIGENCE COMPETENCIES THROUGH PROJECT-BASED LEARNING: A CAPSTONE APPROACH

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## ABSTRACT

In today's quickly evolving technological landscape, engineering graduates must be able to understand the fundamentals of cutting-edge technologies. Under this perspective both students and faculty must explore the digital world and Artificial Intelligence (AI) as allies in technological innovation. As the demand for AI expertise continues to rise, equipping students with essential AI competencies has become imperative. For their final capstone projects, engineering students were asked to come up with an innovative system, under the supervision of four faculty members. This paper presents the student's learning experience while designing AI based systems in real-world scenarios and resulted in fostering hands-on experience in novel technologies.

Keywords: Higher education, educational innovation, artificial intelligence

# **1** INTRODUCTION

Artificial Intelligence (AI) literacy has become a necessity of the modern world, especially for engineering undergraduate students, not only computer scientists [1]. Defined as the ability to understand the basic techniques and concepts underpinning AI across various products and services [2], AI literacy is emerging as a pivotal skill sought after by industries driving the current and future labour market [3] [4]. Despite its undeniable significance, the formal integration of AI education has been lagging compared to other areas such as medicine and applied science [5].

The critical need for AI literacy in formal education emphasises the role of students not merely as end users but potential problem-solvers capable of employing AI technologies across diverse scenarios to propose ideas and create solutions [6].

The development of AI skills among final year undergraduate students from Tecnologico de Monterrey was accomplished drawing on the Technological, Pedagogical, and Content Knowledge (TPACK) framework [7] [8] integrated with Project-Based Learning (PBL) technique. The educational model of the Tecnologico de Monterrey is centred on a challenged based model, where students are engaged and work collaboratively to develop disciplinary and transdisciplinary skills [9].

## 2 ENGINEERING DESIGN

At Tecnologico de Monterrey, final-year students majoring in Mechatronics Engineering must complete a compulsory capstone project. This capstone project follows the PBL technique to develop disciplinary competences in all the four main areas of Mechatronics Engineering, namely: control, electronic, mechanical, and software systems. AI technology is not a compulsory topic in the current curricula. Nonetheless, including AI in their project design allows for the students to develop technological innovation.

The incorporation of PBL within the framework of capstone projects serves as a pedagogical strategy of paramount significance in higher education. In the context of capstone projects, where the emphasis lies on culminating academic knowledge and skills, PBL provides a both structure and hands-on methodology. The integration of project-based learning in capstone projects aligns with the overarching goal of preparing students for the challenges of their respective fields by instilling a sense of self-directed inquiry and promoting a deeper understanding of the subject matter and engineering project design.

During the academic semester February-June 2023, 39 students participated in the capstone projects. The students were divided into teams with a maximum of 5 members. Each team was formed autonomously according to their member's interests.

## **3 IMPLEMENTATIONS**

The teams had a choice to either select a project proposed by faculty members or to submit their own. With the objective of developing AI competences among the students, various capstone projects incorporated prerequisites that demanded the utilisation of AI technology. In all cases, the capstone project had to comply with several requirements as listed below:

- Must apply technological tools for the design of mechatronic systems.
- Include at least three areas of the mechatronics engineering.
- Define the product's system-level design.
- Detail design for a physical product.
- Must resolve or alleviate a technological need.
- Must evaluate technical and economic feasibility.

During the detailed design implementation, each team defined the user needs and product attributes to establish the target specifications, schematics, drawings, design alternatives, and production details for each phase, allowing the opportunity to create innovative technological design.

Three projects utilising AI technology were chosen, each one developed by a different group of students. These projects are described as:

- 1. Collaborative Robot Applications in Assembly Task project, herein referred to as CORAL project, integrates a collaborative robot (cobot) and Deep Learning to assist users in assembly tasks; particularly during part handover and storage.
- 2. Gesture Detection System for Collaborative Robot Control project, or Sign-a-bot, aims to design a system capable of controlling a collaborative robot through hand gestures.
- 3. Smart Traffic Light system project, or Visual Road, identifies pedestrians in a crossroad hence selecting the timing of the traffic lights to assign priorities.

### 4 **METHODOLOGIES**

The capstone project course runs for a 10-week period. The initial phase in the pedagogical process involved teams comprehending the requirements and deliverables for their respective projects, concurrently discerning both theoretical and practical needs. Through their analysis, it became evident that the incorporation of AI was imperative. Notably, none of the students engaged in the AI capstone projects possessed prior experience in AI technology; nevertheless, they were proficient in numerical, analytical, and programming skills.

The teams internally segmented into specialised areas based on the project requirements. Broadly, they established three domains: mechanical, electronic and software systems. Mechanical system's students were on charge of the design and construction of any physical element that the final product may require. Those in charge of the software system were responsible for any task that requires coding, e.g., AI algorithms, digital user interface, among others. Finally, the electronic system sub team was responsible for the selection and integration of the mechanical and electronics systems.

The students exercised full control over the project's development, with faculty members assuming roles more akin to project advisors rather than traditional lecturers. Once the teams recognised the advantages AI posed for the solution of their projects, they requested an AI tutorial focusing on vision identification and speech recognition.

To address their concerns, Introductory short courses were conducted by the lectures employing platforms such as Edge Impulse [10] and Teachable Machine [11]. Additionally, frameworks like TensorFlow [12] and TinyML [13] were reviewed. Owing to the unique nature of each project, the AI courses served only as an initial guide for the teams to explore tailored solutions pertinent to their respective projects.

To keep track on their development, a weekly meeting was convened wherein each team presented their progress and disclosed any challenges they may have encountered.

#### **5 RESULTS**

All three projects integrated hardware and software into their design according to their requirements. However, due to their nature, each project followed a distinctive path towards its completion.

*CORAL*. Its objective was to evaluate the feasibility of the interaction human-cobot by means of voice commands on assembly tasks. The team had previous experience with cobot technology. However, they identified that a more complete collaboration between the human user and the cobot could be possible if the system was responsive to voice commands and perceptive to visual cues.

Voice commands recognition was achieved by integrating a Convolutional Neural Network (CNN). It recognises four commands ("bring", "take", "go", "cancel") and seven numbers ("one", "two", "three", "four", "five", "six", "seven"). A pretrained hand-tracking CNN system identifies the user-hand position from RBG-D data to hand over or collect the assembly part. Finally, another CNN uses a camera to classify the parts received from the user and place them in a store area. Figure 1 and figure 2 shows the system functionality.

The system developed by the CORAL team allowed the user a more natural interaction experience compared to that of a standard cobot. The final prototype demonstrated the capability to respond to voice commands, track the user's hand movements, and autonomously execute certain simple tasks such as sorting.



Figure 1. This diagram shows the functionality achieved by the CORAL project. Taken from [14]



Figure 2. Testing setup used by CORAL. Taken from[14]

*Sign-a-bot*. Its aim was to create a more natural interaction between the user and the cobot in settings where verbal communication is neither feasible nor preferable, utilising a set of 18 customised sign language gestures.

A CNN was trained to identify gestures captured through a webcam. Subsequently, the system utilises these recognised gestures to command the operations of the cobot. Figure 3 shows some of the set of gestures recognised. Figure 4 presents the assembled system consisting of a camera, lighting, OLED display and microcontroller board for gesture recognition.

The implemented system enables the user to manipulate the cobot along three linear axes (X, Y, Z), three rotational axes (U, V, W), execute predefined movements or routines, and utilise a pneumatic

gripper. This array of options gives the user the ability to work with complete spatial freedom within a specific workspace.



a) Move Up b) Open gripper Figure 3. Hand gesture used by Sign-a-bot to interact with a cobot



Figure 4. Sign-a-bot assembly system

*Visual Road*. The objective was to control the signal phasing of the traffic lights at a pedestrian crossing through the detection of pedestrians and vehicles. The AI model was created using Roboflow [15], where feature extraction and training were performed. Finally, the model was executed using YOLOv5 [16]. Figure 5 shows a real validation of the performance of the system.



a) People

b) Car

Figure 5. Road crossing identification performed by Visual Road

## **6** CONCLUSIONS

This paper presented a successful integration of AI competencies into the final-year students in Mechatronics Engineering at Tecnologico de Monterrey. The initiative, guided by the Technological, Pedagogical, and Content Knowledge (TPACK) framework and implemented through Project-Based Learning (PBL), aimed to address the growing importance of AI literacy in technological innovation. The implementation phase involving 39 students in capstone projects revealed the effectiveness of Project-Based Learning in developing AI skills. The selected AI projects—CORAL, Sign-a-bot, and

Visual Road—illustrate the practical applications of AI in diverse domains, ranging from human-cobot interaction to sign language recognition and intelligent traffic control.

The methodology employed during the 10-week capstone project course allowed students to comprehend and fulfil the project requirements, even in the absence of prior experience in AI technology. Faculty members served as advisors, guiding the teams through challenges, and facilitating the exploration of tailored AI solutions.

The results of the projects showcase tangible outcomes where hardware and software were seamlessly integrated. The CORAL project demonstrated the feasibility of human-cobot interaction through voice commands and visual cues, employing advanced technologies such as Convolutional Neural Networks (CNN). Sign-a-bot introduced a natural interaction between users and cobots through customised sign language gestures, detected and interpreted by a trained CNN. Visual Road, addressing traffic management, employed Roboflow for feature extraction and training, and YOLOv5 for execution.

The written feedback provided by students at the end of the course highlight the importance of acquiring AI competencies at the undergraduate level. They expressed their enthusiasm on the potential and opportunities of AI utilisation, and the enriching experience gained from integrating AI into their projects as the sole viable technology capable of delivering possible solutions within the established timeframe.

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# PROMPT ENGINEERING ON THE ENGINEERING DESIGN PROCESS

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## ABSTRACT

Exploratory use of prompt engineering in generative AI is undertaken in engineering design teaching. The initial findings using Bing Copilot and Chat GPT on the design process are presented. Research on the influence of prompt construction is of interest, and multimodal AI searches for an engineering component image show it does affect the AI's output. AI is shown to be of moderate use in creating a product design specification (PDS) and elements of a morphological chart. Whilst AI's natural language processing (NLP) outputs look very convincing, they need to be checked for technical accuracy.

Keywords: AI, prompt engineering, design teaching, design process

# **1** INTRODUCTION

The term artificial intelligence, (AI), is attributed to John McCarthy, and generally considered to date from 1956 [1], although its roots may go back a decade further with the creation of an artificial neural network (ANN) model by McCullock and Pitts [2]. On 30<sup>th</sup> November 2022, OpenAI introduced Chat-GPT, a generative pre-trained transformer capable of generating new results from the large text data sets it was trained on [3,5].

ChatGPT uses a deep neural network architecture comprising layers of transformers that enable it to process inputs in natural language text. It can respond to follow-on inputs or questions and refine its answers to create a conversational "chatbot" with replies also in natural language. An alternative to ChatGPT is Google's Bard, a "chatbot" designed using a language model similar to GPT 3.5 [4]. Microsoft also has its own AI large language model (LLM) called Bing Copilot. The ability of these

AI LLMs to generate useful and accurate results is assisted by probability to predict each word (or token). A study on these three AI LLMs, shows they are all effective in translating radiology reports into patient-friendly transcriptions with understandability scores above 70% [6].

Applying these AI LLMs effectively has given rise to a new research interest called prompt engineering in which user's questions or prompts are evaluated against the accuracy or usefulness of the AI's answers. A study on prompt engineering with ChatGPT shows how an iterative methodology can optimize interactions [7].

This paper explores prompt engineering in the engineering design process, with generative AI language models Bing Copilot, previously Bing Chat, and ChatGPT.

## 2 METHODOLOGY

The research approach uses prompt engineering in two generative AI software systems to explore elements of design teaching, outlined below, in the first year of a mechanical engineering course. Bing Copilot is used in parts (a) and (b) and ChatGPT in part (c). Coincidentally, there is another generative AI software also called Copilot which is used for generating programming code. A study in teaching concludes that there is pedagogical value in students interacting with this transformer language model so they can reflect on code failures [8].

Using prompts of natural language in the conversational mode, the product design specification (PDS) is refined to

- a) use conversational prompts on parts of the design process (PDS, morphological chart, CAD model),
- b) explore how prompt construction influences AI image outputs,
- c) use natural language prompts to check the technical accuracy of a short essay.

## **3 DESIGN PROCESS**

The students enrol onto mechanical engineering programmes with strong analytical skills in "closed" problems. Research highlights the importance of design education to teach an open mindset using "unframed" problem solving so that students not only function in a design discipline but also in an "expanded field" in which wider issues occur [9]. The first-year students are given an "open" brief and create their designs using the linear design process [10], and the following section considers generative AI and its impact on teaching the design process.

## 3.1 Product design specification

The developments in AI's transformer language models enable not only the prompts here to be in natural language but also the outputs [8] and therefore be more usable in student work. The teaching gives a PDS template to the first-year groups and introduces a British standard to promote awareness of the PDS's scope and show how a few specification elements can be developed. Further specification elements in their PDS shows additional effort, so this section explores how Bing Copilot's AI assists with it.

This year's design project is to create a table tennis ball launcher. The launcher must be automatic and land the ball in three separate areas, so the first prompt is, "write a product design specification for a reciprocating table tennis ball launcher with three target areas." The AI LLM responded with an "Overview" (textural statement), and four specification elements:

- i. Key Features
- ii. Technical Specifications
- iii. Performance Metrics, and
- iv. Use Cases

Under the AI's Technical Specifications is stated the power source: input 220V AC and output 12V DC; and it also states, *"motor: brushless DC."* In the current design project, students are limited to a battery voltage of 9V, so a follow-up prompt says, "It must be 9V battery operated." AI's response appends the product design specification's title with, "battery operated," which is encouraging, but under the Technical Specifications the motor type is still listed as brushless DC (BLDC). This combination is not impossible, but generally BLDC motors are used in the 12-48V range and, therefore, might not be the best option.

Nonetheless, looking at a specification for a 9V BLDC motor, it shows the continuous operating range has a maximum speed of 50000 rpm and delivers a maximum torque of 1.3 mN-m [11]. Adding a reduction gearbox of 200-to-1, still produces a relatively low torque of 0.26 N-m and an output speed of 250 rpm. Whilst lower operating speeds are possible within this motor's operating range, it seems that this type of motor is better to suited higher-speed applications, such as, driving the propellors of drone. In Bath's design project, students have full control over their design, so their prototype might have high levels of friction between rotating parts from misalignment or incorrect bearing decisions. Having a higher torque motor would, therefore, be better at overcoming frictional forces and continue to drive mechanisms so that they can demonstrated in a presentation. Another point in terms of suitability for the Bath design project is cost. This motor's unit cost is £63.47, which represents 75% of the students' budget for purchases from external suppliers.

The point is that AI did not suggest another type of electric motor, even though they are widely available, namely, the brushed-type DC motor, and at a tenth of the price, including a gearbox. It is possible that first-year students might spot this themselves, but it is unlikely: the trend suggests that students have a reducing level of hands-on engineering experience.

Another technical point is that the AI's PDS does not include a controller, which is needed to operate the BLDC motor. Again, it is unlikely first-year students would spot this and therefore not order it. Also, from the author's experience, students tend to believe software-generated results even over their own correct bench-mark calculations, and so might tend towards accepting AI searches more and more. So, if students omit an essential part, such as a controller, it would result in a hold up in the prototyping phase, which, for students experiencing the design process for the first time, is something to be avoided, pedagogically.

Reviewing AI's four specification elements above, it is noted that there is not a safety or legal element. This is not necessarily an issue for engineering design teaching, particularly in this first-year design project, because the emphasis is on delivering the stages of the design process, along with the application of a little mechanics theory. That said, when the follow-up instruction, "Include British Standards and

ISO standards" is entered, AI outputs a list. And although the list is generic, it is helpful to the tutor in saving time, whilst still making students aware of standards in a wider industrial context.

In a new search, in which AI is asked to write a PDS, maintenance is listed as a specification element. This is useful as it extends the learning into in-service considerations, such as, the need to specify maintenance schedules involving lubrication points and part replacement. In the first-year design project, this may be useful for awareness, but is not needed for a single prototype. However, the omission of maintenance in the previous search points out, perhaps, the slightly random nature of the AI software. This underlines the importance of the teaching, in which guidance on, in this case, the British Standards and design elements enable students to ask relevant repeated questions to, hopefully, refine the AI's search.

## 3.2 Concept design

This section explores the assistance AI gives in creating a concept using a design technique for this purpose called a morphological chart [11]. For the above reciprocating table tennis ball launcher (9V battery operated), AI is asked, "Generate a morphological chart." The response is shown in table 1.

		Options				
Functions		1	2	3		
1	Reciprocating mechanism	Linear actuators	Ball feed system	Guides and rails		
2	Ball launching mechanism	Wheel / paddle material	Motor types:	Spin adjustment		
3	Target areas	Positioning systems	Spin adjustment mechanism			
4	User interface controls	LCD display types	Control buttons	Emergency stop		
5	Power source	Battery compartment design	Voltage regulator types			
6	Materials and durability	Frame material	Ball hopper material	Moving part durability		
7	Assembly & maintenance	Assembly instructions format	Lubrication points			

Table 1. Al's suggested morphological chart for a battery-operated table tennis ball launcher

There are several points to consider here, and the first is the appropriateness across the range of functions. The first two, reciprocating mechanism and ball launching mechanism, are relevant.

However, for the suggested function options, it is questionable as to how useful those are for the reciprocation mechanism. One might expect the name of a complete reciprocating mechanism to be given, such as, a quick-return mechanism, because students could investigate this and learn more. However, AI's suggestions are at a level below, the part level, and this, is *not* a function concept. For example, AI's sub-list for "linear actuator types" are lead screw, rack-and-pinion, and cam-driven, which, although could move a launching head back and forth, they would need another mechanism to create the forward and reverse motion for this to happen. One would suggest the reciprocating mechanism would convert, for example, a continuous rotary motion into a linear or angular motion all-in-one.

It is, also, strange to have "ball feed system" listed as an option for the reciprocating mechanism. Rather, it could be put as a separate function. Also, questionable is "power source." It might be a point of pedantry, but the machine is already known to be powered by a 9V battery, so, arguably, this function is redundant and needs only to be listed in the PDS. Similarly, item 7, seems misplaced and might only confuse students in terms of thinking they need to develop concept solutions. As already discussed, maintenance is useful for creating an in-service schedule, but would not be one of the functions of the working machine.

To develop AI's morphological chart for the table tennis ball launcher, the following instruction was given, "Add ball storage function." Interestingly, AI now gives what should be two concepts, "ball hopper extension" and "automatic ball feeder," see table 2, but they really are two parts which form the "ball storage system." This is explained by three bullet points listed for the hopper extension: 1. Extend
the existing hopper to accommodate more balls, 2. consider a transparent polycarbonate extension with a secure lid, and 3. Capacity of up to 200 balls.

	Functions	1	2	3
1	Ball storage system	Ball hopper	Automatic	
		extension	ball feeder	

Table 2. Al's suggested concept solutions for a ball storage system

For option 2, one might think this should be a function, and as such, would have concepts solutions like a Geneva mechanism or rotating disc with a hole. The three sub-points are: 1. a motorized system, 2. components, and 3. operation. The components listed are conveyor belt, ball sensor, and motor. Together they might form one concept solution and therefore give students a basic concept solution. Alternatively, this might be viewed as only half a solution (or a transfer system) and in need of another mechanism by which the balls can be fed one at a time, and then transferred to the launching function. It may also be a red herring, because if the hopper is above the launching function, gravity would transfer the ball.

#### 3.3 Multimodal-LLMs component images

Since the introduction of GPT-4 in 2023, AI can accept image and text inputs thereby becoming multimodal large language models or M-LLMs [3, 13]. This is a significant change because "AI capable of generating images from a text prompt are becoming increasingly prevalent in society and design" and so a study is made on text-to-image AI in the concept generation stage of the design process [14]. Research interest in visual prompt engineering shows the potential of redefining the field of computer vision applications [15]. In the creative process of art and design education, student and instructor survey results indicate prompt engineering to have a profound impact on generated imagery [16].

In exploring AI images, it would be useful to gauge the effect variations in the construction of the prompts have. A study in prompt engineering finds that *"crafting effective prompts can be challenging, leading to potentially inaccurate or contextually inappropriate responses,"* and so proposes a prompt methodology, GPEI: goal, prompt, evaluate and iterate [6]. A variation in the consistency of AI outputs as a result of different prompt styles is also found in medical applications [17].

The approach here uses text-to-image prompt engineering in Bing Copilot (image creator) asking it to output an image of an engineering component, a spur gear. Six prompts are used and in each one the natural language question has a different verb, and it is one which might be used in a design assessment. Although it is uncertain what significance this has, it was decided to introduce a scale by which to measure the output of the searches.



Figure 1(a). Effect of changing the verb in natural language prompt construction in text-toimage AI outputs of an engineering component; 1(b). An example of an ASCII-based image

In figure 1(a), is the result of AI searches relating to Bing Copilot outputting a drawing of a spur gear with a PCD of 20 mm and a MOD of 1. The scale ranges from 1-7 where: 7. is an accurate drawing, 6. is an inaccurate 2D drawing, 5. is a CAD model, 4. is an accurate image or picture, 3. is an image with the correct gear type, 2. is an image of inaccurate gear type, and 1. is text and or web links.

In figure 1(b) is an example of an ASCII-based diagram in AI's output for the spur gear prompt. It is graded at 6 in the radar plot to optimistically recognize the shape is influenced by the prompt. It may be that too much is being read into the diagram, but the value in the centre is correct for the values in the prompt and has some control over the 2D image or pattern. Although this is not a useful image for teaching, research shows how computers can use ASCII art to construct images more realistically [18]. To explore prompt construction further, notwithstanding how current design teaching uses parametric software, text-to-image natural language prompts ask AI for 3D models. When asked to "*Create* a 3D CAD model of...," AI responds, "I apologize, but I'm unable to create a 3D CAD model in this chat interface." However, when asked to "*Design* a 3D CAD model of...," AI responds, "Certainly! Designing a 3D CAD model for a reciprocating, three-target area table tennis ball launcher powered by a 9V battery is an exciting challenge. While I can't directly *create* the CAD model here, I can guide you through the conceptual design and key components you'd need to consider." This shows that variations in prompt construction can elicit different responses.

# **4** AI ESSAY INVOLVING TECHNICAL POINTS

To find out more about how AI responds with engineering information on gears, a prompt in natural language asks ChatGPT, "Write me a 100-word essay on the advantage of spur gears over helical gears." The AI software responded with:

# ChatGPT

# ChatGPT

Spur gears offer distinct advantages over helical gears in certain applications. Firstly, they are simpler in design and easier to manufacture, leading to lower production costs. Additionally, spur gears produce less axial thrust compared to helical gears, making them ideal for applications where axial space is limited or where thrust forces need to be minimized. Moreover, spur gears exhibit higher efficiency due to their straight-toothed design, resulting in smoother and more precise motion transmission. Lastly, spur gears are often preferred in applications requiring intermittent or infrequent engagement, as they produce less wear and noise during operation, contributing to longer gear life.

#### Figure 2. A short AI essay on the advantages of spur gears

The details in AI's comparison, in figure 2, are all useful, except one. The last sentence suggests noise is less, but this is not true. An advantage of helical gears is that they create a gradual engagement and reduced noise. If it is possible to know such statements can be produced by AI, then they may be used to reinforce lectures by asking students to find the erroneous point. Equally, even if the search is not given, it may still be a useful teaching exercise to ask students to critique such an AI search.

# **5 CONCLUSIONS**

The application of AI research is relatively less established in engineering design teaching, compared to other disciplines such as medicine, so exploratory findings are presented on phases of the design process using Bing Copilot and ChatGPT.

In prompt construction, it is found that the type of verb, such as, create and produce, used in an M-LLM search elicits different levels of information. These findings suggest that there is a slight learning curve for the user, particularly in conversational searches.

The assistance an AI "chatbot" gives in creating a PDS is helpful, particularly from conversational prompts where NLP outputs give human-like descriptions. The assistance it gives with morphological charts is modest. Whilst some of the functions it identifies are valid, others are less so, or not at all, and this could be less helpful to first-year students. Similarly, the concept solutions suggested are not always complete separate solutions, so care is needed to discern what is useable or, indeed, how it can be made useful.

In a comparison between two engineering parts, AI is shown to give a well-written answer, which would be useful in an essay. However, one of the points it gave is incorrect, and so there is a need to carefully check it for technical accuracy. Pedagogically, it may be possible to reverse the negative aspect of AI by using it as a teaching tool, in which, students critique AI searches on tutor-led questions.

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# REGENERATIVE PRODUCT DESIGN: A LITERATURE REVIEW IN AN EMERGING FIELD

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### ABSTRACT

Regenerative practices have evolved over time from the paradigms of sustainability and regenerative sustainability. This literature review focus on guides and methods in the emerging field of regenerative product design and regenerative materials. The study identified a knowledge gap and a need for methodologies to bridge the higher system levels of socio-ecological processes and regenerative architecture with the product and material levels. The study presents 10 common denominators for regenerative design processes found in architecture and socio-ecological introduces a first attempt at classifying regenerative materials. The study's findings indicate a clear need to develop strategies and methods that product designers can implement in their future professional practices and design educations.

*Keywords: Regenerative development, bio-based materials, regenerative materials, regenerative sustainable behaviour, product design* 

### **1** INTRODUCTION

Regenerative practices have evolved over time from the paradigms of sustainability and regenerative sustainability. Central to circular and regenerative economies and cultures are the prevention of the depletion of raw materials and the continued undermining of ecosystems [1]. The key difference between sustainable and regenerative design is the holistic worldview fundamental to regenerative practices and going from "recycle, reduce and reuse" to "restore, renew and replenish." The term regenerative refers to a process that repairs, recreates, or revitalises its own sources of energy, air, water, or any other matter [2], [3]. Regenerative design sets an ecological benchmark that is pre-industrial and net positive in impact [4], [5], [6]. Mang & Reed [6], supported by du Plessis [7], suggest a transition towards a new worldview as necessary, from a mechanical view towards an ecological one. Accommodating a transition towards a regenerative future entails understanding regenerative practices, not only on a higher system level but also the materials in a product and how they affect the user's behaviour and interaction with the product. Regenerative systems can be defined in different scales depending on the temporal and spatial framing; the most common are global, regional and local. Architects have been working with regenerative buildings for the last decade and have developed theoretical framing, methods and assessment tools. This literature review aims to map out existing definitions and methods on an emerging level, the product and material level.

*Our world is in transition. We no longer live in an era of change but are witnessing the change of an era* [8].

#### 2 METHOD

The initial literature study was conducted using backwards and forward snowballing [9] as a systematic search strategy. Snowballing was applied as it dramatically reduces the amount of noise in database searches, mainly when the keywords for searching include general terms (e.g. design and material). Searches were conducted through Google Scholar, Science Direct, Lib Search and ResearchGate. The primary keywords used were regenerative material, regenerative design, regenerative sustainability, regenerative systems and the second set of searches combined with manufacturing, framework, methods, sustainable behaviour, design for behavioural change, and sustainable future. This reduced the initial search result of 40 601 papers to 182 papers; of these, 94 papers were selected as primary sources. A comparative study [11] of the literature and electronic sources was conducted. In the first step, the commonalities and distinct differences of the collected definitions and methods were noted. The material

was then coded top-down and bottom-up, resulting in 10 main categories (see Table 1). Each category was summarised in short descriptions.

# **3 REGENERATIVE GUIDES & METHODS**

In the initial review, no guides or methods for regenerative product design were found, so the review was expanded to architecture and social-ecological systems. Regenerative development as a scientifically grounded approach acknowledges the principles of interdisciplinarity and methodologies within systems thinking, which recognises the interdependencies and feedback loops among ecological, social, and economic systems [12]. Working within a field of high complexity, in the cross-section between disciplines and with different expertise and skillsets required in a regenerative development process, requires a strategy that breaks down the complexity into manageable parts. Most of the reviewed guides and methods offered around 10 guiding principles or steps, and Table 1 lists the most common denominators with short descriptions.

Defined as materials made of 100% organic raw material from a renewable resource and 100% compostable.
Must derive from regenerative non-polluting feedstocks that do not compete with food or feed production.
Organic waste streams from food industry, agriculture, and forestry. (Can also
in the future be non-organic waste processed with biotechnology e.g.
mycelium and bacteria into nutrients.)
Non fossil fuelled derived energy with net-zero impact.
Low energy consumption in manufacturing, use face and end of life/ new life.
In some cases, contributes to lower energy use in its application during use
face.
Actively restore and revitalise ecosystems and communities for positive and
lasting change.
The extraction and harvesting of the raw materials do not negatively impact
the region's habitats and ecosystems or contribute to deforestation.
Stakeholders are acting in an ethical way and contributing to regenerative
systemic change in local and global communities.
Designing ecosystems that integrate natural and human living systems that
contribute to and sustain health and wellness for both.
Materials which directly contribute to the sequestration, neutralisation, and
elimination of GHGs. Renewable materials that contain CO2 contribute to an
increase in sequestered carbon. Low embodied carbon in the manufacturing
process, transport, use face and embodied in the material itself.

Table 1. Common denominators identified in reviewed regenerative guides and methods

In architecture, the Building Information Modelling (BIM) tool is a digital representation of physical and functional characteristics of a facility; it is often used in combination with Life Cycle Assessment (LCA), which is also commonly used in product design. When analysing the BIM tool combined with an LCA tool through integrated methods, it became clear that the limitation of this approach is that BIM-LCA tools require a wide range of input data that usually are not present in the early stages of development; thereby, the regenerative design process loses momentum, and do not provide a holistic overview. Supporting methods are needed to provide a richer understanding of the regenerative aspects during the design process. Several of the reviewed architectural guides and methods are challenged when it comes to combining quantitative measures, e.g. Regenerative Contribution Units, with qualitative ones, e.g. Sustainable Development Goals and calls for further development. Integrating data science and artificial intelligence (AI) as tools can contribute to accelerate the transition towards the regenerative approach [32]. Examples of regenerative design guides for system development are The Regenerative Lens and The Regenerative Evaluation tool, which try to break down complex systems into comprehensible parts for novices and communities. The Regenerative Lens [13] is a conceptual crossdisciplinary regenerative systems framework that can be used as a reflexive tool that can be applied as an orienting tool to guide practices for those unfamiliar with regenerative development and to

conceptualise regenerative systems. It focuses mainly on regenerative social-ecological systems and identifies five key parameters to achieve regenerative outcomes (1) embodied ecological worldview (2) mutualistic interactions (3) high diversity (4) agency, and (5) reflexivity. The Regenerative Evaluation tool [14] provides general guidance for thinking and decision-making that identifies regenerative development principles and core characteristics of regenerative living systems. It is a qualitative evaluation tool for reflection and action, suitable for co-creation in a community. The review found clear dominance of assessment methods and identified a profound lack of generative design methods. The only method found that directly dealt with the design perspective was the framework *Designing from a place* [15]. It builds on theories and extensive practical experience from developing regenerative architecture and can be applied in product design projects with a few adjustments. The Regenerative Design and Development method identify four principles (1) co-evolving mutualism (2) place-sourced potential (3) regenerative capability, and (4) vocation of place (fig.1).



Figure 1. The overall framework guides and structures the approach to the Regenerative Design and Development method [15]

# 4 REGENERATIVE MATERIALS

Regenerative materials are materials that play an active role in restoring and regenerating natural resources, ecosystems, and biodiversity. A material cannot be regenerative in isolation; its potential to regenerate depends on the infrastructure, communities, and ecosystems within which it exists. Materials should preferably be built on circularity at three levels: raw materials, recyclability, and biodegradability to allow for cascading [16]. Building a regenerative materials system entails designing compostable materials that return biological nutrients to soils at the end of life. Biopolymers such as chitin, sodium alginate, carrageenan, keratin, gelatine, and whey protein have the potential to support crops' nutrient needs as compost in regenerative agriculture systems. They can also add beneficial carbon and organic matter needed by plants and soil microbes back into soils and enhance their ability to sequester carbon [17]. The U.K.-based company Biohm was one of the first companies to develop models for regenerative material development. They have divided the development into four categories (1) regenerative decarbonisation (2) organic waste streams as material resource (3) mycelium technology (4) bioremediation with mycelium and bacteria [18]. Another example of implementing regenerative practices is The Regenerative Cotton Standard (RCS) certification by The Aid by Trade Foundation that aims to help smallholder farmers be more resilient to the effects of climate change and offer companies a solution to future-proof the production of cotton as an essential raw material for their textiles [19]. RCS targets the entire production system to achieve these aims rather than only the cotton itself.

#### 4.1 Agricultural resources as material resource

Agricultural resources for regenerative material development must derive from regenerative, nonpolluting feedstocks that do not compete with food or feed production [16] [20] [21] [22]. Agricultural residues and by-products are a viable feedstock option for biomaterials production if the sustainability of underlying agricultural systems is considered sustainable. In regenerative farming the use of cover crops offers lignocellulose biomass as well as the residues from the main crop and buffer zone pruning [20] [22]. The other category of agricultural resources is biomaterial feedstocks such as cotton, nettles, hemp, natural latex, cork, and wool that can be sourced from polycultures or livestock-integrating regenerative agroecosystems. An overlooked regenerative outcome is using the biomaterials as soil nutrients when it is no longer possible to reuse the material [20]. An emerging category is ocean farming, which, besides providing 'ecosystem services,' regenerative ocean farms can also boost marine biodiversity. The farms' assemblies mimic the vertical structure of an ocean reef, providing layers of different habitats for a wide diversity of marine species [16]. Raw materials that are sourced from regenerative ocean farms are, e.g. seaweed, algae, eelgrass, and mussels (used for cleaning the water and not suitable for eating).

### 4.2 Organic waste streams as material resource

Using secondary biomass sources such as industrial byproducts and post-consumer food waste reduces the demand for primary crops, reducing stress on soils, land use, and biodiversity [21]. The food industry provides a constant flow of residues from processing food stock before reaching consumers. The residues can sometimes be processed in two steps, first for animal feedstock, and then the final residues become biomaterials. Biopolymers such as PHA can be derived by bacteria from food waste and qualify as regenerative biopolymers as it is compostable and a part of the biological cycle [17]. PLA, on the other hand, is only compostable in industrial compost in a controlled environment and only qualifies as sustainable, not regenerative, material, as it contributes to microplastics if it ends up in nature.

#### 4.3 Forestry resources as a material resource

Regenerative agroforestry practices improve and increase ecosystem services at the local and landscape level, capturing carbon, improving biodiversity, controlling erosion, and improving water resource management [23]. Residues from regenerative forestry and wood biomass are important material resources and have been throughout our history. With new processing methods, both biochemically and mechanically, the wood biomass offers lignin, cellulose, hemicellulose, oils, bark extractives, and derivates combined into new materials having regenerative potential and replacing fossil-based materials.

### 4.4 Living materials

When living entities such as mycelium, algae, yeast, and bacteria were introduced to the intersection of biology and design, it created a new landscape, bio fabrication of materials, artefacts, and architectural systems. Co-designing with nature entails manufacturing under life-friendly conditions, in water, at room temperature, without harsh chemicals or high pressures. Bioremediation might offer great potential in the future with strains of mycelium that can consume plastics, e.g. PE, PU, PET, and PS, into sugars, benign hydrocarbons, and carbon dioxide. The sugars and hydrocarbons are consumed by the mycelium and the carbon dioxide is transformed into oxygen using photosynthesising organisms [18].

# **5 SUSTAINABLE BEHAVIOURS**

In a regenerative future, good intentions must be transformed into responsible behaviour. The first step is recognising that a sustainable future needs to transform physical and social infrastructures [24]. If we do not address intangibles like motivation, will and behaviour, the tangible solutions that seem so obvious will continue to elude us. The users' behaviour becomes an essential part of the system by facilitating changed perceptions and behaviours from the current take-make-dispose culture towards environmental and circular user behaviours, e.g. care, maintenance and emotional bonds with a product as the first step towards regenerative practices. Design for behavioural change provides methods that identify the driver for users and strategies to encourage desirable environmental and circular behaviours. Increasing environmental awareness amongst users has shown to be an efficient strategy [25] [26].

# 6 **DISCUSSIONS**

According to Wahl [5], reconnecting with nature is a precondition to achieving a regenerative global and local system. The regenerative architectural framework *Designing from Place*, developed by Mang and Reed [15], states that it demands a radical change in the designer's mindset and stresses the importance of how designers interpret the user's role in a built environment. In literature, regenerative materials are, in general, defined as (1) can be sourced sustainably, (2) used efficiently, and (3) recycled or repurposed at the end of their life cycle [5]. This definition needs to be expanded to include the following parameters: energy, water, biodiversity, health, and equity to be able to provide a holistic view. In material design, there are emerging approaches, e.g. bio-fabrication [27], livingness in materials

[28], DIY materials [29], organic waste streams as material resources [30], and established methods like Material Driven Design [31], that could be useful in regenerative design practices as they interconnect the design of the material and the product in an early stage of the design process. Mang & Reed [15] state that each time design practitioners select a particular set of methods and techniques to address a design problem or measure and evaluate the solution, they implicitly or explicitly express what they believe is the ethically appropriate way to work based on their worldview. This literature review identified skills such as Eco literacy, facilitating participatory and co-creative processes, psychological literacy, and cultural sensitivity are needed when working with regenerative development processes as a designer.

# 7 CONCLUSION & FINAL REMARKS

This literature review in the emerging field of regenerative product design has identified a need to develop guides and methods supporting the design process of regenerative products made of regenerative materials. Literature provides rich theory, case studies and guidance for, e.g., the selection of construction systems, measurable performance indicators and thresholds when developing regenerative architecture. The identified common denominators for guidelines and methods in the regenerative development of architecture and social-ecological systems offer a foundation for further development of methods in the field of product design and design education. The study concludes that a product or material cannot be regenerative in isolation; its potential to regenerate depends on the infrastructure, communities, and ecosystems within which it exists. To be considered a regenerative material, the raw material must come from a regenerative source and be processed in a sustainable and circular manner. The study identified four categories of regenerative material resources: agricultural resources, organic waste streams, forestry resources, and living materials. A series of existing methods and frameworks from materials design have been suggested as inspiration or for integration in the future development of regenerative design processes. Further studies will be made to explore the dynamics and different elements of existing regenerative design methods from surrounding fields as a step towards developing a regenerative product design process. This paper has been written in collaboration between a doctoral student (main author), two BA design students and a product designer.

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# EXPLORING THE USABILITY OF AI PROMPTS FOR MECHANICAL ENGINEERING DESIGN DEVELOPMENT

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# ABSTRACT

Computational support for concept exploration has been a research development in the last two decades, and the ascent of AI tools such as Chat GPT and generative design is further expanding it. Mechanical engineering tends to focus on more stringent functional requirements and compliance with regulation, and while the potential of AI developments to support it exists, it also likely requires significant oversight by the human. Exploring the use of AI in mechanical engineering design and the level of trust placed on its outcomes is an important question for future engineering design development, especially since AI and machine learning are improving exponentially. This paper explores the levels of helpfulness/need for oversight and checks by humans in terms of where AI could be beneficial in the mechanical engineering design process, how this could be supported, and how reliable can it be. Exploration of students' perception of AI and its objective usefulness was contrasted, by performing a comparison between designs conducted with and without AI support. AI tools used focused on product design specification generation, concept image generation and generative design. Then recommendations were given on tools that are currently considered to be helpful for mechanical design development, highlighting the positives and negatives of the approach using AI and potential for adoption of AI in engineering design education.

Keywords: Mechanical engineering design; education; AI; generative design

# **1** INTRODUCTION

AI scenarios are being discussed with possible futures envisaged ranging from the, worst case scenario, collapse of the society in which education would be necessary to adapt and survive, to fully automated AI luxury scenario where machines take over human work but the outcomes are positive for the society, requiring educational focus on other productive endeavours [1]. The history shows us that technological progress is rarely stopped, and that AI developments will likely continue regardless of societal concerns. A good example is writing, we have gone from quill to pencil to pen, to typewriters to computers. Each jump in technology has been met with apprehension and concerns about its effect on the future, but ultimately, we have devised ways to use that technology reliably, responsibly and in ways that improves our activities - no one is using typewriters these days. Regardless of the scenario that the future ends up resembling the most, our ability to use AI effectively and efficiently will be crucial for mechanical design of the future. Instead of fighting progress, a more productive approach would be to establish ways to support learning in AI mediated environments [2]. Utilising pedagogical practices that include collaboration between educators and learners to re-imagine education futures and further enhance them to include more creativity, complex problem solving, and critical thinking are a step towards this [2]. To explore pedagogical practices in utilising AI in the context of mechanical engineering design, this paper explored the AI tools' potential to support product design specification (PDS) and concept design generation. It reports the outcomes of a student project focusing on a mechanical design of a Formula 1 (F1) wheel nut, first independently and then using AI. Challenges they have encountered throughout that process were analysed and recommendations are given for pedagogical approaches to use of AI in similar student projects in the future.

# 2 ADVANTAGES AND CHALLENGES OF AI FOR MECHANICAL DESIGN

Mechanical design is a highly regulated field, in terms of the need to comply with safety requirements, risk assessments and standards guiding final product certification procedures. Therefore, even if we approach AI optimistically, as a tool that can help improve our design process, we need to ensure that we fully understand what kind of outputs it is able to provide and how we could validate them.

AI has the potential to improve many aspects of a mechanical design process:

- AI does not draw from designers' prior experience so it would not be limited to designers' preconceived notions of functionality, which can lead to fixation or bounded ideation [3, 4]. Ideas that might not have worked in the past, might be feasible with advances in technology and AI suggesting them for consideration may re-introduce them, while experienced designers would potentially overlook them.
- AI is able to rapidly provide summaries of information available to it, and in some cases (e.g. PDS development) this could be highly beneficial to a designer [5].
- AI produces fast, high quality, visual representations. In mechanical design, visualisation, whether in a form of a sketch or an image, can often convey the problem or the solution far more effectively than a written description [6].
- AI can provide shape optimisation based on loading requirements and limitations on space usage defined by designers [7]. This combined with new manufacturing processes can lead to significant advances in part performance.

AI also has, potentially significant, drawbacks that need to be controlled:

- It is difficult to establish if AI suggestions comply with standards and regulations for a specific context, as AI often is not transparent about data sources, leading to a lack of trustworthiness [8]. More concerningly, AI may indicate it complies with standards and regulations whereas in reality its decision making is based on inaccurate data, which could subsequently lead to costly late-stage design changes likely unacceptable for the designers [9].
- Scientific principles and emerging requirements those place on mechanical designs can occasionally be too complex for AI to integrate in concept generation contexts [10].
- All solutions AI suggests are limited to information it has access to, and therefore can lead to a very specific type of fixation (e.g. "naturalistic" shapes too expensive to manufacture) [11, 12].
- Users typically do not know where the data they are inputting into the AI system is stored and who may have access to, leading to potential IP issues for both parties [10].
- It is difficult to access the information about, and potentially even understand, the approaches AI takes, making it difficult to evaluate the proposed solutions (i.e. black box approach) [10].

In other highly regulated fields, medical for example, similar challenges have been identified and concerns have been risen regarding AI reproducibility and generalisability [13]. Despite the high number of models published for running of mechanical ventilators (12,422 in 2019), only 130 models received approval for clinical practice from the FDA in 2020, due to lack of validation [14].

# **3 EXISTING AI OPTIONS AND HOW THEY COULD BE USED**

Three types of AI applications are explored in the context of mechanical design in this paper: (1) natural language models, (2) image generation models using chat prompts, and (3) generative design models. All three types rely on machine learning and probability models, however from a user perspective they have very different uses and applications.

*Natural Language Models* provide written answers to questions or prompts given to them by the user. They can be a useful tool for high level questions users are seeking answers to such as "What are the types of brake mechanisms typically used in a car?". The quality of the response is subject to the prompt wording (e.g. specifying the tone of the Chat GPT to "as if I'm an engineer" improves response detail and complexity of answer), as shown in Figure 1. This approach could be used to explore the PDS and potentially gather useful data in the early conceptual design stages.

*Image generation models* produce an image based on a prompt from the user. They can often be trained by supplying reference images different weights can be assigned to different elements of the prompt. Exclusion criteria can also be added. Most current image generation programs are used for generating artwork and allow the style of art to be specified (e.g. animated or painting). Some developments aiming to support engineering design specifically are evident, such as Leo (www.getleo.ai) where the user would be able to provide a description of a design from which the software generates CAD that is editable by the user. However, this solution is still at relatively early stages of development and currently only provides image generation, as can be seen in Figure 2. Image generation could be used during brainstorming, while the basic visualisation of shapes and their associated functions are being explored.

#### Answer without style specified Answer style specified "as engineer" 1. Disc brakes: These are the most common type of brakes found in modern cars. Disc brakes Disc Brakes consist of a rotor, caliper, and brake pads. When you press the brake pedal, hydraulic pressure Disc brakes employ a rotor, typically made of cast iron or composite materials, mounted to the forces the brake pads against the rotor, creating friction and slowing down the vehicle. Disc vheel hub. brakes are known for their reliability, efficiency, and ability to dissipate heat quickly, making the \* The caliper, housing hydraulic pistons, encloses the rotor. Within the caliper, brake pads suitable for high-performance vehicles. usually made of friction material like ceramic or semi-metallic compounds, are held 2. Drum brakes: Drum brakes are less common in modern cars but are still used in some rear-whe When the brake pedal is pressed, hydraulic fluid is sent from the master cylinder to the caliper, drive vehicles and older models. Drum brakes consist of a brake drum, brake shoes, wheel causing the pistons to squeeze the brake pads against both sides of the rotor. cylinder, and springs. When the brake pedal is pressed, hydraulic pressure pushes the brake This action generates friction between the pads and the rotor, converting kinetic energy into shoes against the inside of the brake drum, creating friction and slowing down the vehicle. Drum heat, effectively slowing down the vehicle. brakes are generally less efficient than disc brakes and are more prone to overheating, but they Drum Brakes are simpler in design and often less expensive to manufacture. Drum brakes consist of a cylindrical brake drum attached to the wheel hub Inside the drum, brake shoes, fitted with friction linings, are position In addition to these primary types, there are also some specialized braking systems used in \* Hydraulic pressure from the master cylinder pushes brake shoes outward against the inner certain vehicles or situations, such as regenerative braking in hybrid and electric vehicles, wh surface of the drum when the brake pedal is pressed. es energy from braking to recharge the vehicle's battery, and anti-lock braking system Friction between the brake shoes and the drum creates the necessary braking force (ABS), which prevent the wheels from locking up during hard braking, improving control and converting kinetic energy into heat and slowing down the vehicle. stability. Regenerative Braking (found in hybrid and electric vehicles): \* This system harnesses the kinetic energy produced during braking and converts it into electrical energy to recharge the vehicle's battery. When the brake pedal is pressed, electric motors act as generators, converting the ve kinetic energy into electrical energy. This energy is then stored in the battery for later use, such as po during acceleration or providing electrical accessories. Anti-lock Braking System (ABS): ABS prevents wheels from locking up during hard braking, maintaining traction and ste control. Sensors monitor wheel speed, and if they detect rapid dece eration indicating potential

#### lock-up, the ABS controller modulates hydraulic pressure to the brakes.

By rapidly pulsing the brake pressure, ABS allows the wheels to continue rotating while still providing braking force, preventing skidding and maintaining stability.

#### Figure 1. Chat GPR output; left - basic question prompt, right -"as an engineer" prompt



Figure 2. LEO brake mechanism created from text prompt and basic sketch prompt

*Generative design* requires the user to input the location of forces on a predesigned 3D model, limit areas where material should not be placed, choose a manufacturing process to be used, and then uses finite element analysis to find the best mechanical structure optimising for mass reduction and strength requirements. Generative design is used during detailed design, when the key design decisions were already made, and the shape is being optimised for strength and weight enhancement.

# 4 CASE STUDY OF F1 NUT DESIGN

Potential for use of AI in mechanical design education was explored on an example of an F1 wheel nut development. A final year mechanical engineering student was given a task to "explore where in the design process AI could be beneficial, how they would use it, and how reliable they think it can it be". F1 wheel nut was chosen as it was simple enough to design twice in the time frame given, but complex and regulated enough to consider key mechanical engineering challenges that are making use of AI difficult during the design process. Its design and the forces it must be capable of withstanding are bounded by the FIA regulations and physical constraints of materials used. At the same time as F1 is a popular sport and AI software was expected to have a range of resources at its disposal. The student had expertise based on their past internship with an F1 team and could make informed judgements when key

decisions needed to be made. Performing this project allowed the student to improve their design skills and learn about maintaining robustness of design while incorporating AI developments in their design process. It also enabled them to critically evaluate it and learn how to incorporate new tools in their processes only when they are certain their outputs can be trusted. Student was given a list of potential tools to use in all three AI application types described in Section 3. They were also given the option to add new tools they discovered independently. They created one design on their own, without the use of AI. Then they used AI to create a different design. Two outcomes were then compared.

#### 4.1 Use of Natural Language Models

Chat GPT was used to create a PDS of a final design including secondary locking feature and thread size. Chat GPT, Perplexity AI and Bing AI Chat (Copilot) were used for concept design generation. It was found that increasing the complexity of the prompt in Chat GPT had a significant impact on the PDS created. Requesting a PDS for "a wheel nut" resulted in a "hexagonal" shape of maximum outer diameter of "50 mm". Neither was applicable within FIA regulations. Increasing the complexity of the prompt by requesting references the AI stated that "size and thread are to be compatible with current F1 standards" but did not specify what these were. This meant that the student still needed to check the outcomes and add crucial relevant data. Despite the complex prompt, the Chat GPT generated PDS still specified incorrect values, e.g. specifying the maximum weight of the wheel nut to be 60g (too low). On the other hand, some values were over specified such as consistently setting the material as "lightweight titanium alloy with corrosion protection"- unnecessary as the alloy would not corrode anyway and the protection would add undesirable cost and mass. Using Chat GPT function to create an initial PDS and then editing it to better align with requirements still took 10 minutes less than it took the student to create the PDS on their own. However, the student had already performed all the research allowing them to make those judgements during their independent PDS creation, and if that time was added the total time required to fully complete the activity was not shorter. AI does automate some repetitive activities, which may be beneficial regardless.

For concept generation Chat GPT produced verbal descriptions of the concepts that were more creative and had a wider scope than those designed by the student. The student primarily considered factors such as reliability, low mass and adherence to FIA regulations. However, AI lacked engineering knowledge and often suggested unrealistic outputs such as: (1) use of magnets to aid quick snapping or release (This increases complexity of the operation while not adding much benefit); (2) use of composites for ultralight construction (Composite manufacturing is extremely time intensive and due to the short lifespan and large quantity of wheel nuts required it would significantly increase the cost of the wheel nut production, that due to unidirectional strength would not be capable to withstand rotational force); or (3) adding "smart" elements including sensors to prevent over-tightening or under-tightening (FIA requires passive sensors. Proposed location of sensors would mean they could get damaged and battery powering them would create chemically unstable environment. The sensors already exist in the wheel gun.). Word descriptions suggested by AI were often vague and difficult to translate into usable concepts as they were not compliant with the technical requirements or always follow the scientific principles. Ultimately, there were few credible sources regarding wheel nut features, e.g. material used or the forces

exerted on it (such as the tightening force produced by braking). But even when credible sources were available, such as the technical datasheet for the Dino Pauli wheel gun, the AI used more popular but less reliable sources instead. It was unable to reference peer reviewed publications and books, as they were not freely available online. In general, the information produced roughly agreed with that produced by the student, but references by Bing AI required checks to assess their reliability.

#### 4.2 Use of Image Generation Models

Leo, Dream Studio, Alpaca, Starry AI and Microsoft Bing AI were explored for concept generation. Most are trained for artwork and did not respond well to engineering descriptions, even when reference images were provided. Figure 3 illustrates the response of Microsoft Bing AI image generator to the prompt "a side mirror for a Formula One team which is aerodynamic", displaying a solution that is not particularly aerodynamic, nor displaying an F1 car.

It was difficult to create a prompt (detailed or generalised) to be accepted by Leo. Further development of the software may change that, but at this stage it did not meet the requirements of the problem explored. Overall, the outcomes of image generation were not usable. They were either highly artistic or very simple, mechanically, did not consider function of the product in any way and often included unnecessarily complex forms e.g. turbine on the side of the car in Figure 3 that serves no purpose.



Figure 3. Microsoft Bing AI image generation

### 4.3 Use of Generative Design

Generative design was performed in Fusion360 for three commonly used materials (Aluminium 2014 T6, Stainless Steel 17-4-PH and Titanium 6Al-4V). Its outcomes, shown in Figure 4, allowed the designer to compare them - an improvement to traditional way of working. Five-axis CNC was specified as it is a common manufacturing method in F1 teams. Additive manufacturing was allowed for greater freedom with shape optimisation (although it would often not be used, due to high cost). The outcomes of generative design were interesting, although not entirely applicable. Some suggested elements were taken on and merged with the design student created on their own, to create a medium range solution that could potentially be functional, pending further testing. Using thin ribs to connect two parts of the wheel nut reduces the mass but could be a safety hazard in high-speed environments.



Figure 4. Generative design shape optimisation (top - Fusion360 generative design, middle – modified by student to comply with regulation, bottom – standard wheel nut design)

#### 4.4 Students' Perception of AI and Objective Usefulness

Student performing the case study has shown high ability to evaluate the outcomes of AI at the appropriate stages of the development process. They suggested that AI may be useful for PDS creation and generative design, with intervention from the designer, and only as inspiration otherwise. This agreed with the educators' perspective. However, this is likely significantly influenced by the student's work experience with an F1 team, which is not common across the cohort. Overall, in the teaching practices outside of this case study AI was occasionally perceived by students as trusted source, even when its outcomes were vague and unjustified by peer reviewed sources. An exercise similar to the one performed in the reported case study would likely be beneficial to include in the curriculum.

# **5 RECOMMENDATIONS FOR AI USE IN EDUCATION**

It is likely that future AI will be adapted for the needs of specific fields and that data sources the algorithms have access to will allow curation, increasing the reliability and robustness of the proposed solutions. However, in their current form they should be used with caution. Discussion of AI abilities

and validity of the outcomes they generate should be prioritised with students early in the process. Following recommendations are made, based on the outcomes of the study described in this paper:

- AI use in appropriate contexts can be encouraged, but the validity of its outcomes should always be questioned.
- Discussion should be engaged in with the students to establish what the novelty of the AI solution is and how they can assess if the problem is genuinely being solved.
- All AI outputs should be evaluated against engineering standards and engineering principles.
- All AI outputs should be compared with outcomes of other experimental or analytical methods.
- AI limitations in the specific context should be explored and fully understood by the designer.

These agree with the existing suggestions, found in the literature, to encourage learners to be critical consumers by questioning AI intelligence and trustworthiness [15], AI can be used with problems it excels at but human skills need to supplement it. It should not be seen as the ultimate solution. Instead, it needs to be managed, if its sources and general principles it employs are validated, students can learn to use it and generate reliable outputs.

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# THE INFLUENCE OF CULTURAL DIFFERENCES IN MOTION FOR ENHANCING NONVERBAL COMMUNICATION

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# ABSTRACT

Nonverbal communication is an important and helpful way to deliver messages. Motion is one element of nonverbal communication that can enhance the clarity of messages between the sender and receiver. However, the perception of motion varies based on the diverse backgrounds of participants, with the difference in cultural background being one thing that affects interpretation. Nevertheless, there is a lack of research on how people from different backgrounds perceive motion. This study aims to verify the factors influencing the perception of vitality and understand how individuals in various locations perceive motion. The experiment employed motion graphics, utilising angle, acceleration, and fluctuation as tools to investigate their influence on the evaluation. This research implements an experiment with participants from Japan and Thailand, utilising Head-Mounted Displays (HMDs). These 10 questions are categorised as positive mood states, which correlate with the feeling of vitality. The results reveal differences in the evaluation of motion perception between Thai and Japanese participants. Specifically, Thai participants significantly rated attributes such as lively, vigorous, cheerful, active, alert, energetic, helpful, and efficient higher compared to Japanese participants (p < .01). Understanding cultural influences on perception leads to enhancing nonverbal communication and guiding diverse product development for varied target audiences. In terms of education, the use of learning materials designed to evoke positive emotions enhances comprehension. Researching methods to elicit positive emotions is essential for the future.

Keywords: Cultural differences, motion, emotional evaluation

# **1** INTRODUCTION

Nonverbal communication has evolved significantly since its inception with static images in prehistoric times, such as the cave paintings found in the Altamira cave in Spain or the Lascaux cave in France. These images were used to depict personal experiences and tell stories [1]. This evolution can be observed in various forms, such as sculptures like Michelangelo's Pieta, which tell stories about the Christian religion. The progression has continued into modern times with the development of animated graphics and motion. Animation, defined as giving life to the inanimate, creates a sense of movement and vitality [2]. This ongoing evolution aims to enhance the receiver's perception of messages and sensations through visual media [3]. In today's world, the transition from print to digital media has reshaped the way we communicate and access information, with screens now serving as the primary medium. This evolution highlights the significance of motion graphics, which utilise elements like colours, symbols, and physical movements to convey messages [4]. Motion, a component of nonverbal communication, involves the change in an object's position, leading to various perceptions [5]. Understanding how motion conveys messages is crucial, significantly enhancing communication between senders and receivers [6]. Furthermore, studies indicate that motion can deeply affect our emotions and cognitive processes. For instance, rapid, flipping text can convey playfulness and urgency, while a slow, gentle appearance of text against a black background can create a sense of peace and mystery [7]. Moreover, motion elicits emotional reactions in viewers [8], influencing cortical arousal and attention [9]. Although studies have investigated motion's emotional effects, much remains unknown about its impact on particular emotional responses, like vitality. Understanding this sensation is vital for enhancing medium realism and narrative clarity.

In addition to examining how motion affects emotions, it's imperative to consider participants' backgrounds to gain a deeper understanding of how motion graphics influence evaluation. Cho [10] explored the impact of design experience on interpreting motion attributes like moving speed, aggressiveness, and pleasure. When studying participants' backgrounds, one crucial factor to consider is cultural differences. Culture profoundly shapes individuals' behaviours, thoughts, and emotions, encompassing linguistic, symbolic, and aesthetic aspects such as languages, symbols, colours, and images. Moreover, cultural disparities extend to distinct ways of thinking, emotions, personalities, and perceptions [11]. Colours hold different symbolic meanings in various cultures. For example, in Asia, orange represents positivity, whereas in Western cultures like the United States, orange is associated with road warning signs and hazards [12]. Cultural distinctions in nonverbal communication are globally apparent. For example, in America and Europe, greetings often involve handshakes and smiles, while in East Asia, bowing with hands at the sides is customary [13]. This research emphasises the importance of understanding participants' cultural differences, particularly in assessing motion factors, to enhance nonverbal communication. It aims to develop emotionally impactful content suited to diverse audience groups in the future. The Bauhaus, a pioneering institution in art and design education, has had its principles integrated into art colleges and design schools [14]. Bauhaus methodology utilises three core design elements - line, dot, and graphic elements - arranged in different ways to create new compositions [15 and 16]. These compositions aim to evoke diverse emotional effects like noise and quietness through form and composition [17]. In this study, the Profile of Mood State was utilised as a tool for assessing emotional states [18]. The insights gained from this study can lead to various applications, such as in the education field. Using materials that evoke positive emotions enhances comprehension, as several studies have demonstrated the expedited learning associated with positive academic emotions such as enjoyment and pride [19, 20, 21, and 22]. The objective of this research is to clarify how individuals evaluate stimuli related to their perception of vitality and how cultural backgrounds affect this evaluation through motion graphics. The result leads to the development of emotionally impactful content that is suitable for diverse audiences from different cultural backgrounds.

# 2 METHOD

# 2.1 Participants and motion stimuli

This study involved two groups of participants: 39 Japanese and 20 Thai. There were nine motion stimuli, each characterised by three different motion variables with three levels each: displacement (linear), sine curve, and fluctuation, with corresponding angle levels of 60°, 90°, and 120°, acceleration levels of without acceleration (WA), slow to fast (STF), and fast to slow (FTS), and fluctuation levels of without fluctuation (WF), low fluctuation (LF), and high fluctuation (HF). These three factors were developed according to a previous experiment to verify the factors that can evoke a sense of vitality [23]. The stimuli were the display of an animated white sphere for around 15 seconds. Participants evaluated the questionnaire by using the Head-Mounted Display (HMD) to view the animation. Following each stimulus, they removed the HMD and provided their evaluation. Using the HMD ensured consistent setup, minimising distractions, and enabling natural interactions in an immersive virtual environment because of its high resolution of 1832x1920 pixels per eye.

# 2.2 Questionnaire Design

In this study, the affective words from the Profile of Mood States 2nd edition (POMS 2) were used as evaluation phrases. POMS 2 is employed as a psychological assessment tool to measure an individual's mood state [24]. It comprises 65 phrases representing various moods, such as Tension-Anxiety (TA), Depression-Dejection (DD), Anger-Hostility (AH), Vigor-Activity (VA), Figure-Inertia (FI), Confusion-Bewilderment (CB), and Friendliness (FR) [25]. To select the best phrases that express the sense of vitality, 65 phrases from POMS were evaluated by 63 university students (37 males and 26 females, mean age: 19.2, SD: 1.18) using a 5-point Likert scale (ranging from 1 = "Not at all" to 5 = "Extremely").

The evaluation results were derived using cluster analysis methodology. Among the 65 evaluation phrases, they were categorised into two groups: Group A, mainly comprising phrases associated with positive mood states, encompassed phrases from the Vigor-Activity (VA) and Friendliness (FR) sub-scales. Group B, primarily composed of phrases linked to negative mood states, consisted of phrases from the Depression-Dejection (DD), Confusion-Bewilderment (CB), Tension-Anxiety (TA), Anger-Hostility (AH), and Figure-Inertia (FI) sub-scales. Notably, the mean evaluation score in Group A

surpassed that of Group B (Group A = 2.18, and Group B = 1.53). Based on these findings, ten evaluation phrases were chosen, predominantly originating from the Vigor-Activity sub-scale. These included lively, vigorous, cheerful, energetic, useful, uneasy, active, alert, full of life, and efficient. These ten phrases were then assessed using a 5-point Likert scale, ranging from 0 = "Not at all" to 4 = "Extremely."

# **3 RESULTS**

The two-way ANOVA was performed to evaluate how the factors (angle, acceleration, and fluctuation) influenced the perception of vitality among two distinct participant groups (Japanese and Thai participants). The results indicated that the ratings of the three factors by Thai participants were significantly higher than those by Japanese participants in the evaluation of lively (p < .01), vigorous (p < .01), cheerful (p < .01), active (p < .01), alert (p < .01), energetic (p < .01), helpful (p < .01) and efficient (p < .01).

In the evaluation of angle (Figure 1, i), For Japanese participants,  $60^{\circ}$  had a significantly higher rating than  $120^{\circ}$  in the evaluation of lively (p < .01), vigorous (p < .05), cheerful (p < .05), uneasy (p < .05), energetic (p < .05) and full of life (p < .01). Furthermore,  $60^{\circ}$  had a significantly higher rating than  $90^{\circ}$  in the evaluation of lively (p < .05). In the evaluation of acceleration (Figure 1, ii), For Japanese participants, FTS received significantly higher ratings than STF in the evaluation of lively (p < .01), vigorous (p < .05), cheerful (p < .05), active (p < .05), energetic (p < .05), full of life (p < .05). Moreover, FTS received significantly higher ratings than WA in the evaluation of uneasy (p < .05) and full of life (p < .01). In the evaluation of fluctuation (Figure 1, iii), Japanese participants significantly rated WF higher than HF in the evaluation of helpful (p < .05) and efficient (p < .05).



Figure 1. Results of evaluation. A significant difference was found as \*p < .05 and \*\*p < .01

#### 4 DISSCUSSION AND CONCLUDING REMARKS

The research aims to clarify how participants evaluate stimuli related to their perception of vitality and how participants' cultural backgrounds affect the evaluation through motion graphics.

The findings revealed disparities in the evaluation of motion perception between Thai and Japanese participants, indicating that individuals from diverse cultural backgrounds will demonstrate varying perceptions and evaluations of motion graphics. Thai participants significantly rated the three factors (angle, acceleration, fluctuation) and the three levels higher compared to Japanese participants (p < .01) in attributes such as lively, vigorous, cheerful, active, alert, energetic, helpful, and efficient. These findings indicate that cultural factors may impact the evaluation process. Individuals from different cultural backgrounds exhibit varied responses to colour perception and optical illusions, demonstrating the influence of culture on various psychological processes, including fundamental perception [26]. Each culture transmits, shares, and shapes various aspects such as behaviours, languages, values, music, art, and shared beliefs, thereby distinguishing one culture from another. As a result, individuals from different cultures interpret visual images differently, influenced by their unique experiences and learned behaviours [27]. For example, a study contrasting Japanese and American viewers' responses to an underwater video show differing visual interpretation. Americans focus on size, colour, and movement details, while the Japanese emphasise broader context and object relationships [28]. Differences in evaluation between Japanese and Thai participants may be influenced by the physical environment, which shapes their experiences. In Japan, where media and technology are ubiquitous in daily life, individuals are likely more accustomed to encountering dynamic and visually engaging content, potentially shaping their perception and evaluation of motion graphics. In contrast, in Thailand, where the media landscape may be less pervasive, individuals may have different perceptions of motion graphics.

The results indicated the influence of three simulation factors (angle, acceleration, and fluctuation) on the perception of vitality. At the Angle factor: According to Japanese participants,  $60^{\circ}$  received higher evaluation than 120° in the evaluation of lively (p < .01), vigorous (p < .05), cheerful (p < .05), uneasy (p < .05), energetic (p < .05), and full of life (p < .01). Furthermore,  $60^{\circ}$  had a higher evaluation than  $90^{\circ}$  in the evaluation of full of life (p < .05). For Thai participants,  $60^{\circ}$  is better in providing the sense of lively compared to  $90^{\circ}$  (p < .05) and  $120^{\circ}$  (p < .01). The assessment revealed that Japanese participants attributed importance to angles of a narrow degree, with  $60^{\circ}$  receiving higher ratings compared to other angles ( $90^{\circ}$  and  $120^{\circ}$ ), thus providing a stronger sense of vitality. For Thai participants exhibited a preference for  $60^{\circ}$  over  $90^{\circ}$  and  $120^{\circ}$  in the evaluation of motion perception, especially in eliciting feelings of liveliness among both participant groups. Stimuli moving at  $60^{\circ}$  may mimic the natural movements and rhythms found in living organisms, while those at  $120^{\circ}$  might appear less rhythmic and less associated with vitality. Motion characterised by more pronounced rhythms may evoke sensations of frequency similar to biological vibrations seen in physiological processes like breathing and heartbeats [29].

At the Acceleration factor: Differences among acceleration factors were observed in the evaluation by Japanese participants, while no significant differences were reported among Thai participants. For Japanese participants, FTS compared to STF. FTS received higher evaluations than STF in the evaluation of lively (p < .01), vigorous (p < .05), cheerful (p < .05), active (p < .05), energetic (p < .05), and full of life (p < .05). It appears that the changing of acceleration factors influences the evaluation of motion graphic stimuli by Japanese participants. Furthermore, cultural differences may play a role in shaping participants' perceptions of the Acceleration factor. For example, Ichio's study [30] investigated the differing perceptions of speed and duration between Thai and Japanese children. It discovered that Thai children, influenced by language differences, prioritise temporal order less than Japanese children. Additionally, language differences affect colour perception, such as the absence of separate words for red and orange in languages like Shona in Zimbabwe [12].

At the fluctuation factor: There were significant differences were reported in the evaluation by Japanese participants. They perceived WF as providing a higher sense of helpfulness and efficiency compared to HF (p < .05). Previous research on the interaction effect between angle and fluctuation suggested that participants can feel a sense of vitality even without a fluctuation factor [3]. However, no significant differences were reported among Thai participants.

This study explores how cultural differences influence participants' evaluations of motion factors and their impact on vitality perception. It examines how variations in motion attributes affect assessments, highlighting both similarities and differences across backgrounds. These insights improve our understanding of specific motion factors shaping vitality perception. The findings can enhance nonverbal communication, guiding tailored content creation for diverse populations and specific emotional effects. For instance, in education, adapting materials and strategies to diverse student needs can enhance communication and learning outcomes. Utilising VR aligns with constructivist principles, promoting active engagement and deeper understanding. It enriches edutainment experiences by emotionally engaging learners through motion graphics.

# **5 LIMITATION AND FUTURE STUDY**

1) In future studies, we intend to utilise the Two-Dimensional Mood Scale (TDMS) to assess Thai and Japanese participants both before and after the evaluation. TDMS was employed to measure mood states in the moment [31]. By employing the TDMS, researchers can effectively measure the emotional experiences of participants before and after exposure to the stimuli, facilitating an accurate comparison of emotional responses among Thai and Japanese participants. 2) To gain a deeper understanding of how participants' backgrounds affect the evaluation, future studies aim to include participants from diverse cultural backgrounds. Additionally, the study intends to explore individual factors such as age ranges, gender differences, and varying levels of design experience. 3) For a more comprehensive understanding of participants' evaluations, future studies could investigate physiological responses alongside evaluation, potentially enriching our insight into participants mechanisms. The documented linkage between emotion evaluation and physiological responses [8] emphasises the importance of further exploration of this connection. 4) For study on how cultural differences impact evaluation, an experiment involving scientific content will be conducted using virtual reality. This will enable students to explore and learn in an interactive environment. The study will compare the learning outcomes of Thai and Japanese students to assess the effectiveness of this technology across different cultural contexts.

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# HOW WILL THE EMERGENCE OF AI IN THE WORLD OF INDUSTRIAL DESIGN CHANGE THE TRAINING NEEDS OF OUR STUDENTS?

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#### ABSTRACT

In 2023, artificial intelligence (AI) emerged in various professional fields, including Industrial Design, sparking ongoing discussions about its impact. Many designers are experimenting with AI tools to assess their value in the design process. Academic research also surged, mapping AI tools applicable in different design stages and proposing new emerging roles for industrial designers. Beyond tools, the day-to-day challenges for Industrial Designers due to AI remain unclear. This contribution focuses on the perspective of professional designers, who are the prospective employers of our students. Through online questionnaires and the snowball technique, our team conducted exploratory research in which 48 professional Industrial Designers from eight different countries (Germany, Denmark, India, Italy, the Netherlands, Russia, Spain, and the US) participated. Their professional insights reveal the stages of the design process in which they are applying AI tools, the specific AI tools that they use, challenges that they face, and both benefits and risks that AI generates in their work. Professional input also highlights necessary changes in industrial designers' education to update the role of Industrial Designers to the AI impact. These findings serve as a foundation for updating Industrial Designer curricula, addressing training needs identified by professional designers who face all these challenges of AI today.

Keywords: Artificial Intelligence, industrial design, professional designers, skills, curriculum of universities

#### **1** INTRODUCTION

It's evident that the year 2023 has seen the emergence of artificial intelligence in numerous professional settings, including the field of industrial design. Industrial design is the process of creating and developing new products, including their form, function, and aesthetics. The field of industrial design is constantly evolving, and new technologies are continually being developed to aid in the design process. AI tools, with their ability to analyse data and generate new ideas, have the potential to revolutionize the way products are designed. [1].

Across all professional forums and associations of Product Designers, discussions are ongoing about this technology and how it will impact the professional practice of Products Design. Many professional designers and their teams are experimenting with the new tools that incorporate this technology, exploring their possibilities and analysing how their application can add value at different stages of their design process, considering the strengths and weaknesses of their teams. In short, artificial intelligence is transforming product design in many ways. From using machine learning algorithms to analyse large data sets and extract useful information to using AI-based design tools and improving the efficiency of the design process itself, AI is helping designers create more innovative and efficient solutions.

In the academic sphere, there has been a proliferation of publications in recent years exploring the impact of AI in the design process. Some academics have identified and mapped AI-based tools that can be applied in different stages of the design process. Cautela et al. (2019) analysed twenty start-ups, investigating in which phases of the project and how often AI was implemented in the design process. Their results show the predominance of AI applications in the research, team building, and task management steps [2]. Isgró et al. (2021) conducted secondary research through literature review and web search, collecting and mapping existing AI-enabled design tools in the design process. Their research work showed that only a few AI applications have taken hold in design so far, and many others only existed as research or concepts [3].

While AI serves as a valuable tool, academics highlight that it does not replace the designer [1,5]. Moreover, academics also delve into the practical implications of AI adoption exploring what is actually happening in the day-to-day professional practice of designers. To what extent is AI likely to change the way design is practiced? That is, which decisions are made, and which can be automated, and which ones cannot? What changes in competences are required? And which roles should lead this transition? [4].

AI tools, on one hand, require a certain level of expertise and knowledge to use effectively. However, this can pose a barrier for some designers who lack the necessary skills or resources. On the other hand, the market and clients are increasingly aware of the transformative impact of AI. As other professionals incorporate AI tools into design processes, their demands and requirements will evolve. This leads us again to consider the implications for training future industrial designers.

Preparing future designers for AI technologies involves equipping them with the necessary tools and knowledge to use these tools safely while maintaining responsible control over the design process. Recognizing that AI systems and human-AI collaboration are fallible, it becomes the designer's responsibility to assess the machine's output. They must decide whether to incorporate it into their work or discard it if it does not meet expectations. As operational tasks increasingly shift to AI, designers may transition into roles more focused on evaluation and supervision [5].

Figoli et al. (2022) proposed that in the era of AI the role of industrial designers can shift to be a design arbiter, a role that combines the designer's skills and sensitivity with critical analysis expertise. The design arbiter evaluates outputs generated by AI systems and ensures their appropriate integration into the design process. The ability to effectively collaborate with AI systems, specifically designing for AI, becomes a crucial competence for the designer arbiter [6].

In the form of a position paper, this contribution main objective is to guide further discussions among academics based on the perspective of professional designers, who are the prospective employers of our students. These professionals at present can provide a more realistic view of what is happening in their professional practice and what profiles of young Product Designers can bring value to their teams and companies in the coming years.

#### 2 METHOD AND CHARACTERISATION OF THE SAMPLE

This exploratory study was developed using an online questionnaire, distributed following the snowball technique through LinkedIn thematic groups of industrial design and also using alumni of the industrial design engineering degree from Tecnun, the School of Engineering of the University of Navarra (Spain), as starting contacts. The questionnaire had four different sections. The first section of the questionnaire collected general information about the designer's profile to determine if they fit into our research. The second section included questions to determine their interest and knowledge about AI. The third section explored their experience in using AI in their work, and the fourth section focused on gathering their opinion on the impact of artificial intelligence on the work of industrial designers and the training of future professionals.

The sample of designers participating in this study is balanced between young designers (46% have less than 5 years of experience) and experienced designers (17% have between 6 and 10 years of experience, and 38% have more than 10 years of experience). Considering the typology of companies in which they carry out their professional activity, the sample is also fairly balanced: 18 of the designers work in design studios, 10 in design consultancies, 13 in companies with their own products, and the remainder in other types of companies. In this sample, designers working in SMEs predominate, accounting for 75% compared to the remaining 25% who work in large companies. Asked about the geographical origin of their clients, 44% had clients of national origin and 56% of international origin.

Asked about the field of industrial design in which they carry out their professional activity, 81% of the participants engage in physical product design across various sectors such as consumer electronics, household appliances, industrial products, automotive and other means of transportation, biomedical products, lighting, furniture, etc. The remaining 19% are involved in other activities such as packaging design, UX/UI design, service design, and graphic design.

In the following sections, we present the results and conclusions of this research work obtained from the responses of the participants to our questionnaire. It is important to highlight the great interest shown by the participants in knowing the results of our research. In the final part of our anonymous

questionnaire, participants were invited to send us their contact details if they wished to receive a summary of the results obtained, and 35 out of the 48 participants provided us with their details.

### **3 RESULTS**

In the first part of the questionnaire, we posed questions to understand the relevance that these professionals consider training in the application of AI to their professional field to have, and whether they have received training, and if so, by what means they have done so. The first question posed to professionals asked whether they considered it important to receive ongoing training on the use and applications of AI in the field of industrial design; an overwhelming majority of 94% responded affirmatively. However, when these professional designers are asked if they have received training in the use of AI for their professional field, only 44% of them respond affirmatively.

Of the professionals who had received training, 77% have self-taught using tutorials and online resources, while the remainder have been trained in courses offered by official institutions (universities and vocational training centres) or by software companies incorporating AI into their tools for the industrial design field.

In the second part of the questionnaire, we focused on the use of AI in their professional activity, the specific tools they have used, the phases of the design process in which they have applied them, and delved into their challenges, benefits, and risks. Most of the questions in this part of the questionnaire were open-ended, allowing the designers to explain their experiences in their own words. 65% of the designers reported having used AI tools in their work. In Table 1, we identified and classified the names of the AI tools that these designers are using in their work processes regularly, and in Figure 1, the stages of the design process in which they use these AI tools.

Type of AI tools	Name of specific AI tools
Text generation	ChatGPT, Gemini/Bard, Bing, Copilot, Claude, ChatPDF,
	Gamma, Tome, Miro Assist
Image and sketch	Leonardo, DALL-E, Midjourney, Vizcom, Stable Diffusion,
generation	Firefly, Photosonic, Bing Image Creator
Automatic image editing	Photoshop Beta, Vizcom
and rendering	
Market trend analysis	Orange Datamining, Rapidminer

Table 1. Cl	assification of the	Al tools us	ed by industria	l designers partic	ipating in this
		re	esearch		

Q6: In which stage/s of the Design process has AI been useful to you?





Below, Tables 2, 3, and 4 present the challenges, benefits, and risks that these designers have identified when using AI tools in their work.

Challenges	Explanation	Number of designers that experiment this challenge
Few tailored for design	Training and/or numerous iterations are required for high-value output.	15
Large variety of tools	With such a wide range of AI tools available, it's hard to map and select them and decide which ones to train in, since we're unsure which ones will last.	7
Learning to give them the correct prompts	Creating the correct prompts to obtain a response close to the designer's expectations can be challenging.	6
Understanding of the context and the user	It's challenging to ensure that AI tools understand well who the user is and the context in which they need to respond.	2
None		2
Co-design with IA vs IA mastering design	Use them as tools and not give them the main role in the design.	1

# Table 2. Main challenges found when incorporating AI into their design processes

Table 3. Main bene	fits that AI can bring	to product design process
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Benefits	Explanation	Number of designers that proposed this benefit
Efficiency and speed	Speeding up research and content generation to translate ideas into other materials useful for communicating ideas to clients (image, videos, sounds, etc.)	18
New inspirations	Getting preliminary design ideas and expanding ideation	15
Automatization of repetitive tasks	Fast processing of repetitive or non-creative tasks.	14
Better design decisions	Exploitation of data for better design decisions	6
Enhancement of visualisations	Refinement of design aesthetics while saving time/cost	4
Smarter products/services	Products/services that can anticipate their context (including the user), inform users, detect or predict events, and relieve human efforts during work	1

Tahle 4	Main	risks	that ΔI	can	hrina	in	the	Industrial	Desian	nrofession	al field
	wann	11343	linal Ai	can	bring		uic	muusinai	Design	profession	ai iiciu

Risks	Explanation	Number of designers that proposed this risk
Problems of privacy,	Use of the same data through AI tools can lead to similar	11
Intellectual Property	solutions, or companies, due to the fear of losing control over	
(IP) control and	their data, may develop their internal AIs and reduce their	
confidentiality	innovation capacity by relying on endogenous data.	
People thinking that IA	Some jobs will become obsolete because of increased intrusion,	11
can replace/substitute	such as purely aesthetic designers, potentially resulting in a	
designers	significant loss of quality in design.	
Reduce creativity	AI can cause designer's block when a reference is available.	7
Loss ability for	By skipping steps in the creation/design process and accelerating	5
informed decision	it, it's possible that we may overlook things along the way or	
making	neglect relevant factors in the process and critical reasoning, such	
	as empathy.	
Biased decisions and	Make decisions and generating solutions based on flawed or	4
design solutions	biased training data	

Reduce skills of designer through visual representation	If design generation can be highly accurate through written commands, the motivation to develop a designer's skills in shaping an intangible idea through visual representation may	3
	begin to depreciate.	
Waste of time	Too much time is wasted in getting tools to achieve what we	2
	want.	
IA leading role	To give IA a leading role and let it guide the design.	1
Hallucinations of IA	This is a phenomenon wherein a large language model (LLM) perceives patterns that are non-existent or imperceptible to human observers, creating outputs that are nonsensical or altogether inaccurate.	1

Finally, in the last question of our questionnaire, the participating industrial designers shared their ideas about the changes they would like to see in the educational programmes of industrial engineering studies at universities to address the impact of AI on their professional activity. The results obtained are presented in Table 5.

Table 5. Changes proposed by professionals in the university education of industrial
designers

Changes in the university education of industrial designers	Explanation	Number of designers that proposed these changes
Practice with AI tools to inform	Focus on practicality, use AI tools to inform the design	20
the design process in different	process, and don't delve too much into academic theories to	
existing courses of the curricula	fully realise the potential of AI for impactful design work.	
Understand how AI technology	Set and teach methods that can support young designers in	12
works	acquiring a critical evaluation mindset to use AI in a smart	
	and meaningful way. Also, teach about ethical bases, biases,	
	and risks of AI.	
Specific courses on AI	Teach about different types of AI and their evolution.	4
Creativity in the era of AI	Give students the knowledge to know how to use AI	3
	correctly so that their designs are not alienated by AI and	
	cultivate their creativity to develop their own style.	
Learn to make the right	There is a mindset that needs to be acquired in order to	1
questions or prompts	master the use of AI, including what to do and what not to	
	do with AI, as well as understanding its limitations and	
	ethics.	
Faculty and guest experts with	Firstly, it is necessary to train university faculty themselves	1
professional experience in the	and also to seek support from professionals and experts with	
use of AI tools	professional experience in the correct use of AI.	

# **4** CONCLUSIONS

We divide the conclusions of this work into two areas. The first set pertains to the current situation related to training, knowledge, and use of artificial intelligence tools by professional designers who participated in this study. The second set includes conclusions about how the education of our industrial design students should adapt in response to the emergence of AI in product design. Finally, we present our position as a starting point for an interesting discussion among conference participants and share ideas for future research.

In summary, 96% of the participants recognize the importance of AI in their professional field. However, less than half of them have received formal training in this area. They primarily acquire knowledge through self-study and practical tutorials or online resources. Regarding the AI tools they use, they apply them mainly in the initial stages of the design process, including market and user research, briefing, insights generation, concept development, and data analysis. These tools fall into four categories: text

generation, image and sketch generation, automatic image editing and rendering, and market trend analysis.

When asked about the challenges, benefits, and risks associated with using AI tools in their professional practice, designers identified several key issues. The main challenge is the wide variety of tools available and the time required to master them to achieve good results. This effort is compounded by the uncertainty of whether these tools will remain available in the market. On the other hand, AI technology offers significant productivity benefits, such as increased efficiency, speed, and the ability to automate repetitive tasks. However, opinions on the impact of AI on creativity are divided. Some professionals believe AI tools can help designers overcome the fear of a blank page, while others fear that these tools might lead to creative blockages. Finally, industrial designers identified two main risks related to AI: privacy issues, intellectual property control, and confidentiality on one hand, and the mistaken perception that AI can replace industrial designers, leading to professional intrusion, on the other.

Regarding the necessary changes in university curricula for future industrial designers, professional opinions are clearly divided. Some professionals advocate for a practice-focused approach, emphasising the use of AI tools in various design phases without extensive academic theory. Others believe it is crucial to understand how AI technology works to foster a critical mindset for its intelligent and relevant use. This division highlights the need for educational research to determine the most appropriate way to incorporate AI technology into the curricula for upcoming industrial designers.

Our position for opening discussion at this conference is that combining both approaches in our students' curriculum can greatly enhance their professional value. Practical experience with AI tools can make their design processes more efficient and potentially more creative. Meanwhile, a deeper understanding of AI—such as the types of data it uses, its algorithm families, and their capabilities—will enable them to visualize how AI technology and collaboration with AI experts can advance their product design projects, leading to the creation of smarter products.

To conclude, we want to emphasise the importance of continuing research in this field to clarify many of the uncertainties, such as the impact of using AI tools on designers' creativity or the benefits of more practical training versus training with a deeper theoretical understanding of AI, or a combination of both. One limitation of our work is the sample size, so we encourage our academic colleagues to conduct quantitative studies with larger samples to seek generalisable results, as well as qualitative studies to better understand the causes of these effects that AI is having on professional practice.

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# THE USE OF LLMS IN ACADEMIC WRITING INSTRUCTION FOR FIRST-YEAR STUDENTS IN THE ENGINEERING BACHELOR PROGRAMMES

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### ABSTRACT

The introduction of Open AIs Chat GPT in November 2022 changed the game on academic writing instruction. Questions on how the use of large language models (LLMs) will affect students' writing skills were discussed among educators and in academia. This article aims to obtain understanding on how to adapt course content in academic writing in the engineering studies to the use of LLMs. It also aims to evaluate how students may use LLMs effectively in their academic writing instruction, and how staff's instruction can be improved. The academic writing instruction was prepared in collaboration between academic staff in the discipline, the university library and the writing centre. Survey findings and experiences from a project given to first year engineering students reveal that students want and need academic writing instruction, but that it needs to also embed instruction on the use of LLMs. The problem areas in academic writing are the higher order skills, such as critical thinking and information literacy. When asked where students seek help to improve academic work, the LLMs appear as the lead supervisor. This calls for a need for educators to engage critically with the LLMs and how students use them. Academic writing instruction may need to include responsible use of LLMs into the course content.

*Keywords: Large language models, academic writing instruction, engineering sciences, higher order writing elements* 

# **1** INTRODUCTION

The introduction of Open AIs Chat GPT in November 2022 changed the game on academic writing instruction. It raised questions both on how to use the new tools wisely and how to adapt the writing courses to work alongside with the tools. This article evaluates how the use of large language models (LLMs) may contribute to the writing instruction courses in academia in general, but specifically in the engineering education.

#### 1.1 Background

Even though the engineering sciences evaluate practical tasks in the bachelor and master's programmes, the written report is still the core of assessment. Academic writing instruction has in recent decades been two-pronged; The genre-oriented approach has emphasised instruction on how to use formats, templates and language conventions within the discipline [1], [2]. The other approach to writing instruction emphasises 'the higher order elements' such as critical thinking, source competency, language awareness and rhetorical skills [3], [4], [5].

It is argued [3], [4], [5] that templates and disciplinary requirements, such as style and fixed structures may stand in the way of text flow and argumentation flow, and that students find it difficult to write according to these formal requirements. However, on surveys [1] that question what the engineering students find the most difficult in academic writing, three challenges appear:

- 1. Information literacy
- 2. Genre orientation and text structure
- 3. Creating good research questions

These challenges show that students struggle both with form as well as the higher order writing elements, such as critical thinking. Academic writing instruction has attempted to cater for these needs prior to the introduction to LLMs in academia. The question remains on what changes in writing instruction will be required now that the students have AI to help them write.

The LLMs have shown capability to aid students in at least two of these problem areas [6]. They can generate seemingly flawless well-structured text as well as demonstrating critical thinking in terms of asking topical questions for the students to reflect upon. This begs the question of what it is that our engineering students need to develop language skills for, when they no longer need to produce their own text. When grammar, spelling, text structure and maybe even the art of analytic thinking, can be handed over to the LLMs, the question of purpose rattles the core of language instruction.

One of the fundamental issues of language and knowledge acquisition in academia is critical thinking. A major part of that entails information competency. The ability to think critically and make balanced judgement about information students find and use is pivotal. Therefore, language skills, and by extension, critical thinking, is important for the development of information literacy. The question of overreliance on LLMs in students' academic writing exercises raises issues both on bias in the LLMs' training data and the problem of skill degradation among students, both in which 'the higher order' writing skills may suffer loss [7], [8], [9].

The Sapir-Whorf hypothesis [10] suggests that a person's language will shape her world view and may even determine her thoughts. Language is thus an active component in the ability to reflect upon and to create new meaning in our surroundings [11]. Developing writing skills therefore becomes an act of developing thinking skills, as Johansen puts it; "Writing is the technology used for thinking" [12]. The LLMs, on the other hand, are only form. They do not have access to meaning. They cannot create anything new, that is factually reliable. They can only copy what they have been trained on or hallucinate [13]. In the article 'On the Dangers of Stochastic Parrots' [14], Bender and Gebru warn us about the dangers of bias connected to the LLMs' training data. In a time where social views are rapidly changing, the use of static training data, and the hegemonic voices they represent, may pose a threat to the increasing diversity in academia. The challenges we see in the use of LLMs in academic writing training [15], [16] call for a closer look into the content of courses in academic writing in the engineering education.

#### 1.2 Research question

How may students' use of LLMs change how we conduct academic writing instruction?

# 2 CASES

# 2.1 Information about the course

Students from all engineering programmes at UiA must take the course "Technology, Environment and Sustainability [17] in their first year. This includes students from the programmes Civil and Structural Engineering, Computer Engineering, Electronics and Electrical engineering, Renewable Energy and Mechatronics. The course is divided into two parts. This article covers the section on academic skills, with focus on information literacy, writing and the use of LLMS. Three two-hour lectures were given during two weeks in the beginning of September 2023, and the exam question was made available for the students at the same time. The lectures were optional. Each week the rest of the semester, a changing group of students had mandatory guidance on their exam paper. There were also optional guidance sessions based on drop-in for all interested students in the course. The students were evaluated on two papers. One was an article, about a chosen technology, written by the student in collaboration with one or more chosen LLMs. The second was a report written without LLMs. The report was about their experience with writing together with an LLM, and their evaluation of the results. This was the main assignment for evaluation.

#### 2.2 Planning the course

The educator team for academic skills consisted of three teachers with different fields of expertise, each providing one lecture. Academic writing was covered by a writing- and language lecturer with engineering students as their speciality. Source literacy was covered by a research librarian for computer science and engineering research. Introduction to LLMs was covered by a researcher in the field of AI.

All work at the University of Agder, Norway (UiA). In addition, there was a group of other lecturers in the course who were available for guidance, both the mandatory and optional sessions.

While planning the content of the three lectures in academic skills, the educator team also prepared the exam paper, so they were always aware of what the students were supposed to gain from the lectures. UiA also has a writing centre that was informed of the paper, so that students in this course could have easy access to other sources of support for academic writing. In addition, there is a well-functioning mentorship programme (FYSE) for all these students, who were also available for support, though not with the same capacity and knowledge of the taught subject.

# **3 METHODOLOGIES**

A survey, made in SurveyXact, was distributed to all 332 students in the course. It was distributed in our learning management system Canvas in November and December 2023. 90 students enrolled in the course responded, equalling a response rate of 28%. The entire survey included 55 questions, where 25 were relevant to this article. The survey consisted of both qualitative and quantitative questions. This provided the students with the opportunity to give feedback and input both with fixed answers, and on what they felt important to share to the educator team. This paper also draws on the first-hand experiences of the educators, as well as some observations from the final exams in the course and the educators' reflections on the lectures and learning outcomes.

# **4 RESULTS AND DISCUSSION**

The selected variables for the question of how LLMs may change the way we teach academic writing are as follows:

- Students' satisfaction with the given lectures
- Students' challenges regarding academic writing
- Where do students seek help to improve their texts?

#### 4.1 Lectures in academic writing

91% of the respondents in the survey answered that they will use the lectures in academic writing, and the following training, to improve written work in other courses in their engineering education. It seems that most of the respondents are aware that training the 'writing- and thinking' muscles' [12] is a crucial part of being able to analyse, synthesise and to reflect, both theoretically and practically. *Figure 1* shows the perceived usefulness of the lectures in academic writing. A large majority of the respondents found the lectures useful, especially for understanding the importance of good writing skills.



Figure 1. How useful were the lectures in academic writing?

Still, the survey shows that only 42% of the respondents were actually present at all three lectures. It is reasonable to assume that their interest in lectures on academic writing is low [18]. Generally,

students in the professional studies find academic writing very difficult [1], [4] and tedious work, and the temptation to outsource writing tasks to the LLMs may be all too difficult to resist.

#### 4.2 Students' challenges in academic writing

Findings shown in *Figure 2* reveal that many of the higher-order writing elements, such as developing a research question, understanding the task, and information competency are difficult for students. These elements are important to continue to incorporate into academic writing instruction.



Figure 2. Academic writing: Evaluate the level of difficulty for the following

The students also, not surprisingly, struggled with using the LLMs. Open comments from students, as well as supervision sessions, confirm that the difficulties the students faced were related to both that the tools are new to the students, but also that they introduced a very different way of producing text. Students commented that prompting became a skill they needed to learn in addition to learning general academic writing. Training in how to prompt is an element that may have to be included in academic writing instruction [14], [15]. On questions of which language model was used, all respondents replied they had used ChatGPT 3.5. Only five respondents had tested other LLMs in addition to Chat GPT 3.5. These were Bing, BARD, Chat GPT 4, Perplexity, Phind and Assistant by Scite. From the exams we saw at least one student using the SnapChat AI.

Results from the survey also show that a majority of students found the lecture on searching, critical thinking and reference management to be very useful. However, as shown by *Figure 2*, many students find the various information literacy skills somewhat or very hard. An observation made while reviewing the exam papers was that several students struggled with the importance of knowing where they find their information. Several papers had an LLM cited as the source of information about how LLMs work, and what issues they can represent. There were also several cases where the owner of the LLM was cited as the only source of the same information. Very few papers had credible sources outside of encyclopaedias. It poses the question on how we in higher education can expect future engineers to use and develop advanced models in their speciality, when they do not prioritise learning how to find and use quality information, as Lievens points out [19].

With the exception of paraphrasing, under 27% found information skills not challenging, even if they found the lecture useful. The issue of information literacy is increasingly important when university students use LLMs as their writing and sparring partner. Biases in LLMs are discussed in [7], [14], [16] and the overarching issue is that in our world where the narrative in public discourse is rapidly changing from hegemonic narratives to a broader diversity, the LLMs are still stuck in a narrative of static data fed into the LLMs training materials [14]. This issue must be regarded differently from training the

students in being critical to which website they obtain their information from. It brings aspects of source criticism to a whole different level.

### 4.3 Where do students seek help to improve their writing?

*Table 1* shows that a slightly higher number of students had help from LLMs than from academic staff to improve their written assignment. These are numbers that instructors in academic writing are disappointed, but not surprised by. On further questions of what the LLMs were used for, four categories can be obtained:

- 1. Text generation, translation, and proof reading
- 2. LLM as a learning partner: language training and text feedback
- 3. Plain outsourcing/plagiarism
- 4. Finding information

	Not challenging	Somewhat	Very challenging
Question		challenging	
Understanding the task	27%	53%	20%
Using a language model effectively	23%	58%	19%
Structuring the text	25%	56%	19%
Paraphrasing	41%	45%	14%
Properly referring to sources	23%	52%	25%
Developing a research question	22%	56%	22%
Finding relevant sources	13%	64%	23%

Table 1. In what degree did the following contribute to improving your written assignment?

The numbers in *Table 1* indicate that the introduction of LLMs into academia calls for a change in how we teach. Students' discussion in their lab reports show that more training and instruction in the use of LLMs may help them reflect upon how to use LLMs wisely in their academic writing training. To incorporate this into academic writing instruction seems to be in order, in addition to showing students what people can do that machines cannot do [13].

One of the responses in the survey was that "it is difficult to know how to use language models without training". Other students gave the same feedback in various phrasing. This response needs to be seen in light of the attendance in the course, where 58% responded that they did not attend all lectures. From observation, most students in the course did not attend the optional guidance sessions either. This finding highlights an issue we can see in all parts of academia, where we face the question of combining student responsibility for their own learning with the attendance necessary for the relevant learning outcomes.

# **5 CONCLUSIONS**

It is necessary for student success with academic writing, and critical thinking in general, that we as educators at universities and colleges take responsibility for engaging critically with LLMs.

Even when we engage in cross-disciplinary discussions during both planning and follow-through stages, there are still no guarantees that the students learn the necessary skills without more thorough guidance during the work phases of student academic writing.

On the introduction of LLMs into the engineering education and students' work on academic writing, we see that the higher order elements seem more important to teach than ever. Critical thinking as well as text production-training will be a part of that. Another issue that may need to be included in academic writing instruction is appropriate and responsible use of the LLMs [16], including how to prompt, as well as awareness of bias in the various models.

A third issue concerning academic writing and the use of LLMs, that needs further investigation, is how the written work of students is assessed. It is clear that even though students may submit better texts, they may not have become better writers [8]. Assessing the end product therefore seems futile, and a need for process-based assessment is emerging.

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# LEARNING ACTIVITIES TO DESIGN A PARAMETRIC SOLUTIONS SPACE FOR PRODUCTS IN INDUSTRY 4.0

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### ABSTRACT

The fourth industrial revolution, Industry 4.0, presents challenges for industrial design engineers. The European Union report on Industry 4.0 highlights trends shaping industrial design in this era (i.e. new technologies, different user expectations, advancements in industry). Among the new technologies, parametric design stands out as a powerful tool for creating complex, customised structures using computational algorithms. Therefore, parametric design might be considered essential domain-specific knowledge for future industrial design engineers within Industry 4.0. This domain-specific knowledge of parametric design involves shaping a solution space (i.e. potential products) through procedural thinking (mind-set shift). Inputs, outputs, and workflows need to be considered and are illustrated in the paper with an example. This enables the creation of unique or small series of products tailored to the specific needs of stakeholders. These products can then be efficiently produced using digital manufacturing techniques. However, current engineering and design education often lacks the necessary teaching and learning activities to prepare students for parametric design and procedural thinking. This paper reports on the implementation of educational paradigms for a course on parametric design with the Grasshopper plugin for Rhinoceros. The course (3rd year Bachelor at Ghent University) introduces students to the principles and applications of parametric design (solution space), as well as to foster their creativity, procedural thinking, and problem-solving skills as industrial design engineers. In this paper we will elaborate on the course structure, illustrate the procedural thinking outcomes and discuss the lessons learned and the implications for future courses and research on parametric design education.

Keywords: Parametric design, Grasshopper, procedural thinking, learning activities, Industry 4.0

# **1** INTRODUCTION

The emergence of the fourth industrial revolution, Industry 4.0, significantly influenced industrial design engineering education. Motyl et al. [1] stress the need for broader engineering skills and domain-specific knowledge related to this. This knowledge should expand beyond merely smart machines as industry 4.0 will also encompass breakthroughs in both physical and digital realms [2]. Consequently, it is proposed to rethink industrial design engineering education to prioritise problem-solving and innovation [3]. Considering this research, it is evident that Industry 4.0 affects industrial design engineering education. Educators should cultivate digital competencies and design relevant learning environments to meet the demands of these new technologies. The question remains: What should these learning environments entail?

#### 1.1 Parametric design as cross-roads within industry 4.0 trends

A European Union report on learning environments (in general) and foreseen goals for industry 4.0 poses a partial answer as they identified some trends related to industry 4.0. Below, these trends are further explained and specified for the field of industrial design engineering.

A first trend includes **new technologies**, which are stated to be inherently intertwined with both physical and digital innovations are often referred to as 'phygital' [4]. Among these, parametric design stands out as a powerful tool for creating customised structures using computational algorithms. Visual programming in parametric design software enables designers to freely engage with geometry and create personalised solutions.

Secondly, **industry advancements** encompass the adoption of novel technologies within manufacturing [4]. Notably, Dauter [5] posits that Industry 4.0 enables intricate, and innovative designs using advanced software tools and simulations. This necessitates new training programs and educational curricula to prepare industrial design engineering graduates for these evolving demands [6], [7]. This paradigm shift is also evident in the context of the course and the case we discuss in this paper. The students learn how to align the personalised design of a product to the manufacturing, considering the possibilities of digital fabrication techniques and the outputs and inputs needed.

Thirdly, the consideration of **different user requirements** emerges as a pivotal trend. These user requirements encapsulate the needs and expectations of end-users for a product or system, constituting a fundamental influence on the design process [4]. Song and colleagues [8] posit that Industry 4.0 has impacted consumer behaviour, including a growing preference for personalised products. Loy and Novak [3] further underscore that Industry 4.0 facilitates a transition from conventional mass production to bespoke mass customisation. Consequently, this paradigm shift affords shorter product life cycles. Anticipating the trajectory of future user expectations, characterised by a desire for heightened product diversity and personalised experiences, underscores the imperative for agile innovation in product development [4]. The Parametric Concept Canvas (PCC) [9] was used by the students during the project-based part of the course to define which type of personalisation was useful and possible within an Industry 4.0 production system. This PCC lets designers reflect on the value of personalisation and this from different perspectives. However, it also triggers the designer to reflect on how this personalisation can be realised (breakdown between standard parts, interfaces and personalised parts) but also digital production techniques that can be used to realise the personalised elements. As such, it is a suitable tool for our students during the course's project part.

Industry 4.0 clearly offers many opportunities to be able to manufacture small series of products or unique personalised products that have real added value over their mass-produced counterparts. However, it is imperative to recognise that designers occupy a pivotal position in this landscape. Their role extends beyond mere aesthetics, they are tasked with shaping solution spaces that facilitate the creation of bespoke solutions. Computational, parametric flows play a vital role in achieving this in an efficient manner, using the data input to create an output which matches the demands and wishes of the user, and which can be produced in an Industry 4.0 context.

# 1.2 The need for a change in parametric design education

Computer aided design courses in engineering & design curricula mainly focus on correctly producing 3D geometry for manufacturing purposes. Parametric design is often limited to creating variations of a base geometry in which geometric relationships are more rigidly defined and constrained allowing less variability. In a customisation context the physical manifestation of the geometry is not predefined. The curriculum (i.e., Bachelor of Science (BSc) program in Industrial Design Engineering Technology) lacked a specific methodology/approach and learning activities to rephrase aspects such as functionality and manufacturing in an algorithm. Students are to master the algorithmic way of thinking, which consists of breaking down the worldly processes into representations, simplifying the representations to just their structure, and further simplifying that structure to focus solely on its computable aspects as described [10]. We came across many resources focusing on architecture and furniture design, yet we envision many applications in the domain of product design beyond aesthetic customisation or topological optimisation.

Moreover, learning activities in which parametric design facilitates the designer to really become a metadesigner are important, especially when we consider the added value of personalised products. This was also stated by De Mul [11], "the designer (...) should become a meta-designer who designs a multidimensional design space that provides a user-friendly interface, enabling the user to become a codesigner, even when this user has no designer experience (...). The task of the meta-designer is to create a pathway through design space, to combine design bricks into a meaningful design." Parametric design facilitating the designers to become meta-designers was also addressed in this course.

# 2 COURSE SET-UP (METHOD)

The course (9 credits, 210 h of study time) was planned in the first semester of the third year from the Bachelor of Science (BSc) program in Industrial Design Engineering Technology of Ghent University (26 students submitted a final report and participated to the examination). The data was collected in 2023.

The students received 12 weeks of theory, complemented with a project in which they designed a personalised product and developed a computational workflow. In this project, the students themselves experienced how they could implement the theory (i.e., on digital fabrication techniques, robotics, personalisation of products, industry 4.0, algorithmic design, etc.) in their specific project (i.e. Projectbased-learning, PBL). The lecturer's role was to facilitate this by coaching the students, which is typical for PBL projects [12], [13]. Within the project, students had to design a solution space (not 1 product) that allows to efficiently design and produce a customised product considering a particular stakeholder. This entails students to make a mindset shift towards the design and manufacturing of an instance of a product within the solution space. They must consider the interactions with the algorithm, the inputs, the outputs, the constraints, etc. They had to consider the whole process and identify the added value of this customised product in comparison to mass-produced products. The students used visual programming in Rhino Grasshopper, incorporating user input (choices of functionality, aesthetics, but also anthropometric data) into the design, considering the manufacturability of the personalised product. Below the structure of the course is discussed based on Biggs [14] constructive alignment framework. Biggs' framework consists of three interrelated pillars focusing on learning goals, teaching and learning activities, and assessment means.

### 2.1 Learning goals

The first learning goal of this course is to teach students how to **efficiently and effectively design solution spaces rather than individual designs with a prototypal physical manifestation**. In such a parametric solution space valuable instances of the product can be created based on an algorithm and different types of input. This demands a mindset shift, because the designer needs to consider a solution space with appropriate restrictions (controlling the algorithm) but not the final product (evolving towards meta-design). The design of solution spaces is linked to the shift towards Industry 4.0 where production systems can efficiently manufacture small series and unique products in interaction with the stakeholder. In doing so, they should be able to abstract functionality into a working algorithm that ultimately generates a producible output. As a second goal, we therefore want to teach students how to use advanced digital production techniques and materials to strategically and efficiently produce personalised products.

# 2.2 Teaching and learning activities

To support this mindset shift, the students were introduced to the Parametric Concept Canvas [9]. By using this canvas, the students are guided to consider different aspects such as functionality, aesthetics, or ergonomics. These can be personalised and linked to the architecture of the product and the manufacturability. Using the canvas should facilitate the development of personalised solutions that have real value.

To support the second learning goal the students received theory courses linked to digital manufacturing, data-driven design, parametric design, visual programming, personalised design and manufacturing. Additionally, there were training exercises exemplifying how visual programming in Grasshopper can be used to develop a flow. This flow uses data as an input to change the parametric model and to develop unique instances within the solution space. However, this solution space was also constrained to ensure the functionality and manufacturability. They had to link their designs to real production facilities, materials and costs. Students build on a 2<sup>nd</sup> bachelor course on industrial manufacturing methods. In addition, they got more in-depth courses, the students are given a list of plugins for Rhino - Grasshopper (e.g. plugins that facilitate building an interface for users to interact with the grasshopper script themselves, or plugin's that can link Arduino output directly into the script). They researched the functionality of these plugins and choose one as starting point for their ideation process. Lastly, during class lectures, students learned to understand the industrial revolution towards industry 4.0 and even 5.0.

#### 2.3 Assessment

Evaluation in this course was done in different ways (see table 1). There was a permanent evaluation based on the project. Additionally, there was an exam and a skills test that assessed visual programming skills. Table 1 shows an overview of these assessments, what was assessed, and how this was carried out.
	What?	How?		
Permanent	Opportunity identification for	Use of the Parametric Concept Canvas [9]		
Evaluation	personalisation	(level of completeness and correctness)		
(Project)	Ability to link geometry to architecture,	Report, CAD – models		
	functionality and personalisation options	(Rationale to construct the model and how it		
	of the concept.	was executed)		
	Ability to link the output to possibilities	Report & Physical Prototype		
	in production, connecting production, to	(Selection of production techniques based on		
	shape, material and cost.	presented rationale)		
Exam and	CAD – model, structure of the script,	Visual Programming Skill Test		
skill test	interaction			
(formal	Formal knowledge G – code, Robotics,	Written examination		
knowledge)	Industry 4.0			
	Feasibility and	Project presentation		
	commercial value of the concept.			

Table 1. Assessment, what and how it was assessed

# **3 RESULTS (CASE STUDY)**

In the project-based learning part of the course, each student developed their own case using a variety of plugins in Grasshopper in which different ways of product personalisation were realised. Plugins were selected by the lecturers (a list was created) based on availability and potential to facilitate processes. The students could select from these plugins based on their needs and the added value for their concept. For example, products were developed using anthropometric data of a user to design a customised product. Typical examples are medical devices such as braces but also customised gloves for target groups that must combine wearing gloves with fine motor activities (the case below). Other projects combine functional personalisation with aesthetic personalisation. The system level (e.g. how data can be collected and used) and then how it can ultimately be produced was considered in all cases. The selection of what to personalise for a certain product category was done by means of the PCC.

The case study presented below entails the design of personalised gloves. The user positions the hand on a measuring device and slides the contact point to the fingertips and edges of the hand. The location of the potentiometer is read by an Arduino development board and communicated to the Grasshopper script (the plugin Firefly was used for this). The 3D representation of the glove immediately adapts to the user input. When completed the 3D model is converted to a 2D pattern which can be laser cut and stitched into a glove. Figures 1 to 4 give an overview of this process in which user requirements are used in the grasshopper script and generate an output which can be used to produce the product. In this case study, a physical interface was built to capture the ergonomic parameters in real time. In other case studies, digital interfaces (i.e., a visualisation grouping the relevant input parameters for the user) were built to interact with the user.



Figure 1. Prototype of the interface developed to measure the hand and to control the script in real time using Arduino



Figure 2. The visual programming script developed in the example case study



Figure 3. The creation of the sewing patterns out of the 3D model of the hand



Figure 4. The prototype which was developed based on the script

# 4 DISCUSSION AND CONCLUSION

Although we could only show one student case in this paper, the overall course results indicate that after 12 weeks of courses, most students can make a mindset shift to designing a solution space instead of a product. They manage to develop an algorithm that can generate the necessary outputs (i.e. based on different types of input) to start manufacturing a custom product. Consequently, many students succeed in developing a computational workflow using visual programming, with or without the help of plugins. The added value of personalisation was not always clear for every product despite the use of the PCC. This tool proved helpful but couldn't prevent some students from designing some products with limited added value in relation to their mass-produced counterparts. Therefore, the results illustrate that the need for customisability of products is not self-evident. Nevertheless, the results also provided an insight into the abstract thinking capabilities of students. While the majority were able to make a shift from reproducing an idea in CAD to scripting an open-ended algorithm, there were differences in the level of abstraction, complexity of the scripting and functionality of the result. The results also indicated

that it was feasible for the students to engage with visual scripting to design parametric flows and geometry which facilitated stakeholder interactions to design a personalised product and for them to become a meta-designer. When considering personalised products, there must be a strong link between design and production. Based on inputs, it should be possible to quickly generate a customised design that can also be produced in an efficient manner. With industry 4.0 in mind, such exercises are crucial to make our designers of tomorrow (i.e. our students) ready for the future. We hope this paper can engage other industrial design engineering curricula to research and develop such parametric flows (from stakeholder to production) within a PBL design context and to integrate similar workflows in courses in their curricula.

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# RETHINKING ASSESSMENT FOR GENERATIVE DESIGN EDUCATION

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# ABSTRACT

Design is a generative activity able to stimulate complex generative change. Such activity and change are intensified within the hype of generative artificial intelligence in the notion of generativity. Within design education, students are engaged through generative actions, reasoning, behaviours, values, etc. that need to be better understood to account for their development and assessment. Recent research has called for a more in-depth engagement with such actions with respect to assessment theory in educational settings. Elaborating on the construct of generativity, I introduce and consider the notion of 'generative learning' as a new paradigm for design education allows to rethink and reposition design and design instructions as complex generative processes wherein assessment aims to value and to challenge those processes. This raises important questions such as how such generative design education is addressed. I discuss a few principles to support this new paradigm for contemporary design education.

Keywords: Generative change, generativity, assessment, theory, generative design education

# **1** INTRODUCTION

Design is a generative activity. Designers generate ideas, products, methods, tools, processes, modes of reasoning, behaviours, etc. Design projects are identified through exploratory, generative, and evaluative sequences of research and design [1]. This paper focuses on examining design instructions through the lens of generative design (GD) processes. Over the decade, generative design (GD), in which interactive software is used to generate designs, has become an integral part of designers' activities. Although GD is not new in the literature, with the development of artificial intelligence (AI), generative designing appears to be a key skill in contemporary design education (DE). Introduced in the context of AI research, GD is attracting growing attention in design research and education because of the potential to address simple to complex technical and societal problems. For instance, Singh [2] viewed the need to introduce an integrative GD framework to improve design exploration; whereas Li et al. [3] suggested an evolving thinking to account for GD thinking and processes. Given the interest, GD has earned its place in DE, hence, shaping instructions (e.g., adopting generative tools and interfaces for interactive feedback with chatbots through prompting) and sparking new undergraduate programs (e.g., Design and AI) to tackle the new challenges faced by contemporary society. With this perspective, however, the idea of generativity, mostly used in the context of the design outcomes, needs to be further extended and explored as a new DE paradigm. Additionally, the introduction in current instructions poses a certain number of uncertainties on how 'generative learning' (GL) and related outcomes could be assessed. Given the changing context of assessment due to technology, current design research is exploring what more is needed, beyond the polarity 'assessment of/for learning', to make learning and assessment more authentic, hence, moving the focus from measurement paradigm to meaningful experience. This paper discusses this problem, thereby investigating key principles needed for a 'generativity theory' perspective of DE. It focuses on teaching and learning through the lenses of assessment as key to understand the teaching-learning duality. The paper is organized as follows: I first investigate challenges and limitations in current assessment in DE in Section 2 below. This is followed by Section 3 which examines 'generativity theory' in design research and education. Section 4 introduces the GL paradigm, while Section 5 discusses few principles adopted from design research to account for assessment in the context of GL. I conclude with a summary of key points, and possible avenues worth investigating.

# 2 LIMITATIONS OF CURRENT ASSESSMENTS IN DESIGN EDUCATION

Current design higher education (HE) is calling for a new generation of designers: e.g., 'polymath interpolators', 'trailblazers', etc. To support these visions, Rodgers [4] identified three key changes required to occur: (1) changes in the design profession itself (discipline misinterpretation), (2) changes in the economic factors in the global market (employment and economic changes), and (3) rapid technological development within information and computer technology. However, instructional practices to support these changes and uncertainties are questioned, in particular, in the DE areas. Additionally, several DE experts, program directors, researchers acknowledge for instance that 'the best engineers are no longer good enough' [5] and that there is no second chance for transforming engineering education and training complex skills. With respect to these challenges, DE has several areas that require more in-depth consideration for the improvement of assessment.

#### 2.1 Different assessment paradigms, assumptions, and methods

Assessment in HE has been through different traditions and assumptions. For instance, Serafini [6] identified 3 paradigms of assessment over the years: (1) the 'measurement paradigm', a longstanding tradition concerned with high-stakes, norm-referenced standardized testing; (2) the 'assessment as procedure' focusing on qualitative data collection to justify the measurement; and (3) the 'assessment as inquiry' that is a student-centred inquiry process for which assessment is part of the learning process. These paradigms are echoing three primary assessment concepts: 'assessment of learning' (AoL) associated with traditional assessment modes (e.g. summative testing), compared to 'assessment for learning' (AfL) and 'assessment as learning' (AaL) which support a more progressive, transformative, formative process [7]. Given the association with innovative approaches like collaborative learning and self- and peer-assessment, recent research has called for a shift to AfL and AaL [8].

Since adopting a single assessment method is not enough to determine competence acquisition, current design instructions mix assessments methods to map student learning, however, not without limitations such as the increase of assessment complexity [9]. Such mapping approaches are often sustained by two famous myths in educational assessments: the 'big data' measurement myth which is the belief that the increase of measurement aspects would improve the measurement point; and the opposite view, 'the silver bullet', acknowledges that there is no pertinence in combining multiple measurements, hence, relying on a single, generally high-quality outcome, to perform the assessment. Limitations remain, such as, for instance, the failure to capture holistic learning. As Ashwin mentioned, any silver bullet will bounce back against Goodhart's Law suggesting that once a measure is converted to a performance indicator it stops to be a 'good' measure [10].

#### 2.2 Assessment in design project/problem-based learning

Learning in design can be of different types: formal, informal, and nonformal learning; making design assessment a truly complex instructional process. Among active instructional approaches, project/problem-based learning (PBL) is considered as a key pedagogy for design. PBL Assessment in design presents several challenges. Design is viewed as a complex, subjective, open-ended and illstructured activity requiring the development of complex coordinated knowledge, skills, and attitudes (KSA), in a variety of aspects, that are crucial to a successful completion of a design task performance. Design students are expected to integrate and acquire multiple competencies such as decision making, problem-solving, management, and collaboration which appear to be hardly captured through traditional assessments. Given current advances in computing and non-invasive technologies, it is argued that design learning can be captured only if the learning is understood and there is constructive alignment between instructions, learning objective and assessment. As the result of a competency-based approach, PBL assessment is still highly summative-oriented relying on various design learning outcomes (LOs) while integrating the learners (self/peer-assessment). Sometimes, industry mentors are included to assess certain competencies that a faculty member cannot assess very well, such as the market value. Design supports the generation of multiple types of outcomes, processes, etc. Therefore, understanding generativity in the context of design and education assessment is essential.

# **3 GENERATIVITY IN DESIGN RESEARCH AND EDUCATION**

'Generativity' is a paradigm which can take various forms. When discussed within the literature, the concept of generativity appears to mean different things to researchers from different areas. The concept of 'generativity' was introduced by Erikson [11] in the context of a theory of personality development

with the primary concern of guiding the next generation of individuals. It is addressed as a psychological construct that is situated in the psychology of individual lives considering key social challenges. What does it mean to be generative? From Erickson's psychosocial theory, one should strive to contribute to positive changes that benefit self and others, to avoid stagnation. This human-centricity is crucial for design as a collaborative and creative activity. Erickson originally centred his vision of 'generativity' on the achievement and development of children, but he also explained that the notion could include productivity and creativity in people.

The idea of generativity is also central to design science research which usually studies generativity in terms of the generative power of design theories, methods, and their 'generativeness', their robustness. From this line, Hatchuel et al. [12] view design science as 'the science of generativity'. There are now several design theories that support the paradigm of design as a generative process, i.e. its ability to produce novel solutions [13]. With the development of generative AI, in particular large language models (LLMs), design has taken a new shift in many ways. Broadly situated, the LLMs potential in design lies in enabling five key tasks: converting text prompts to design specifications, converting designs to manufacturing instructions, creating design spaces and variations, calculating performance, and exploring performance-based design solutions [14]. Additionally, in the early design phases, a student designer in need of better representations and appreciations of an imagined product can choose to visualise concepts in high fidelity without the need for prototyping or expertise in visualisation techniques, such as rendering, and to vary the aesthetics of those concept designs through chatbot-type interfaces. Although this is quite extensively used in design focused HE, not all educational systems have adopted this view. However, it is important for institutions to know how to better frame the use of GD to maximise the benefits and minimise the negative consequences.

#### **4 GENERATIVE LEARNING: A NEW PARADIGM FOR DESIGN EDUCATION?**

Learning can be viewed as a process of generation, integration, and coordination of knowledge, and their constituent skills and attitudes (KSA). Piaget [15] viewed this process as assimilation and accommodation. Assimilation refers to the *generation* of new ideas and concepts, i.e. knowledge structures (KSs), and their mapping into existing schemas; whereas accommodation implies learners modify existing schemata to the new *generated* KSs in memory. According to Epstein [16] generative behaviours result from an orderly, dynamic competition among previously established behaviours. From this perspective, generativity is not limited to creation but also extends to a dynamic integration of with existing KSs. Schön [17] called this theoretical shift a 'generative metaphor'. Furthermore, two key learning processes in complex learning are schema construction and automation [18], which can be seen as characteristics of complex GL processes. Learning happens when there is a change in long-term memory [19], therefore GL can be used to support this complex change. Generative people are found to be productive in different ways, including teaching and mentoring in real life [20].

What does this mean for design instruction? From a cognitive perspective, a meaningful learning experience is associated with the generation of relevant connections between KSs without which any assessment for learning seems irrelevant. From an educator perspective, and following Ball's [21] 'model of generative change', generative teachers "refers to the teachers' ability to continually add to their understanding by connecting their personal and professional knowledge with the knowledge that they gain from their students to produce or originate knowledge that is useful to them in pedagogical problem solving and in meeting the educational needs of their students" (p. 47). With this, Ball used the term 'generative change' to describe "a process of self-perpetuating change wherein a teacher's pedagogical practices are inspired and influenced by the instructional approaches and theory that he or she is exposed to in a professional development program" (Ibid.). Following this line, effective generative change occurs if both instructors and students engage in a mutual development. In this article, I use 'generative learning' to imply that change wherein instructors generate meaningful learning experiences for their learners who will be able to develop pertinent GL processes necessary to their educational and professional development. This being said, the question now is whether the generativeness of a well-structured knowledge system is established or not, and how to measure such generativeness.

As discussed earlier, the literature on assessment abounds with paradigms and contestations. Generally, four worldviews are referenced to how theories are used in assessment research: post-positivist (addressing the objective measurement aspect with criterion and psychometric research), interpretivist (addressing subjectivity in social interactions), critical-transformative (addressing how knowledge is

reshaped, reconstructed with respect to social issues), and practical perspective (concerned with making a difference in the assessment) [22]. A main concern is that critical theories are lacking (Ibid.). Given the lack of agreement in addressing assessment contestations and challenges, more research is needed that would help consolidate assessment practices. For instance, Forde-Leaves et al. [7] re-examined the assessment inquiry discourse with three key aspects: *autonomy*, *logic* and *basis of success*. They developed a framework, which, they argued, reconciles polarised positions on assessment practices that hampered the development of an integrated theory of assessment by showing complexities underlying them. However, this framework has not yet been tested to account for key contextual and social assessment aspects, especially in design education.

# 5 FEW PRINCIPLES FOR GENERATIVE LEARNING AND ASSESSMENT

In this section, I discuss a few assumptions for GL. Teachers are key to foster student learning. From this angle, Ball [21] investigated the development of educators' generative knowledge, and how they used this knowledge in their thinking about students and teaching. His model positions teachers as 'generative thinkers' able to address the challenges faced by their students through continuous change and development. Inspired by this model of 'generative change', key research principles for assessment of/for GL need to be explored.

#### 5.1 Creative learning and assessment

A real flaw of the majority of current assessments in HE is that most are based on predetermined results, which makes it impossible to assess key skills such as creativity and critical thinking [23]. For instance, within design, creativity assessment (CA) methods such as criterion-referenced and/or norm-referenced assessment are often developed to compare the design LOs with standards and criteria, and with fellow learners, respectively, to set learner performance. However, even though holistic CA methods are lacking, subjectivity remains with rating inconsistencies and change/variety of the assessment interpretations. The measurement aspect needs to be improved, for instance, combining raters from diverse background and often specific expertise to measure creativity while mitigating inconsistencies through well designed criterion [24]. Future CAs need to address psychometric methods with suitable qualitative methods (e.g., user validity) assisted with think aloud verbal protocols for instance.

#### 5.2 Traceability

Design is a complex, ill-structured activity, for which designers use their *knowledge-in-action* [25]. Therefore, an essential component of assessing designers' learning is understanding their action through traceability. Prior research suggested that learning and assessment should be visible components [26]. Sometimes instructors lack an understanding of the learning paths and outcomes when students come up with the designs. Additionally, as our models of human cognition are debated, and with respect to GL, traceability appears to be a highly valuable skill in GL practices. Traditionally, the assessment load falls on the instructors/mentors who may not always be aware of the individual and collective contributions of students as the result of PBL structuring. Even though self/peer-assessment is introduced to address this issue, the problem remains. Therefore, to reduce the assessment complexity, the assessee needs to highlight as much as possible for him/herself and the assessors, the design thinking, and the individual and collaborative generative actions/processes for the learning and performance to be appreciable. This is crucial especially for effective feedback. For instance, in interacting with generative tools, the Chatbot history is a mine of richness that can be exploited by both students and instructors with respect to the assessment. Therefore, a critical assessment theory advocates the traceability assumption for all reasoning from progressive to radical generative processes and outcomes.

#### 5.3 Interactive feedback

Feedback is viewed as one of the most effective instructional approaches in classroom. As a basis of assessment, it has a powerful influence on learning [27] and is central to assessment. Drawing on sustainable assessment theory, Boud and Molloy [28] suggested we rethink our model of feedback for learning, shifting from a teacher-driven to a student-driven feedback approach. Some design instructors support the minimally feedback approach to students, while plenty of research have proven the importance of explicit instructions and feedback in learning. There is no effective generative change in learning without appropriate feedback. Additionally, the way through which, and the time when the feedback is provided matter and can affect the learning and assessment.

#### 5.4 Critically transformative

An assessment should reflect its context to become a transformative force. In competency-based assessment, authenticity plays an important role for this transformation. Gulikers et al. [29] identified 5 dimensions of authentic assessment which are: the task (addressing whole learning experience as experts do), the physical context (reflecting the way expertise is used in professional practice), the social context (resembling the social processes in a real-life, professional situation), the result or form (related to the type and amount of output), and the criteria (addressing how you evaluate and requiring appropriate criterion-referenced judgments). Over the past decade, critical theories such as the 'transformative learning theory' were introduced to support adults' shift in frames of references, perspectives, and habits of mind [30]. This theory, for instance, posits learning as the process that transforms problematic reference frames, thereby increasing their inclusion, openness, reflection and emotional ability to change. With regards to design, students need to develop a deeper engagement in their reflective and reflexive actions within their GL. They often need to ask what is the value of the generated design outcome.

#### **6** CONCLUSIONS

In this paper, I discuss the extension of a limited notion of 'generative design' to a more holistic concept of 'generativity' and 'generative learning' for DE practices and discuss their relevance. Inspired by Ball's 'model of generative change', I argue that design instructions can be viewed as a process of cogeneration of KSA, behaviours, processes, etc. From this perspective, learning, when applied to DE, is this generative process in which students develop those actions. I review the notion of generativity and generative designing to see how they can be adapted to an instructional perspective, yet still considering key aspects of how teaching, assessment, and learning happen. Applying these notions in DE allows us to rethink of design as a GL process wherein assessment is the extent to which learners have generated meaningful learning experiences. The question of how such complex design learning is assessed is being asked. Few important assessment principles from literature are presented. The discussion sought to investigate whether framing a GL philosophy into a theory is appropriate or not for DE. In light of this, the paper opens an avenue for the investigation of GL processes involved in design, and the foundation for a new way of viewing design as a GL process of actions and behaviours. To account for a relevant theory, there is long way to go. Additional research is needed on the discussed assumptions. For instance, it is pertinent to challenge the notions described here through experimental research and to understand the positioning of this approach with respect to a suitable assessment framework as described in [22] for a critical theory of educational assessment consistent with generative design education. With the advance of assistive technology, mixed measurements methods can help explore the assessment perspective with respect to the GL processes.

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# STUDENTS' EXPERIENCES FROM USING AI IN ENGINEERING EDUCATION

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#### ABSTRACT

A mandatory course, ING101 Technology, Environment and Sustainability, is taught the first year in the Civil and Structural Engineering programme, Computer Engineering programme, Electronics and Electrical engineering programme, Renewable Energy programme and Mechatronics programme at the University of Agder. The students must write a scientific article concerning environment and technology to pass the course. The library and the academic staff collaborated on a new way of solving the task; the students had to use AI in their production of a scientific article and then write a report evaluating the implementation of AI in producing the article. The students were told to evaluate how the use of AI affected the working process, their learning outcome and the final product, the scientific report. The students were able to choose how they wanted to use AI.

This study uses survey data collected from the students in ING101 to investigate the positive and negative perceptions and effects of using AI in engineering education. By looking at the results from the survey and the reported experiences from the students we can evaluate how AI can assist in higher education. This information can be used to influence the way we let our students work on projects, reports, and exams, and to what degree AI should be(come) a learning tool in engineering education.

Keywords: AI, engineering education, survey, ChatGPT

# **1** INTRODUCTION

Over the past year AI, has become readily available for everyone, including students in higher education. According to an opinion poll conducted in November 2023 [1] 27% of Norwegian students state they use ChatGPT every week or month. Initially, the educational system in Norway did not want the use of AI in their examinational projects due to the fear of reducing the amount of independent work. Teachers filed a report of concern to the Norwegian parliament [2] just one week after ChatGPT was published to the general public [3]. Their main concern was the challenge for examiners to evaluate the difference between self-produced work and AI-produced work. Students have always found creative ways to cheat on exams [4], but with the help of plagiarism control it has been possible to detect this to some degree. However, ChatGPT stands out since it was designed to generate human-like texts [5]. This makes it hard to tell the difference between self-produced and AI-produced content. The detectors for plagiarism in use by universities today cannot identify text generated by ChatGPT [6]. When students are caught cheating using AI, it is because of wrong referencing and quotations that do not exist [7].

Still, AI can be a resourceful tool which can be useful for the students' learning and the products they produce. According to Meyer et al. [8], ChatGPT can assist with research and academic writing, provide immediate feedback and examples, be a source of inspiration and increase student engagement. Kasneci et al. [9] also highlight that Large Language Models (LLMs) can assist in critical thinking and problem-solving skills for university students. Another argument made by Adelshola et al. [10] is that the students might not be subjected to information overload. However, they also warn that relying too much on AI to solve problems might impair the students' cognitive reasoning. Along the same lines, Shidiq [11] subsequently argues that over-reliance on ChatGPT may affect the students' ability to develop critical skills and hinder their creative writing skills.

Based on the popularity and possibilities AI presents in higher education, one could argue that students should be taught how to engage with ChatGPT. Meyer et al. [8] suggest that students can be taught ChatGPT correctly and in line with the ethics of their educational institutions. As Meyer et al. state: *"The issue should not be whether the student used ChatGPT, but how."* If doing so, the students could be required to submit their ChatGPT transcript, track changes made with ChatGPT, and point out and

address errors made by ChatGPT. One aspect Adeshola et al. [10] mention is that when allowing more use of ChatGPT, the educational systems need to leave room for students to receive guidance from their teachers and mentors to promote student engagement.

The purpose of this paper is to explore the students' experiences with AI being a mandatory tool in their exam. Data for this study was collected using a survey sent out during a compulsory 5 ECTs course, reviewing the course exams provided by the students and comparing some of the results with a Norwegian national student survey "Studiebarometeret" [12]. We want to find out the positives and negatives of AI in engineering education from the students' perspective and discuss the opportunities of AI in engineering education.

# 2 CASES

The case used in this study was a 5 ECTs mandatory course, ING101 Technology, Environment and Sustainability, taught to first-year engineering students at the University of Agder. This course is compulsory for students within Civil and Structural Engineering programme, Computer Engineering programme, Electronics and Electrical engineering programme, Renewable Energy programme and Mechatronics programme. 333 students were enrolled in the course, 315 students were registered for the exam, 295 students completed the exam, and 256 students passed the course.

The course has a final exam consisting of writing a scientific article and a report. The scientific article was to be written with the assistance of AI/LLMs and the purpose of the report was to evaluate the process of using AI/LLMs. The students still had to follow the university's regulations regarding plagiarism and source referencing. The topic of the scientific article was *technology in a societal perspective*, and it had to be between 900 and 1100 words. The students had to follow a template for both the scientific article and the report. The course is graded as passed or failed.

# **3 METHODOLOGIES**

The methods used in this study were two surveys and the reports made by the students. Every year the course has a course evaluation in the form of a survey distributed to the students. This was modified with questions regarding the students' use of AI/LLMs since 2023 was the first time ING101 used AI in the exam. The questionnaire had 55 questions, but only 4 of the questions concerned AI/LLMs. However, the students also had the opportunity to submit open free-text answers, where some of the comments were relevant for this article. The survey was made with the survey program *SurveyXact* and was distributed on November 21<sup>st</sup>, 2023, on the learning platform *Canvas*.

The total number of exam reports were 295. A random selection of reports was made by reviewing the first 42 sorted by candidate number. These reports were examined to understand the students' opinion on advantages and challenges with using AI to write an academic report, and how they used AI to solve their exam.

To compare the results from ING101, the results from the Norwegian national student survey "Studiebarometeret" is also used. "Studiebarometeret" [12] is a survey distributed to over 70 000 students in Norway every fall. The survey is given to students in their second year of their bachelor's-or master's degree. This article will use the 2023 results for second-year bachelor students in Civil and Structural Engineering programme, Computer Engineering programme, Electronics and Electrical engineering programme, Renewable Energy programme and Mechatronics programme.

# 4 RESULTS AND DISCUSSION

Table 1 provides an overview of the data concerning the survey sent out in the course. It was distributed on November 21<sup>st</sup>, 2023, and contained 55 questions where four of the questions are relevant to this article. The response rate was 27%.

Distribution date	Total number of questions	Number of questions regarding AI	No. of respondents	Response rate
21-nov-23	55	4	90	27%

Table 1. Data about the survey

As illustrated in Figure 1, 19% of the students found it very challenging to use the language model effectively. Most of the students, 58%, found it to be somewhat challenging. A possible explanation of

this could be that this is the first time the first-year students are trying to use AI. Results from "Studiebarometeret" [13-16] show that only 10% of the second-year students at the same study programmes do not use AI at all in their study, except for the Mechatronics students [17] where 35% of the students never use AI in their study.



Figure 1. Academic writing: Evaluate the level of difficulty for the following

The answers for the second question on finding relevant sources, illustrated in Figure 1, shows the same tendency in the distribution. 64% find it somewhat challenging and 23% find it very challenging. Of the 42 exam reports, 26 candidates address challenges regarding wrong or non-existent sources when using AI. When using AI, it provides sources that the students have to validate. Some of the sources did not exist and they also had to validate if the statements made from the sources were in fact true. This also accords with Alshater [5], who showed that ChatGPT lacks transparency, making it difficult to hold these technologies accountable for any error they may produce. Although 19 of the reports highlighted that the use of AI can be time saving, this insecurity regarding sources proved to be more time consuming than reading the sources themselves. However, some of the chatbots allow the user to upload sources they want to include – giving the user more control. In the course survey regarding which chatbot the students applied in their exam, 57 out of 57 replied ChatGPT. Most of them used the free version (3.5), but a few invested in the newer version (4.0). Only three out of the 57 also mention another chatbot than ChatGPT. Some of the students pointed out significant differences between the free version and the paid version. In the free version the chatbot sometimes replied that it could not answer, but when prompting the same question in the paid version it gave a fulfilling answer. According to Alshater [5] the chatbots depend on the data they are trained on. Meyer et al. [8] point out that the LLMs reply with confidence regardless of whether the information is true and/or accurate. This can fool the users to rely on the information provided by the chatbots. Blindly trusting the generated information from chatbots, increases the risk of plagiarism, and was also the cause where students were caught cheating [7]. The students grew more sceptical towards using chatbots when they were made a compulsory part of their exam. The students mention that they thought highly of chatbots prior to their exam, but after the project their confidence had diminished. Because of the lack of tracking of sources and made-up auotations the students found it easier to do the work by themselves. They discovered that the chatbots did not discuss the results but simply repeated them. They also mention that when they prompted the chatbot to write within the word limit, it did not stay within the limits. When told to write a full article it tended to repeat itself. However, the students were pleased when the chatbots wrote smaller paragraphs. They still saw the potential to use AI to generate ideas and to formulate relevant research questions. It could also guide them in an applicable direction. When the students were asked to rate their satisfaction with using an LLM for academic writing, 77% answered somewhat or very satisfied, as illustrated in Figure 2. This indicates that although the students found it hard to use the chatbots effectively, as shown in Figure 1, when they learned more about how to prompt and how they worked they were satisfied. Although half of the randomly selected reports noted that they used ChatGPT to

improve the language in their scientific article, they also emphasize that the produced, and intended improved, language was overcomplicated, pompous and somewhat foreign. They still found it beneficial in translating, and still helped the students to formulate and structure their text. Some students also mentioned that they experienced some biased answers from the chatbots. This finding was also reported by Alshater [5], stating that chatbots may have the potential for bias because of the data they are trained on.



Figure 2. Rate your satisfaction with using a language model for academic writing

The results from "Studiebarometeret" [13-17] show that when asked how the students use AI, a total of 75% have used it to explain the syllabus, concepts, and terminology. This use is the most common use of AI, outscoring the second alternative of generating programming code. Generating summaries and outlines of texts is one of the benefits with LLMs mentioned by Kasneci et al. [9]. This can better the students' understanding of the main points in a text. Some of the students in ING101 used AI to inform them about the contents and topics in longer articles and books by writing a summary. This could be an effective way of evaluating a large number of sources and avoid the information overload mentioned by Adeshola [10]. As an educational system, we want our students to develop critical thinking and research skills, improve their academic writing, and most importantly learn, but also learn how to learn. Although it may be argued that AI might have a negative impact on creative writing skills, developing critical skills and the students' cognitive reasoning [10, 11], this paper found that by making the students use AI in their exam they grew more sceptical towards chatbots and their output. Because of many cases of cheating and plagiarism recently reported by the media [18], the students were very careful when using chatbots. This made them more curious on how the chatbots found their sources, and more critical towards the generated information. A consequence of this exam project was also that it made the students more sceptical towards the credibility of the sources used. They also had to divide their scientific article into paragraphs because of the limitations in ChatGPT, giving them smaller amounts of text to evaluate resulting in a better overview of their text. Since the students had to follow the university's regulations regarding plagiarism and source referencing in their scientific article many of them found it hard to trust AI. This resulted in students using their critical skills by running quality assessments on almost everything generated by the chatbots. Another consequence was the students evaluating the language used by the chatbots. The students found this project to be interesting because they were allowed to use a tool whose legality is discussed by different educational institutions [10]. The future of AI, according to Neumann et al. [6], is addressing the question on how to integrate AI into higher education. We need to follow up on Meyer et al. [8] and not look at whether the students use AI or not, but how they use AI. We should raise the question on how we evaluate exams in the future of AI, if we should include transcripts, track errors and changes made by chatbots. Still, introducing AI to first-year students showed positive results in making them critical to work done by others, and analytical towards structure and linguistic formulations. After exploring the limitations first-hand, the students might be discouraged from abusing AI tools for cheating and plagiarism.

#### **5 CONCLUSIONS**

This study set out to investigate the positives and negatives of AI in engineering education from the students' perspective. The students found chatbots useful in helping them formulate academic texts by translating, structuring, and formulating the language. It also helped them discover and summarize potentially relevant sources. Most of the students were satisfied with using AI for academic writing but were inconsistent in their answers if it was time saving or time consuming. The negatives of AI pointed out by the students were first and foremost the lack of transparency when referring to sources. Other negatives were the chatbots' inability to stay within the word limit given in the exam, incapability to discuss and not just repeat results, not being able to write longer texts but only paragraphs, and the possibility of bias. The students also mention that all the chatbots were very dependent on the prompting, giving them better results when they knew how to formulate the appropriate questions. However, there appears to be a significant difference between free and non-free versions of chatbots.

The second aim of the study was to discuss the opportunities of AI in engineering education. Although AI may impair the students' cognitive reasoning, affect the students' ability to develop critical skills and hinder students' creative writing skills, this exam project forced the students to be critical and thorough when using AI. The students therefore used their critical skills by running quality checks, controlling the language and challenged them to be accurate when prompting questions. By allowing the students to use AI, a tool that there is still no consensus of using amongst educational systems, they had the opportunity to familiarize themselves with chatbots, which could encourage student engagement. The students still had to follow the university's regulations regarding plagiarism and source referencing, requiring them to apply their critical thinking skills.

Considerably more work will need to be done to determine how we implement AI in engineering education. Further research might explore how students would prefer to use AI for their projects, reports, or exams. More broadly, understanding how to evaluate student hand-ins must be readdressed if AI becomes a commonly used tool in higher education.

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# CONNECTING THE LOOP: TEACHING END-OF-LIFE DESIGN ISSUES THROUGH PRACTICAL WEEE DISASSEMBLY

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# ABSTRACT

It is often cited that '80% of a product's environmental impact is decided at the design stage' [1] and yet it can be very difficult to ensure that undergraduate students truly appreciate the impact of their decisions in the early stages of the traditional double diamond design process. Whilst lectures, statistics and information can give the students an academic outlook on end-of-life issues, there is much to be gained from a hands-on engagement in the delivery of education around these pressing problems.

This paper examines two case studies from two sessions where design for disassembly was taught in a practical way, with each student physically taking apart a waste laptop through a guided session completed in collaboration with a local community interest project focussed on WEEE. By examining feedback from each session, these case studies discuss the impact of physical sessions on the understanding of disassembly by undergraduates, and also its context and importance in the role of design in the circular economy (CE).

The circular economy – a system that aims to keep materials and resources in constant flow, whilst also creating a regenerative future is arguably a critical system to be understood by all undergraduates, equipping them with the broadest sets of skills and contextual, experience-based understanding. This work is relevant to anyone teaching product design - particularly those teaching circular economy elements and the impact of design on end-of-life processes.

Keywords: Circular economy, disassembly, WEEE, product design, pedagogy, HE, education

# **1** INTRODUCTION

Despite initiatives such as the 'Reduce, Reuse, Recycle' [2] mantra from the 1970's, our lifestyles and demands on Earth's resources has only increased, and unfortunately quite dramatically. Over the five years from 2018 – 2023, our material consumption reached around 500 gigatonnes, which equates to around 28% of all the materials that humans have ever consumed since 1900 [3]. Instead of 'reducing' our global consumption we are accelerating, and at speed. In 2023, Earth Overshoot Day – the day where humanity's demands exceed the natural resources that can be annually replenished – fell on  $2^{nd}$  August, 151 days before the end of the calendar year [4]. Therefore, it is becoming increasingly important that we not only address global consumption, but ensure that we are using, and reusing resources and materials as efficiently as possible. The circular economy, a series of cross sectoral closed-loop systems can be part of this transition – encouraging practices such as refurbishment, repair, reuse, regeneration and at the last resort, recycling. However, for too long, recycling has been the main focus of industry, which is problematic as by its very nature, recycling is a destructive process. Recycling does not always translate to usable materials at the start of the supply chain either, as between 2017 - 2023 there was a decrease in secondary (life) material use of 21% [3].

For some products, recycling poses a complex range of issues, from social, to material, to environmental. Once such growing waste stream is WEEE – Waste Electronic and Electrical Equipment – which encompasses a wide range of products, from fridges and washing machines, to computers and mobile phones, and constitutes the largest, fastest-growing source of waste globally [5]. In 2019, around 52.6 Mt of WEEE was produced globally, equating to around 7.3kg per capita – a growth of 9.2 Mt from 2014 [6]. According to the United Nations Global E-Waste Monitor, this figure is estimated to rise to 74.7 Mt by 2030 – almost doubling in just 16 years, fuelled by growing consumption rates, short

lifespans of products and lack of repair options. Most concerningly, only around 17.4% of WEEE was reported as being collected and recycled properly [6].

However, when combined with a well-constructed circular economy, WEEE has significant economic opportunities, with the raw material value locked up in waste products equating to ca. 55 billion Euros [7]. Higher up the waste hierarchy, reduction, sharing, repair and leasing also are huge opportunities for WEEE. For example, the European Union WEEE Directive lists the reduction of WEEE as a primary objective, along with efficiency of material use and reuse of items, including also Extended Producer Responsibilities and targets for the collection of WEEE [8].

Another barrier to a functioning circular economy is the issue of WEEE exporting (both legal and illegal) – particularly when recipient countries are poorly prepared for the correct handling of these items. 23% of WEEE generated in developed countries is sent to approximately seven developing countries, and 75-80% of all WEEE produced globally is exported solely to developing regions in Africa and Asia [9]. This translates to both deep social and safety impacts of WEEE, which contains a large variety of substances that are hazardous to both human and environmental health, from mercury, to brominated fire retardants, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). The uncontrolled and unsound disposal of products are directly linked to the health of exposed workers and widespread environmental damage to land, waterways and air [6, 10].

So how does this relate to higher education (HE), and especially, Product Design education? Fortunately, there are multiple avenues that can be explored. According to the Ecodesign study by the European Commission in 2012, up to 80% of a product's environmental impact is decided at the design stage [1], therefore embedding core aspects of product circularity, such as disassembly, repair and material recovery in HE could translate to WEEE that is simpler to handle at the end-of-life stages, once a student designs transition to industry. Indeed, De Ios Rios and Charnley have also shown how a working CE can only be created through a change to design skills [11] so it is the responsibility of HE institutions to manifest this change. It has been observed however that there is a distinct gap in the education of circularity to design students, which is concerning as they will be the creators of 'things' in the future – without a clear understanding of an entire products lifecycle, design decisions can be made with unintended consequences that could lead to poor options at end-of-life [12]. This is despite educators advocating for the use of disassembly sessions to better teach assembly and simplify manufacturing systems for many years [13, 14]. As attentions have turned away from just 'manufacturing efficiency' to the advancement of circularity, these core product design skills become even more critical.

These observations led to the two pilot case studies discussed in this paper; examining the possibilities of cross sectoral value-creation for WEEE if disassembled in the UK through a practical design sprint and WEEE disassembly session, and how undergraduate product design students rank the importance of disassembly, repair, second-life materials, upgradability etc both before and after a practical WEEE disassembly session. Would their perception of the importance of disassembly ease in products change? How can we reimagine opportunities for WEEE (and specifically waste laptops) in the UK, and how can we prevent problematic WEEE in the design stages through educational interventions?

#### 2 REIMAGINING WEEE IN THE UK THROUGH DESIGN INTERVENTIONS

# 2.1 CASE STUDY ONE: The Design Sprint and Business Model Creation

The first case study examines a Higher Education Innovation Fund (HEIF) project completed in summer 2023 entitled 'mining a WEEE stream for greater economic, social and environmental value', led by Claire Potter (course convenor BSc/BA Product Design, University of Sussex) in collaboration with local partner Tech Takeback and University of Sussex Business School. The purpose of the project was to evaluate the potential of reusing scrap WEEE materials into new products through higher value circular economy solutions. This project helped to build on the Multi-Criteria Assessment Tool (previously created by the US Business School) and was structured to find possible income generation opportunities for disassembled laptops, their materials and component parts through three stages:

- Secondary research identifying the main materials found in scrap laptops, opportunity for recovery (and current values), current recycling by Tech Takeback (and values), global issues and impact of WEEE, case studies of design-led products made from global waste WEEE.
- **Design Sprint** (one day in May 23) which brought together professional designers, artists, Tech Takeback employees / volunteers and students from cross-disciplines together to initially disassemble a variety of scrap laptops (See Figure 1) and create concepts for the materials and components using design briefs related to 'Fashion', 'Packaging' and 'Toys and Games'.

- Assessment of briefs Each selected final group idea was Design Assessed by Project Lead, Claire Potter, for possible localised commercial viability. These were further analysed using the Business Model Canvas and Value Proposition Canvas from US Business School to identify three key elements, enabling an understanding of where the desirability of value proposition, feasibility of value creation and delivery and viability of value capture could be balanced.
  - 1. Value proposition What value is provided to the customers?
  - 2. Value Creation and Delivery: How the value is provided?
  - 3. Value Capture: How does the firm make financial gains?



Figure 1. disassembled laptops and component examination

In this paper however, we will be focusing on the second stage - the Design Sprint. This started with a brief introduction to the global impact of WEEE from Tech Takeback, (background, statistics and future impact), along with their current local activities of recovering, decommissioning and dismantling waste laptops. After a health and safety briefing and equipment introduction, The Disassembly began.

It is worth noting that the participants of the Design Sprint came from a wide variety of backgrounds and experience – some had never taken apart any form of WEEE and some were very well versed in dismantling a waste laptop. Whilst it may seem that this was problematic, it actually enhanced the learning experience for all – those who were experienced offered help to the novices and became reacquainted with the shock of how complex and resource heavy a laptop can be. One participant remarked how they 'had forgotten how badly a laptop is designed and how complicated the disassembly is' until they were helping a novice. The mixture of experiences also fostered deep conversations and reflections about resource uses, material values and consumption, along with responsibility – with participants reflecting on how they 'would have designed this in a much simpler way!'

Another key discussion point was time. Whilst participants disassembled the laptops, the project partner Tech Takeback gave a running commentary on where they would expect disassemblers to be, which of course, was much further on than most of the participants. Understanding the speed of disassembly required to create economic value from the current usable elements of waste laptops was a key seed to sew for the later stages of the Design Sprint. Participants also reflected together on why WEEE is so commonly exported to developing countries to enable economic viability of resource collection, despite the evident exploitation to both humans and environment. Seeing, experiencing and understanding the consequences of design decisions first hand was described by one participant as 'deeply sobering'.

Material identification was also a very important part of the disassembly session. Whilst many participants could list some materials that went into making a laptop, actually removing them, holding them, list them and weigh them created a deeper understanding of real resource use in a product. Discussions around material values followed, both from a design and economic perspective, with participants being given the current market value per gram / kg of different components. This also fostered a deeper understanding of what are the most 'important' parts to remove and why.

#### Establishing new 'values'

The second part of the Design Sprint purposefully didn't focus on these 'valuable' parts, but on the other elements that were deemed to have no/low economic value once removed from the waste laptop. Thus began the creative element of the day – what can we design that utilises materials / components with low/no current value? How can we make a waste laptop have higher returns to allow UK disassembly to be more economically viable, reducing impacts of exports on developing, underprepared countries?

Each group was asked to create concepts for a new, unrelated sector (Toy and Game, Fashion, Packaging) and was taken through a series of idea generating exercises, allowing them to create a series of experimental designs utilising the waste materials identified in the disassembly section. These took the form of sketches, low-fi models using parts of the disassembled laptops and plans for social media campaigns to target specific users, communicating the origins of the new 'product'. All exercises were completed in a few hours, so the ideas were very loose and conceptual, however they were able to be discussed for economic and local manufacture / making viability in the session and assessed in more detail by project lead Claire Potter in the final report, along with new business model possibilities.

Enabling WEEE to be disassembled and monetised in a local circular economy rather than relying on exporting helps to reduce the impacts on human and environmental health in overseas locations, where recycling is often an exploitative business. The results of this project will be taken forward by Tech Takeback to create new business models for scrap laptops that are donated, as well as the possibility of new jobs and/or income streams from the design and production of new products by local makers. Plus, the participants left the session with a deeper understanding of both WEEE issues and the importance of designing for disassembly (why products need redesigning) and also how materials and could be incorporated in new designs (using WEEE as 'second life' materials). The Design Sprint was a huge success and highly enjoyable for participants, therefore it was decided that the session would be run again, with new participants, and a twist to allow for further, more quantitative investigation.

#### 2.2 CASE STUDY TWO: The Module Disassembly Session

During the autumn '23 semester in the US final year Product Design module 'The Role of Design in the Circular Economy', a similar practical disassembly session was arranged with a completely new cohort. However, before the students (who were all product designers) were given the introduction talk by the partner Tech Takeback, they were asked to rank the importance of the following statements in their own design practice on an anonymous statement sheet (1 being the highest importance, 10 being the lowest):

- Waste as Food (using second-life materials).
- Making Items Repairable.
- Using the minimum amount of materials (reduction).
- Designing items for disassembly.
- Creating items with the lowest embodied carbon footprint.
- Designing items that can be upgraded.
- Creating items that have a transparent (trackable) supply and manufacturing chain.
- Designing and creating items that can be manufactured locally.
- Creating items that are fit for sharing (collaborative consumption).
- Assessing whether a product really needs to exist (reduction / refusal).

The introduction talk and Q+A was then given – outlining the global issues with WEEE, stats, videos and material discussions, and then as with the Design Sprint, each student was given a waste laptop, health and safety instruction, tools and basic advice to start the disassembly. Again, some experienced dismantlers were on hand to assist if needed, but in this session, students were encouraged to try and figure out the laptop construction and order of disassembly themselves. Using this more 'hands-off' approach resulted in the dismantling of the laptops taking a longer amount of time, however this fostered a more animated discussion from students who were frustrated at the poor design decisions that had led to the difficulty of the task. After dismantling was complete, as with the Design Sprint, students categorised, identified and weighed components and materials, to allow for a tangible understanding of economic value and quantities in each waste laptop.

Each student was then asked to complete the same ranking exercise on their retained sheet, with the aim to see if the practical disassembly session had affected the priority of disassembly / repair in their own practice. We can see from Figure 2 below, that over the entire cohort, 'making items repairable' was the most important both before and after the session, (ranking of 1) however 'designing items for

disassembly', 'lowest carbon footprint' and 'local manufacture' all increased in ranking by one place of importance. Interestingly, 'waste as food (using second-life materials)' and 'creating a transparent supply chain' fell in importance (post disassembly ranks of 7 and 10 respectively). 'Does it need to exist' also fell in importance when scored across the whole cohort, although it was still high in importance overall (in top 3 both before and after the disassembly).



Figure 2. Before and after scoring of rankings (lower number = higher importance)

However, this was combined score data from the whole cohort – if we look at individual student product designers, there were some very interesting, detailed observations. After the disassembly, one student raised the importance of using the 'minimum amount of materials' from a rank of 5, to the highest of 1, whilst another student raised the importance of 'designing for disassembly' by three places, and another student by two. 'Making items repairable' also saw an increase in rank by one place in two different students. So, whilst there were not huge movements in ranking scores across the whole cohort after the session, in some students the disassembly experience had a very marked affect in their design priorities. It is planned for data such as this to be collected again in future module presentations to further investigate the immediate impact of disassembly sessions and student attitude changes over time.

# **3 CONCLUSIONS**

Whilst both case studies had differences in session focus and length, cohort type and research methods, there were a number of takeaways and observations from participants and organisers that were the same. Firstly, disassembly is hard, complex and takes time. Participants understood and could better reflect on why WEEE is currently exported to developing countries after experiencing the disassembly first hand. This allowed more participant reflection and empathy for exploitation issues with WEEE and reflect on how re-design could allow for end-of-life products to be re-used or re-processed easier, safer and quicker. Secondly, materials can be held by participants, weighed and quantified, and separation (essential to create high-value second-life materials) can also be discussed with physical context. Participants can also learn to visually identify materials, which is a very useful skill when working with second life (and sometimes unlabelled) components. Thirdly, participants can start to consider how to use second-life materials in new designs – even those in completely unrelated sectors, which previously they may not have thought were possible (e.g. WEEE to Fashion).

There was also a deepened sense of responsibility from the designers – understanding that the difficulties they experienced in the disassembly were the result of decisions at the design stage was very impactful (and as shown above, was reflected in their ranking changes). Ensuring that items are able to be easily disassembled and repaired is critical to a functioning circular economy, and exposing undergraduate students to the current landscape of WEEE helps to galvanise this importance first hand. It is only through practical sessions that these lessons can truly be learnt, understood – and be embedded in the circular practices of our future designers who have the power to create real change.

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# A HYPER-LOCAL PLACE-BASED PEDAGOGY FOR EXPLORING DESIGN JUSTICE, ONTOLOGICAL DESIGN AND SYSTEMS ENTANGLEMENT

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#### ABSTRACT

To design transitions into fairer and healthier ways of living, we need to better understand how systems create conditions that damage the planet and make life difficult, unhealthy and unjust. So how do we support students in understanding and exploring systems? How can we help them cultivate a better understanding of their capacity to make decisions and responsibly navigate complex challenges? This case study research reports on an attempt to develop the capacity of master's students to engage with systems from an ontological design perspective. The pedagogy intended to foreground interrelationships between people and things in systems. Data from a series of discussions that formed a central part of the learning experience are analysed to understand the learning of students in this hyperlocal place-based enquiry. The research contributes to developing discourse about how we teach and introduce students to practise systemic design. It highlights how unjust and unhealthy circumstances can be found in the most familiar situations and that these can provide valuable learning spaces.

Keywords: Responsible design innovation, ontological design, pedagogy, systemic challenges

#### **1** INTRODUCTION

Design education faces criticism for not adequately preparing students for the multifaceted challenges of their future careers. To design transitions into fairer and healthier ways of living requires a shift towards social, ecological, and ethically responsible design pedagogy. Transformative learning and place-based education are pivotal in fostering critical and creative thinking, and this study proposes the design studio as a potent experiential learning environment. By integrating critical theories, this educational approach aims to empower students to deconstruct and reshape the harmful patterns of modern life, advocating for a reflective, relational, and justice-oriented design praxis. An individual's frustration with a cluttered mug collection sparked a reflective student design project transcending its mundane origins, becoming a medium for students to explore and address underlying systems of culture. authority, and resource dynamics within their environment. The hyper-local pedagogy through its simplicity and familiarity, enabled students to engage with systemic issues. Expanding the boundaries of traditional design expectations, the project encouraged students to confront systemic clutter and inequity, fostering a deeper understanding of ontological design and their role within it. This study highlights the challenge of recognising systemic patterns within our personal spheres and questions how privilege may obscure the daily struggles of others. It underscores the value of a place-based pedagogy that leverages socio-material objects for deep systemic inquiry, demonstrating that students can discern and address complex patterns.

# **2 LITERATURES**

It has long been argued that the current frameworks of design education do not sufficiently prepare students for the complex environments they will be working in [1; 2]. In response to this, educators call for urgent action on the development of design pedagogy to focus on the social, ecological and ethical responsibility of the designer, highlighting the importance of addressing critical and creative thinking [3; 4]. Transformative learning approaches offer students opportunities to challenge assumptions and encourage the new mindsets that researchers [5; 6] argue are essential for taking action on deep and long-lasting transitions. Place-based education [7] provides students with quality learning experiences in local settings. Educators continue to advocate for using the world as a classroom, working with real-

life problems and learning through action [8; 9]. A fundamental aspect of place-based education is that it must happen outside of the classroom and within local communities and environments. However, this study counters that position and adopts the micro-environment of the classroom itself (the design studio in this case), as the context for the student's experience and as a powerful experiential learning space. Design education must accommodate a reflective agenda to stimulate a discursive design praxis which questions assumptions and explores alternative futures [10]. This kind of education nurtures relational, ontological and pluralistic approaches, revealing diverse perspectives, contradictions and conflicts [11]. To transform complex systems, students first need help to identify harmful patterns of modern life so that they can dismantle and adjust them, with an awareness of the dynamic tensions and interplays between them [12; 13; 14]. There are several critical design theories which stimulate discussion on modern design and help to surface these conflicts. Ontological design theories challenge the dominant practices that have contributed to the crises of the modern world and help students develop an awareness that not only do we design the world, but the world also designs us and the way we live [15; 16]. Design justice and social-justice-oriented approaches are known to radically challenge designers to centre people who have been marginalised, using decolonial, collaborative, emancipatory and creative practice [17; 18]. These theories are complex and abstract and can be hard for students to apply to their everyday lives. To address this challenge educators have drawn on sociomateriality theory to facilitate pedagogical processes, enabling learners to contextualise, assimilate and apply theoretical notions within their own contexts and environments, turning on their potential as agents [19]. Using sociomaterial objects as a foundation for inquiry helps students understand that our entanglement with 'things' causes us to respond to their changing realities and puts patterns in place [20]. This study demonstrates one model of critical design inquiry which uses place-based sociomateriality to explore aspects of design justice, ontological design and systemic entanglement through a short student project focussing on everyday objects in their studio environment.

#### **3 A PLACE-BASED ENQUIRY**

One day in November 2023, after hours of intense work, Justine felt the need to declutter her thoughts and refocus. The solution; a cup of tea. However, she was quickly reminded of how cluttered her life was when she opened the kitchen cupboard to find the usual mountain of stacked mugs. That day, this mug-mess really bothered her. In the pursuit of calm, she emptied the cupboard and left all the personalised mugs on the kitchen table, committing to determine which mugs had no owner and which mugs should be kept. Then Nick (Nicholas) entered the kitchen and found the mug-mess on the table, he was flabbergasted.

Nick is the most senior member of the research team and has his own office. With his 'privileged' position comes the 'luxury' of having his own cupboard where *his* mug resides and therefore the mugmess was non-existent to Nick. This event was the trigger to create a learning opportunity. Although the project may seem trivial, it was not. The project was a lot more than just a mug-mess. It was about revealing a system - the design studio - and its dynamics. It was about engaging with culture, authority, agency, power, purpose, roles, responsibilities and resources to address a specific situation - the mugmess.

Situated in the context of a UK multidisciplinary design innovation master's programme which brings together students from different academic and professional disciplines the research focuses on a 9-day design project. The project took place 10 weeks into the programme and challenged its 8 students to bring about changes which result in fairer and healthier ways of living in a hyper-local context - their design studio. The brief [21] was inspired by a collection of 21 mugs which had gradually accumulated as students, staff and visitors had brought, used and left crockery in the small studio kitchen when they left the community. The brief asked students to consider the mugs, the systems they represent and asked them: How did we get here? What does this situation represent? How can we deal with the situation? What can you do that can challenge or change the patterns that form this situation? Students were invited to co-produce an exhibition of their actions, thoughts and perspectives, contributing to it daily. Students were given full creative freedom to determine the nature and forms of their project outputs and outcomes. The research and academic team did not pre-determine avenues for dealing with the mugs, nor use specific vocabulary such as 'upcycling' that could have directed students towards a type of output. Focused on designing ways to actively transition into fairer and healthier ways of living, the project permitted the students to put things in place now for how people would live in the studio in the future.

# 4 METHOD

Over the 9 days of the project, at the end of each afternoon, conversations between research group members and students explored themes and outcomes from the project while considering the day's contributions to the exhibition. Each day's exhibit outputs were used as materials and insights to ground and stir theoretical discussions, which touched on how the students might see and understand systems through interacting attitudes, values, norms, choices and behaviours and how creativity might help them better understand responsible innovation. These conversations took place in the design studio and were conducted as a roundtable discussion in two rounds; firstly, each student/student team shared their work and thoughts, and then all attendees contributed in turn asking questions, sharing thoughts and provocations. On the last day students, researchers and visitors navigated the student's final exhibition before students shared the thought process behind their outputs and then the wider group discussed their insights and opinions. The conversations were recorded and transcribed using Otter.ai software and were then cleaned by the research team. The research team analysed the transcripts and photographs of exhibition outputs [22], identifying discussion themes and significant student critiques. The insights derived from this analysis are presented in the following section.

# 5 A LIVING SYSTEM SHOWS PART OF ITSELF

Three themes highlight how the students described their critical engagement with the systems that are the studio: cluttered lives, compassion in action, and beyond the moment (see Figure 1. and [22]).



Figure 1. The Future Unmoulded, a students' contribution to this project

# 5.1 Cluttered lives

"The impact of excessive possessions seems to create a weight, almost mental clutter. It's like background noise that grows louder as more thinking accumulates. I notice it becomes overwhelming, making it harder to focus or find peace amidst the chaos of stuff. It feels like a constant distraction making it challenging to appreciate what truly matters" [22].

The project highlighted the studio as a system of accumulation. More specifically, the studio, a living collection of sociomaterial complex systems, was grasped by the students as a place that more effectively accumulates and retains material resources than it does transform or remove them. Students began to recognise dozens of zones and types of clutter, some identified as temporary mess (piles of pens, paper and development work) and some as lingering pollution (unused banks of computers, rolls of previous project materials, or obsolete signage). This thinking was extended to other parts of their lives with wardrobes and social media accounts being understood as other places of accumulation. These observations came with questions: who is responsible for managing different forms of clutter and excess; when it is unclear who can take ownership and what can they do; how are accumulated acts of neglect that result in different forms and volumes of accumulated clutter experienced by different people in a place?

#### 5.2 Compassion in action

"Within the [design studio], we observe diverse interactions unfold. Some gracefully navigate disagreements, while others exhibit unexpected kindness. These observations spark curiosity about the profound impact of grace and self-compassion in everyday interactions. How might your interactions and responses change in challenging environments? Are there new approaches or habits you may consider adopting to enhance your compassion?" [22].

The students became curious about the distinctions between small but conscious acts of neglect and micro-expressions of kindness or compassion. This was developed through considering the speed it takes to change conditions and the pace of change when the immediate ways to respond are no longer acceptable or desirable. On day one of the project any one of the students could have simply put all 21 mugs into the bin. However, the students had agreed that this should not be a first response, it must be a last response. The students recognised that by having the mugs in their workspace and by being asked to creatively deal with the mugs and future mug-mess, things had changed. The interrelationship between students, staff and the mugs (and other material elements of the studio) changed and developed. Putting the mugs in a cupboard reduced exposure to 'the un-dealt with and the un-cared for'. Students became interested in other ways that sociomaterial systems hide, devalue or ignore, how conviviality and compassion might be systemically encouraged and what acts of tolerance, protest, and outrage would accompany this.

# 5.3 Beyond the moment

"As we navigate life and witness the diverse decisions people make, their considerations are intriguing. There were individuals whose choices seemed to radiate a consciousness of the broader impact on the world. They weren't merely concerned with the immediate gains. Instead, their actions spoke volumes about considering the long-term effects on society and the planet" [22].

'No action, no future!' stated one of the students. But the students also asked, 'which actions are for when?'. Dealing with the mugs became many things: mugs animated short films, they were given new practical purposes (as pen holders - or as tumblers to hold written notes on project feedback), they were branded, rebranded, personalised, and given personalities. They were weighed, ranked, ordered, stacked, photographed and considered in their current, broken, crushed and ground forms with the volume of material available or that of accumulation over 100 years. However, students also grasped different moments which their agency covered. Those were the immediate moment of the project, the moment of their time on the master's programme, and the future moments that certain mechanisms extended unseen into. An example of this was producing provocative gifts which they sought to embed within future induction weeks to influence future students' behaviours.

# **6 DISCUSSIONS**

# 6.1 Hyper-local pedagogy

The academics' hunch was that a simple brief, located in a space that students were familiar with, using objects students could experiment with, would facilitate a deeper conversation about broader systemic difficulties. The simplicity of the brief caused nervous giggles amongst the students when first presented to them. "How is this gonna get me a job?" one queried. "How will this teach me transferable skills?". One student worried their parents wouldn't understand the value of the project if they described it to them. Aware that this would likely be the students' response, the research team underpinned the brief with key theory and explored with the group how small everyday matters can be a window into broader systemic challenges. In addition, and to emphasise the value of such work, the team invested time daily with the group to support their learning. Despite their initial concerns, all of the students took the project seriously and it resulted in valuable and legitimate learning.

# 6.2 Exploring expanded notions of design

Our students went into the project with a certain set of expectations: their practice is problem-solving, human-centred, and in collaboration with a set of stakeholders. This project aimed to explore expanded notions of these expectations. We witnessed the students initially treating the mugs as a problem to understand and solve, with the expectation that they would either eliminate issues or create new forms of value. However, the project asked the students to be creatives purposefully embedded in a setting of systems and patterns seeking means to foreground waste and inequity and to attempt to use their agency

to effect the studio now and in ways that hold a legacy once they leave. This, therefore, was an example of a pedagogy aimed at supporting students' experience of ontological design.

#### 6.3 A Transformative conversation with the materials of the situation

Our students went further than having a conversation with the materials of the situation [23], human and non-human. Through the process, students gave a voice to the non-human and the left behind [22]. They evidenced transforming some of the patterns in the studio and within their own behaviours and professional practice. By 'dealing with the mugs', students considered the sociomaterial 'things' they interact with, and recognised their active role in their design studio space - a system - which they design but are also designed by. Within the comprehendible, safe studio environment, students could feel the systems they engaged with and acted upon. The project encouraged students to enter into a transformative conversation with the systems of a place through forms of designing without the need for abstract mapping or discussion on systems theory.

#### 6.4 Design-justice oriented approach

By using a design-justice-like approach, this project gave priority and meaning to something that is neglected and uncared for - discarded mugs [17] [18]. Focussing on an issue transparent to the voices of authority in the studio, it centred on the lived experience of people with marginalised perspectives, providing insights into the needs and challenges of diverse groups of people. It empowered the student community to lead and control design outcomes and recognise that everyone's experience contributes to a richer design process. It allowed people to connect with each other and the planet - seeking non-exploitative interventions [20].

#### 6.5 Pedagogy for responsible critical design

This hyper-local place-based pedagogy for responsible and critical design challenged the design studio's status quo. By investigating this system, students questioned themselves and their community and sought to understand their individual and collective contributions towards small acts of neglect or compassion in their personal lives and in their design practices. This pedagogical approach offered a safe environment that compelled students to explore, review, challenge and critique their own assumptions, perspectives, behaviours and practices.

# 7 CONCLUSION & FURTHER RESEARCH

This study has made us question our ability to see systemic patterns emerging, particularly in our personal contexts. In what ways do our positions of privilege shield us from the clutter, inconvenience or harm that others experience, even in the same environment? As educators, we pose the following questions; how do we find the mug-mess in our lives? and how do we deal with it?

This research contributes a hyper-local place-based pedagogy that offers a safe environment for student exploration. Overall and by using socio-material objects as the foundation of an inquiry and engaging with the unseen, this project demonstrates that it is possible for students to engage with profound systemic thinking that goes beyond the obvious, identify harmful patterns and learn about systems in a limited space. Subsequently, we aim to use this pedagogical approach in a new responsible innovation master's programme we are currently developing. In this new programme, we aim to establish an approach to evaluate students' ability to identify and see systemic patterns by; (1) structuring a project sequence in a way that supports a gradual engagement with different complexities of pattern, and (2) assessing students through their ability to independently identify and use design to critically engage with systemic patterns. We hope this approach can be complemented with more traditional pedagogies such as mentoring students and teaching specific tools such as system mapping to support students in their responsible design journeys.

So, where are the mugs now, in the bin. The students took some for pen pots, others as souvenirs of the project, but they didn't 'deal' with the majority of the mug-mess before moving on to their next project challenge. The moral of the story has to be that regenerative ways of collective living and being are slow. Revealing systems takes time and effort, it requires someone to take agency, to 'find the mugs' and then 'deal with the mugs' and the patience and solidarity of others.

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# GAMIFIED PRODUCT DEVELOPMENT IN INTERNATIONAL COLLABORATIVE ENGINEERING DESIGN COURSES

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#### ABSTRACT

Design thinking, a framework for structured innovation, is crucial in engineering design. Teaching this methodology demands innovative pedagogy. This study delves into the "Collaborative Product Development in Automotive Engineering" (CoPro) course, a partnership between the University of Wuppertal, RWTH Aachen in Germany, and Hongik University in Seoul. CoPro, comprising five multidisciplinary teams from German and Korean universities, focuses on mechanical engineering and product design. In cooperation with a German OEM, it integrates cross-cultural dynamics and design thinking into authentic challenges.

This paper explores the integration of gamification into the 2022 CoPro course. One team used gamification to introduce novel product features, resulting in a transformative shift. Gamification proved instrumental in conceiving innovative solutions that outperformed other teams. The research emphasizes the transformative impact of integrating gamification in early product development phases, applicable in education and industry. CoPro 2022 showcases the synergy between these elements, offering insights for educators, students, and industry practitioners, reinforcing the value of interdisciplinary collaboration in addressing complex challenges in automotive engineering.

*Keywords: Product development, product design, gamification, automotive engineering, international collaborative course* 

# **1** INTRODUCTION

The course *Collaborative Product Development in Automotive Engineering* is an international, interdisciplinary course that takes place annually in cooperation between the University of Wuppertal and RWTH Aachen University in Germany and Hongik University in Seoul, South Korea. The course, which takes the form of lectures and teamwork phases, is largely held digitally. In May and June, however, there will be two-week reciprocal visits to Seoul and Wuppertal/Aachen respectively, which are characterized by a high work and performance density.

The aim of the course is to teach agile working methods at the interface between design and engineering, as well as to simulate a real project situation in which students have to work under time and performance pressure. An elementary challenge for the students is posed by the different forms of work between engineers (generally detail-oriented) and designers (generally concept-oriented), but also by cultural differences in working methods (Korea-Germany), the necessary bridging of time zones and language barriers and the organization of teamwork in the form of communication and project data management. The annually changing tasks of the course are provided by a partner from the automotive industry to ensure practical relevance. In 2022, two German OEMs were acquired as joint industrial partners. In most cases, the subject matter focuses on current topics from the automotive industry, e.g. sensor technology concepts, safety aspects, sustainable vehicles or mobility in metropolitan areas.

Within the course, students are divided into five teams of six students each, with each team consisting of two German and two Korean engineering students and two Korean design students. The teams work largely independently but with regular feedback from scientific staff as well as the OEM partners and base their regular design reviews on the design thinking process phases. The teams are parallel supervised by one professor in Germany and two professors in Korea. The results of the teamwork are vehicle concepts that include technical designs and CAD models on the one hand and renderings of the

design drafts on the other. In addition, physical mock-ups and prototypes for initial ergonomics and design studies are built during the on-site work phases.

The focus of the course lies particularly in the identification of a relevant problem and a creative and consistent conception of ideas.

Due to the special structure of the course and the high work intensity, the students' results are usually above average compared to other courses from experience of the supervising professors from Korea and Germany. The results are presented to the industry partners by the students in a final presentation.

# **2 PROBLEM AND SOLUTION STATEMENT**

CoPro's annually changing tasks are developed in cooperation with the industrial partners to ensure practical relevance. This year's topic was the development of fully automated mobility solutions for the transportation and delivery of parcels in the B2C (business-to-customer) sector.

Due to its practical relevance to the automotive industry and the simulation of real working conditions in interdisciplinary, international teams, the course offers excellent conditions for evaluating disruptive development methods that are potentially relevant for industrial application.

The five teams in 2022 made comparable progress to previous years and developed innovative approaches to solving the task.

Only one team struggled in comparison, as it had difficulties developing a consistent concept with recognizable added value up to this point.

The team's basic concept was automated parcel delivery via large autonomous freight vehicles that drop off smaller moving parcel boxes at relevant points, which users can then interact with. The aim was to make parcel delivery more efficient, sustainable and user-friendly.

To support this team, it was decided to conduct a guided workshop on user-centred design. In this case, the use of gamification as an innovative method should support user-centricity in concept development and to develop innovative product features.

The integration of a gamification workshop for just one team offers the opportunity to conduct a comparative study and evaluate whether gamification can be permanently integrated into the course concept as a supporting creativity method.

# **3 THEORETICAL BACKGROUND**

Gamification is described as "the use of game design elements in non-game contexts" [1] is a modern approach in motivational and interaction design and offers different tools and methods to analyse and influence human behavior. Hence, it also offers a method to analyse usage behavior and design product features fitting to the user requirements [2]. Gamification follows structured processes during development, such as the *How to design Gamification* (HTDG) process according to Morschheuser et al.

[3]. This process follows the seven consecutive phases of *preparation, analysis, ideation, design, implementation, evaluation and monitoring* and is therefore structurally close to the design thinking process.

Various methods can be used in the phases, such as *Octalysis* according to Chou, which describes motivation through the degree of fulfilment of the eight different Core Drives *Epic Meaning and Calling*, *Development and Accomplishment. Empowerment of Creativity and Feedback, Ownership and Possession, Social Influence and Relatedness, Scarcity and Impatience, Unpredictability and Curiosity and Avoidance of Loss* and thus allows a detailed characterization of the motivational states of people in a particular situation (see fig. 1) [4].

Marczewski describes a similar analysis tool with the six *User Types Hexad* (Socializer, Achiever, Free Spirit, Philanthropist, Player, Disruptor) and, with the Periodic Table of Gamification Elements, offers an associated collection of 52 game elements that provide solutions for gamification concepts (see fig. 1) [5].



Figure 1. Left: Octalysis Core Drives acc. to Chou [4], Right: Periodic Table of Gamification Elements acc. to Marczewski [5]

# **4 RELATED RESEARCH ON GAMIFICATION IN INNOVATION**

The literature review Gamification-as-innovation of AlSaad and Durugbo explores the role of gamification as an innovation tool in organizational processes [6]. Gamification aims to promote collaborative behavior, process enhancement, innovativeness, and contests with rewards. However, integrating gamification into organizational processes can be challenging, especially when core capabilities are not known in the early phases. The review identifies three perspectives on gamification as innovation: intervention, induction, and investigation. Additionally, three themes are highlighted: multi-level modeling and learning, strategic initiatives and transformation, and digital platforms and processes. The text suggests that future research should explore innovative network models to enhance creativity and problem-solving. It emphasizes the need for a comprehensive examination of the experiential and inclusive nature of gamification. In conclusion, the review provides theoretical frameworks for innovation and technology management studies on gamification. It also offers practical considerations for businesses to incorporate gamification into strategic planning, promoting "adult recess" and "adult-style playtime" for engagement, involvement, and inclusivity. Overall, the review aims to advance discourse and scholarship on novel gamification constructs, conundrums, and conditions.

Based on the current state of scientific knowledge, it can be concluded that gamification in connection with innovation is only used at a human level to increase motivation or commitment in the existing innovation process or to adapt the innovation process. The application at product level, i.e. to improve products through an increased understanding of customer behavior and the subsequent application of game elements, does not appear to be part of the scientific discourse.

# **5 RESULTS**

As the elements of the HTDG process had to fit into a workshop, some phases were simplified. Phase 1 (preparation) had already been completed, as the framework conditions were defined by the clear task and the product is a mobility concept that interacts directly with people. The use of gamification is therefore considered to be fundamentally applicable and sensible.

The analysis in phase 2 of the interacting people for motivation profiling normally takes place in extensive qualitative and quantitative research using questionnaires or interviews. A less extensive method was chosen for the transfer to the workshop framework. At the beginning of the workshop, a fictitious persona of the potential target group was created for the group's vehicle concept. Based on this persona, the three most important core drives according to Chou were selected, which potentially represent the target group the most. The following were selected:

- 1. Epic Meaning and Calling (due to the importance of sustainability for society as a whole) and
- 2. Empowerment of Creativity and Feedback (by independently designing the interaction with the vehicle).

For phase 3 (ideation), the team selected the four most promising game elements for each core drive. The criteria for the selection were the meaningfulness in the thematic context of the overall concept and the intuitive possibility of integration. Both the elements collected by Chou and Marczewski's *Periodic Table of Gamification Elements* were used as the basis for the selection. After careful consideration, discussion and a simple dot rating, the following game elements were selected:

- Epic Meaning: Narrative, Free Lunch, Elitism
- Empowerment: Milestones

Figure 2 shows a scene from the ideation discussion during the workshop.



Figure 2. Scene of the workshop

The four selected game elements were then developed further as part of phase 4 (design). The Rotating Brainwriting method was used to encourage creative ideas. During the workshop, the conception was limited to the brief formulation of ideas and small drawings. The results can be described as follows:

- Elitism: Sense of belonging to a group through badges that are awarded according to time. Nature conservation as a possible additional topic.
- Free Lunch: After a certain number of uses, users receive free use. Partial distribution before the launch encourages interest in the product.
- Milestones: Achieved sustainability goals are visualized in the form of a growing tree in the app
- Narrative: Story of the Baby (parcel vehicle) and Motherships (freight wagon)

The so-called *NUF test* was carried out as a method for selecting the concept to be implemented in phase 5 (implementation). The ideas developed are rated by the entire team on a scale of 0 to 10 according to the categories New, Useful and Feasible. The results are shown below:

	New?	Useful?	Feasible?	<b>Total Points</b>
Elitism	5	8	8	21
Free Lunch	1	9	9	19
Milestones	6	3	10	19
Narrative	7	3	10	20

Table 1. NUF-Test results

After the workshop, the idea of a badge concept for the use of the parcel delivery service based on the gamification element Elitism was the most promising concept. However, the group was also encouraged to use the other ideas as a basis for feature development during the course.

In fact, following the workshop, the team decided to include the narrative around the mother-baby relationship of big freight vehicles which drop off small delivery vehicles for user interaction as a product feature in their concept because they gave the *New* category a higher weighting with a similar overall rating. This shows that the use of a structured gamification design process makes the complexity of the original task manageable and supports the making of conscious decisions at critical points. The team's final presentation to the lecturers of the course and the industrial partner companies specifically

addressed the mothership-baby narrative and was consistently perceived as an inherent product feature of the concept. Some slides from the presentation are shown in figure 3 as examples:



Figure 3. Implementation of the narrative in the team's final presentation

In order to evaluate the influence of the workshop and the resulting product feature (phase 6 – evaluation), a survey was conducted with the OEM partners and the supervising scientific staff from both universities following the final presentation (n=5).

The questionnaire focused in particular on the quality and development of the team results (also in relation to the other teams) and the evaluation of the mothership-baby narrative as a product feature. The questions had to be answered on a 5-point Likert scale (strongly agree (score 4) to strongly disagree (score 0), with an additional no answer option). The questions and the evaluated results are shown in Table 2:

Table 2. Results of the evaluation questionnaire (n=5, fully agree=4, agree=3, neither agr	·ee
nor disagree=2, disagree=1, strongly disagree=0)	

		) 1	12	2 3	3 4
#					
1	Team X's final concept was good.			F	•
2	Team X's final concept was above average compared to the final concepts of the other teams.		]	•	+
3	Since the last Design Review, Team X has developed its concept much further than the other teams.		]		
4	I recognized the "mothership baby" narrative in Team X's final design review.				
5	The "mothership baby" narrative fits well with the final concept of Team X.				H
6	I've noticed a stronger focus on the "mothership baby" narrative in Team X since the last Design Review.				•
7	Team X's "mothership baby" narrative would be of great benefit to the success of the concept in reality.			H	н

# **6 DISCUSSION**

The results confirm that the workshop had a very positive influence on the team's final concept. Overall, it was rated as very good (question 1) and above average compared to the results of the other teams (question 2). The general further development of the team concept was assessed as comparable to the other teams (question 3).

The Mothership Baby narrative was explicitly perceived as a very good product feature and very present in comparison to earlier intermediate states of the team concept (questions 4 to 6). A possible influence on product success in the fictitious case of a real implementation of the concept was also rated very positively (question 7).

Given that the team had problems with clearly defining a consistent concept before the workshop, the workshop and the application of the systematic gamification design process had a clearly positive influence on the team result.

Hence, the implications for the next years of the CoPro course are to extend the workshop to all teams in order to support the overall creativity and quality of the course results.

Even if the results are very positive, some limitations of the study must be pointed out. For example, no comparative survey was conducted before the workshop was applied in order to measure direct differences. With five responses, the significance of the results can only be interpreted as a rough estimate but is limited by the number of OEM partners and the supervising scientific staff. Due to the limited time in the workshop format, the phases of the HTDG process could not be dealt with in detail, so a survey with potential users would be more significant than the subjective assessment of the team.

# 7 CONCLUSION

This study describes the application of gamification to support the user-centred design of innovative product features in the context of an international, team-based university course in workshop form.

Prior to the workshop, the selected team was struggling to keep up with the performance of the other teams.

The workshop enabled the team to identify user preferences of their concept in a structured way and then design suitable product features in the form of a detailed product narrative. The survey of the OEM partners and the supervising scientific staff after the presentation of the results showed a major increase in performance and quality compared to the other teams.

Gamification thus offers a new approach to increasing the creativity of students in product design courses on the one hand and a disruptive approach to analysing user behaviour and designing innovative product features in industrial practice on the other.

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# **EXPLORING MATERIAL RELATIONS IN THE AI ERA**

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#### ABSTRACT

Recent evolutions in the accessibility and uptake of generative AI tools have already affected the way design and engineering are taught at university level. The exploration of AI related tools and technologies is increasingly part of formal design study and informal and peer learning. It is however important to place recent evolutions in a longer temporal context. Design activity and education have seen a progressive move away from "thing-based" methods and towards capability, service, experience, and systemic approaches; considering the wider context and impact of design interventions.

These evolutions in design and design education create a learning environment where the abstract, virtual and experiential are, in some cases, more present than the material and tangible. This paper proposes a discussion on the importance of addressing materiality and tangible everyday material experience in this evolving context. This paper presents two different "families" of teaching modules that have evolved over a period of five years with a focus on materiality, material relations and touch. While these two modules represent different ways of exploring materials and material relations, they together permit reflection around forms of tangible/material learning activities that may be relevant in future design curricula, and the criteria and qualities these forms of teaching may need to incorporate.

Keywords: Materiality, responsible design, transition, material relations, behaviour change

# **1** INTRODUCTION

Recent evolutions in the accessibility and uptake of generative AI tools have already affected the way design and engineering are taught at university level. This evolution can also be seen in a longer temporal context, with design activity and education progressively moving away from "thing-based" approaches and towards capability, service, experience and systemic approaches; considering the wider context and impact of design interventions. In this context exploring materiality and more specifically material relations as part of the future design curriculum might seem irrelevant, but these themes may be essential for environmentally meaningful education.

In the context of increasingly crowded design curricula, analysing the qualities and impacts of short, tested modules addressing materiality can be a useful entry point. The modules presented in this paper have been tested in a variety of design education contexts over a period of five years and have been progressively refined through a process of evolution and feedback [1].

Based on insights from these modules, our aim is to create a discussion around forms of material-oriented design education that may be important in a period of fundamental change.

# **2** EVOLUTIONS IN THE DESIGN CURRICULUM

At the start of the 21st century, Alain Findeli [2] wrote an important paper on how design education might operate a paradigm shift away from being "a branch of product development, marketing communication and technological fetishism". Twelve years on, Jennifer Loy was already discussing how design students were finding the responsibility for the world's environmental and social problems laid at their door [3]. Loy describes an extreme pace of change in product design education. Design programs may be becoming more abstract and theoretical in order to integrate necessary content around strategy, systems approaches and political issues. More recently the work of Ceschin & Gaziulusoy [4] highlights how design today must be increasingly systems-oriented for addressing environmental issues. In a special issue on Rethinking Design Education, Dubberley and Davis warn against resistance to the new

paradigm needed in design education. Designers must think in terms of systems, and no longer artifacts, information systems are the new material [5]

But while there is little doubt for the need for design education to continue to evolve in the directions highlighted above in order to address todays' complex problems, systems level thinking may stop us from thinking about alternative eco-compatible behaviour. This potentially may distance us from our experience and perceived ability to act [6]. Designers need to become key advocates for environmental and social responsibility [7] with a grasp of sustainability fundamentals (circular economy; whole systems thinking; sustainable innovation strategies; impact assessment, laws and standards; communication, collaboration, and leadership...) But how to avoid a sense of disconnection? [8] Regeneration principles [9] involve notions of local, situated context and involvement/implication. Equally circular approaches necessitate tangible materials knowledge [1]. It is important that changes to the design curriculum do not turn "material considerations [into] the materiality of culture rather than the design implications of specification and the design opportunities provided by a material innovation." [3]

# **3 MATERIALITY IN DESIGN EDUCATION**

Material knowledge is relevant for designing for circularity [1] and despite the danger of being labelled as the "old" curriculum [5], design education cannot simply reject materiality. Ignoring or avoiding material and stuff [10][11] is not a solution. Encouraging awareness of our material relations in the design curriculum can help to address not just knowledge deficit in environmental education, but also the behaviour deficit [9]. Approaches encouraging hands-on engagement with (and exploration of) materials may have the potential to decrease eco-complacency and avoid psychological distance and separation [9]. While the two short modules described below are relatively simple, they both match some of the requirements needed both for addressing materiality in design education and for more tangible forms of design for the environment.

# 3.1 Method

Revised versions of both modules involve reflective reports by students as part of the course deliverables (see below for details). In the case of the "mapping everything we touch exercise" the eleven reflective reports by the fifth-year master's students were analysed for the key learning points identified by the students themselves in personal reports submitted a week after the end of the workshop. For the second module, the "Netsuke workshop," the reflective reports submitted 5 days after the end of the workshop scoring 17/20 or more were analysed. Only the reports from the last two versions of the module were analysed for the purposes of this article, as the version of the year before included some activities which have been subsequently removed. An initial analysis of these reports provides the basis for the points that are discussed in relation to the two modules. These findings are complemented by analysis of emergent themes identified by teaching staff on these projects.

year	study level	student no.	context	duration (mapping)	next steps (using the everything maps as a start point)		
2021	year 4	23	2 week "speed project" on mate- rial relations	2 days	focus on one issue (re- mapped)	themes used as trig- ger for quick idea- tion	3 concept "trans- formations" of everyday things
2023	year 5	11	1-week intensive workshop on sys- tems/giga map- ping	2 hours	pin-up & group dis- cussion	choice of everyday material aberrations	Exploring systems mapping and re- lated tools
2024	year 2	27	8-week project on the theme of sharing	4 hours	pin-up, iden- tify (non) eco-compati- ble behav- iour.	mapping and dis- cussing sharing is- sues	Project on new forms of sharing for meaningful en- vironmental im- pact

Table 1. Overview of the three versions of the "Mapping everything" exercise

# 3.2 Mapping everything we touch

The book and research project by artist and ethnographer Paula Zucotti [12] has been an inspiration for a number of research projects and teaching modules [13]. Zucotti's protocol is a very effective way of exploring everyday material relations. Participants are asked to list everything they touch over a whole

day, and then this list is used as a basis for a visual mapping and discussion. It is a protocol that is sufficiently different and unexpected to make students want to carry out the activity, despite its' fastidious nature. The entry point for Zucotti is touch, which is valuable in the context of everyday material relations where a certain level of invisibility [14] may occur, particularly in longer object relations. Zucotti's protocol, adapted here, questions things-as-mediation and also encourages a form of active and engaged everyday auto-ethnography. Not so much a module as a module component, this protocol has proved a valuable entry point for different materials/behaviour related activities. Three different instances of this module component are discussed, and Table 1 gives an overview of these.



Figure 1. Everything mapping examples (Y4 students; I.DaSilva & L.Raimbault)

The common points in the three examples are using the protocol as an intensive activity at the start of a project or workshop, asking students to make a "map" of everything touched, and then asking them to consider different ways the represented objects could be grouped/reorganised. These groupings are then illustrated on the first map or in a new iteration of their map.

Figure 1 shows two examples of this second reorganised map by 4th year students in a slightly longer version of the exercise. Figure 2 shows a much quicker version of a reorganised map by a second-year student from the 2024 cohort. This first sorting exercise generates rich information around tangible /in-tangible qualities in material relations, encouraging thinking about the potential and complexity of everyday material objects, our relations with them, and the qualities that could be designed into them.



Figure 2. Everything mapping examples (Y2 student; A. Batoumeni)

The exercise also gives students an unexpected view on their own everyday behaviour. Students from 2024 commented "the amount of times I touch my phone throughout the day is embarrassing", "how different my routine seems when I write it down", "it's concerning how little water I drink". While not all instances of using this module component have included written/text-based reports, a recent project involving 5th year masters' students in Design for Social Innovation did include reflective reports. These reports have been analysed here to highlight the benefits of this exercise identified by students themselves. Seven main points emerge from these reports (student comments in italics):
- **Revealing and reflexive**, showing multiple levels in everyday object relations "*a kind of everyday hunt/investigation to understand the various relationships and systemic correlations of subjects that reveal social, economic, environmental, cultural, temporal and other contexts*..."
- **Concrete, tangible**, "a concrete reflection on objects and our relationship with materials." "for the first layer of the systemic map (it was nice to have a real context to rely on) ..."
- Unsustainable behaviour, "we have...the responsibility to observe how the world works", "becoming aware of my relationship with objects helps me concretely to get out of many environmentally unsustainable mechanisms", "raises the problem of overconsumption" (But interestingly one student commented that [his] private context is not a "real" context for environmental questions.)
- **Surprise, unexpected**, [the] "exercise surprised me because I had never realized how much I could relate to objects. Especially when I counted them, seventy-two seemed to me to be a huge figure.," "that made me ask to myself some questions that we often take for granted."
- Sensitive, sensorial, engages our bodies, "it allowed us to really engage the body and summon each of us into the reflexive process," "we could express the sensitive and sensorial way of connections."
- (Seeing/sharing) diversity of everyday experiences, "The perception is something very important in design because people do not have the same lives and experiences."
- **Detail,** "noting every detail, no matter how minute, proved to be an interesting way of adding depth to the analysis and increasing the degree of representativeness."

Students also commented on how this exercise was a useful warm-up and first step towards systems thinking and mapping.

#### 3.3 "Netsuke" workshop

A hands-on materials-oriented workshop module has been running in current form for the last six years for design students' half-way through their first year of studies. The aim of this module is both discov-

ering material properties through doing/interaction and encouraging students to discover other ways to stimulate and express their creativity. The content of these short workshops (three consecutive days of six hours) has been progressively refined. While previous workshops involved making simple wooden cutlery, or jewellery items, the last three years have taken "Netsuke" as their focus (exclusively and with more rewarding results for students in the last two years). The choice of the netsuke was in part inspired by the work of Edmund DeWaal [15], exploring the importance of things, even in objects of tiny scale, of detail and of the importance of tactile qualities.

year	student no.	day one	day two	day three	completing activity	reports analysed
22	17	creativity exercises using soft wax: pasta then netsuke brief	soft (modelling) wax > hard (carving) wax of netsuke concepts	carving hard wax > carving final wood version	3 (2 in wood)	
23	21	10 quick concepts in soft wax, 2/3 refined concepts in denser modelling wax	hard (carving) wax refined scale model of one netsuke	refined scale model of one netsuke in choice of timber (pear-wood, syca- more, lime, spruce)	18 in wood	6
24	22	10 quick concepts in soft wax, 1/2 refined concepts in denser modelling wax	hard (carving) wax refined scale model of one netsuke	refined scale model of one netsuke in lime wood	22 in wood	7

Table 2. Overview of "Netsuke" workshops

(Netsuke are highly decorative and highly personal objects, roughly the size of a walnut and pierced to include a cord, that were traditionally used to fix personal items to the belt of the Kimono.) The size of the objects means that materials more commonly used for jewellery prototypes such as soft modelling wax and hard carving wax could be introduced to students, adding the discovery of different materials to the experience. In order to enable students to have a "real" object at the end of the short workshop, the final version of their netsuke is carved in wood. The last three versions of this workshop, with first year students in product and UX design, have all included reflective reports as part of the module

deliverables. The points discussed below are based on individual student reports from the last two years (see Table 2 for details), where a warm-up exercise (of modelling ideas for pasta) was dropped. This enabled the majority of the class to finish the assignment and produce a result that was satisfying for them. A small selection of work (of eight students from all three years) is shown in Figure 3.

The student feedback on this workshop has been very positive, with comments confirming appreciation of doing a hands-on activity, and the value of discovering materials through interaction with them for material understanding.



These points echo observations by a number of researchers in the previous E&PDE conference, such as Soares et al. [9] and Ordonez et al. [1].

#### Figure 3. Netsuke in different materials (& different stages of the workshop)

Eight main insights emerging from the analysis of student reports are:

- Learning, students commented having the impression of learning a lot during the three days, and many different forms of learning are commented on; learning to work more precisely, working in steps, iterating, reflecting on the process, making mistakes and re-adapting, using constraints as opportunities, discovering a new way of working...
- **Time**, students realised that they needed to spend more time than they had anticipated, that they needed patience, and not to work with precipitation.
- **Rewarding**, students expressed pleasure on the workshop process and pride in their results (though a very small number of students did also comment that their final versions did not meet their expectations). In several cases the pride in the results was also linked to creating an object that they felt represented them. *"This netsuke really matches me; it regroups all the things I like."*
- **Discovering materials**, students commented needing to adapt themselves to the constraints of each new material and compare the different materials and discovered how the final (natural) material was both more unpredictable, but also enabled them to get to a satisfying level of finish.
- First time and learning new gestures. Many students commented never having done this type of activity in the past, or never having sculpted materials as hard as the carving wax or wood. But comments also showed that the materials represented progressive difficulty, with students commenting that they realised they had already gained some skill in gestures that made working on subsequent versions quicker and easier.
- **Detail**, the scale of these objects meant that students had to think about detail, and also how each different material generates different constraints for detail.
- **Positive group dynamic**, there was a lot of helping between the students, and students discovered very different levels of skill and dexterity among their colleagues, "we could be helped by others in the class who had more experience."
- **Hands, touch,** the largest number of comments concern touch, using their hands, and this activity was clearly unfamiliar for many of the students. Students realised that they needed to work on objects that were the right size to be held in the hand, and that were nice to hold with interesting textures. Comments also mention the first time "touching" certain materials, and being aware of how the heat of their hands initially changed the consistency of the wax too quickly.

#### **4 DISCUSSION & CONCLUSION**

While the two modules described here are of a very different nature from each other, there are a number of common points that can be identified. These aspects may constitute relevant aspects to be integrated into materials-oriented design teaching. These common points are: 1) unfamiliar activities/ material (students may today be unfamiliar with contact with materials in general), 2) hands on/learning by doing, 3) focus on touch, 4) looking at material qualities but also immaterial and symbolic qualities, 5) proximity 6) intensive/immersive activity, 7) engaged, implicating the body, human scale, 8) care, attention and detail, and finally 9) encouraging a reflective process (through mapping, sorting and making a project logbook).

While clearly design education needs to evolve rapidly in the face of the emergence of AI and of complex problems demanding more systemic approaches, it must also equip designers to address the current environmental crisis without generating disconnection. Materiality is an important aspect of environmental concerns; we can't ignore materials, their relation to our behaviour and to our bodies and our physical experience.

While the two modules here are not considered by the authors to be definitive, their common qualities may provide some workable guidelines for relevant forms of materials-based teaching. These may in turn be valuable as a way of balancing the design curriculum to avoid psychological distance and behaviour deficit in future designers.

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# A DESIGN AND AI COURSE: IN CONVERSATION WITH MACHINES

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#### ABSTRACT

This research is based on a course developed as a model automating the design process using Artificial Intelligence (AI) exploring its use of AI in the design process, its shortcomings, and its strength as a design tool. Much of the work generated in class by students were visual communication prototypes but lessons learned can be applied to other disciplines within design. Additionally, goals for the course were to produce a work pipeline for the design process which greatly shortens the concept development stage which allows for longer periods of evaluation of the content. Students were more critical of the results due to their assumed role as creative directors rather than production designers. This is a shift in roles for designers requiring more critical thinking that is clearly articulated in the AI prompt. Students edited prompts to build on the output, seeding the generator with their results. The rapport between student and generator was immediate, shifting toward clear communication in writing prompts and a much greater focus on ideas that were unexpected, and unique as well as those in line with the student's initial vision. A model for mapping the process based on the double diamond model, from the British Design Council was reimagined to include innovative processes and user testing to form three stages of divergence and convergence. Thoughtful discussions concerning the design process were particularly insightful challenging students who were familiar with current practices and those who were not but could leverage AI to write a design brief, craft innovative prompts, and critique potential solutions.

Keywords: Artificial Intelligence, design, education, curriculum

#### **1 INTRODUCTION TO THE DESIGN PROCESS WITH AI**

The course was developed as artificial intelligence and more specifically machine learning (ML) was posed to disrupt the process of design and reshape how designers would work with the technology. In its current form the resulting content is often viewed with scepticism for its ability to produce the exact image in the designer's eye. Some controls have been added to make edits in the three most used software in the class (Midjourney, ChatGPT (formerly Dall-E), and Bing) however, targeted edits that retain the rest of the image are not within the scope of these machine learning tools and if we understand probability theory it is likely they never will be. During the class students used the versioning tools and utilized the concept of recursive prompt engineering. The process has led to redefining our role as designers, which leaves production to machines, freeing up time for conceptual development and research before production and evaluation of a design's effectiveness through to postproduction.

The proposed process combines the innovation stages of the Doblin Group design process for innovation popularized by the Institute of Design in Chicago and the British Academy of Design's double diamond approach. Although, the Doblin process does emphasize research, seeking insights and evaluation of design it could not have foreseen the impact of AI on the process and in particular the variations of possible outcomes that generators provide. The proposed process for this class rebalances the thought process onto preliminary stages as well as testing stages. Within communication design, delivering an effective message requires a well-defined set of criteria and rigorous evaluation. These criteria are developed in these stages with a clear understanding of audience, context, and communicating a message. The first diamond frames our thoughts and lays the groundwork for evaluating and implementing the criteria.



Figure 1. Triple Diamond Design Process – adding a third Analysis and Evaluation diamond. All three diamonds indicate time through pre, post and production stage

The proposed process combines the innovation stages of the Doblin Group design process for innovation popularized by the Institute of Design in Chicago [1] and the British Academy of Design's double diamond approach [6]. Although, the Doblin process does emphasize research, seeking insights and evaluation of design it could not have foreseen the impact of AI on the process and in particular the variations of possible outcomes that generators provide. Within communication design, creating promotional material for goods and services through images, graphics, and typography that all contribute to delivering the same message requires a well-defined set of criteria. These criteria are based on a clear understanding of audience, context and the message that communicate most effectively. The first diamond frames our thoughts and lays the groundwork for evaluating and implementing the criteria.

#### 2 DEVELOPING A DESIGN BRIEF

In previous iterations of the class students used ChatGPT to generate a design brief with a simple prompt to include the subject and a few attributes of the product or service. ChatGPT understood the general framework of a design brief typically including these topics, executive summary, target audience description, project goals, budget, and deliverables as well as a visual language description. An evaluation section, and competitive analysis was often included in a single paragraph. These seven paragraphs were required, and each part of the framework was evaluated for specificity and correctness where possible and changes or inclusions to the brief were handed in. Demographic details were also verified for accuracy with references that could validate the generated text and fit the student's concepts. Prompt ideas were pulled from the brief so that a conceptual line could be draw from what was determined appropriate and accountable for future decisions. Establishing the process and the relationships between idea and evaluation of a decision making clarified the value of both the design brief and the prompts that led to the conceptual and creative generating.

#### **3 DRAWING A LINE FROM BRIEF TO PROMPT WRITING**

Prompt writing is an important part of the pipeline crafting subtle descriptions of a desirable output in which the text or image is described. The prompts used in class were self-generated meaning they were produced by the students rather than a text generator. Prompts for image generation are broken down into three parts; a general description of the content to explore, desired aesthetic qualities, and functional constraints for the output.

#### 3.1 Descriptive prompts: prose, narrative, descriptive, detail

Students were encouraged to use adjectives to describe the project in the descriptive portion of the prompt. Other terms that describe themes, organization of the image as well as object details and environments improve results. How language is used can change the output of the AI and students were often referring to online dictionaries or thesaurus to find different terms in class discussions. Generally, this type of writing is direct but phrasing is also important in achieving not only the specific elements in an image but also stylistic characteristics to help convey the message.

#### 3.2 Aesthetic prompts: style, artist, genre, effects, chaos, stylization

Much of the manipulation of imagery is based around stylistic qualities of the image which immediately indicate the boundaries of AI software. Because models are trained on images that exists online, its abilities are based on past qualities often described by students as 'limiting'. In part, this limit is due to their own exposure to style types and students were encouraged to use resource material such as Garner's Art Through the Ages [2], Doyle's, The History of Illustration, [3] The People's Graphic Design Archive [4], as well as AIGA annuals, gallery collections, and other diverse publications of imagery and design to remind and expand their repertoire. At the beginning of the course students produced hundreds of versions and variations of images they wanted to use but often would ignore the design brief requirements typically of the audience. A common defence of their work was, "I was just exploring ideas" which is what the first stage of the pipeline is intended however, it should be done communicating with the audience in mind. The converging stage of the second diamond is the most difficult for students because refining details into prompts comes down to a well-tuned design vocabulary.

#### **4** IMAGE GENERATION, ITERATION AND REFINEMENT

Open AI's image generator built into ChatGPT provides an editor to produce variations of images as descendants of the first set of results. Using treatments at the end of the prompt such as effects, degrees of variation, and stylization can adjust the description of characteristics with additional parameters, like a sub-style. Adding an effect to an object for example, "a VW bus made out of mashed potatoes" (see fig 2) follows [object or scene] made from [material]. The prompt articulates the image like a Photoshop filter but with a much wider range of materials and visual effects. Still other style descriptors will produce not only image effects but also camera angle, scale and point of view.

Software such as Midjourney use a codified approach to tailor prompt writing. The term "chaos" and value pair are applied in combination with other aesthetic prompts to vary the image in interpretation within the prompt response. The values for Midjourney for example, range from 0-100 units of variation and provide fewer or broader conceptual results. Students were encouraged to use values over 75 to provide a greater set of interpretations in the conceptual thinking stage of the process. Once a direction was determined the image was used with the prompt in the refinement stage of the triple diamond. For example, "a VW bus made out of mashed potatoes in the style of Picasso - - chaos 10 - - stylize 20" will produce 10 units of variety with 20-units of influence of Picasso on the final output (fig. 2).



Figure 2 Using the prompt "a VW bus made out of mashed potatoes in the style of Picasso..." with different sub-styles in MidJourney.

Left: - - chaos 100 - - stylize 5" broad variation, photographic

*Right: - - chaos 10 - - stylize 20" fewer variations, illustrative Arial 10pt, italic, centred, space before 6 pt, after 6 pt. Left and right indent 8 mm* 

# 4.1 Functional prompts: aspect ratio, resolution, image pass, weighted images and keywords, image filtering, camera/lens

Writing functional prompts relies on design knowledge to shorten the production time evident over the course of the class. Students took less time to develop prompts later in the semester and identified writing functional details in the prompt to speed their progress. Although not professional designers, the students had nearly completed their degrees and came equipped with some background using the functional constraints. These are considered functional prompts because of their direct impact on the output with less ambiguity in the values that are associated with the type of treatment. A chart of acceptable treatment and value pairs were provided to students for their reference. Many of the image generators have developed scripts with values to shorten the prompt text. For example, MidJourney uses --aspect or --ar for aspect ratio followed by the width and height values (--aspect or --ar 3:2). Only 7 ratios are available in version 5 which include 2:3, 3:2, 4:7, 7:4, 4:5, 5:4, and 1:1 which is the default. Any values can be added but the image will be set to the next closest ratio. Learning these values and their script was straight forward for students but the concept of weighting was new to most of them. Most generators will use inputs such as texts or images to seed the model and be 'inspired' by this input. Using a URL pathname to an image can be part of the prompt often with the '/image' script or in the case of Dall-E 2, it will prompt the user to input the URL. Using the - - iw (image weight) and range between 0-2 will add weight of influence on the final output based on the image input. Students reported little effect of the weight although changes did occur with a more nuanced affect.

#### 4.2 Generating and evaluating content from the prompts

Students were introduced to the differences between contexts for text and scripted treatments which read differently than body copy for the same communication. For example, using the same type of prompt for the text to accompany the image on a poster may be as follows, "write a short paragraph describing a food sculpture competition using potatoes in the style of 1960's advertisement". The inclusion of the year 1960 as a specific style should have some connection to the audience but should also be included in the image generator prompt. Designing a communication ensures that the message is consistent across text, image, graphics and fonts as well as the way the page is composed. The resulting images are not cubist as one might expect from the Picasso style included in the prompt. Because the stylization value is low the images are less varied and therefore the selected style started on a literal path of 'cubed' and did not vary from that initial starting point. Typically, students and many professionals make these decisions intuitively or with little consideration other than it 'looks good' to them. Sometimes interesting contradictions occur creating novel results which does have value in drawing attention of the viewer. If this can be done in a more consciences manner it puts greater emphasis on the thought process because it must be articulated to the generator. It also removes some of the uncertainty that comes with design work holding designers more accountable evidenced in their prompts. We may see designers submit their prompts as part of the presentation given to clients or meetings within the design firm. Discussions in the class shifted from design quality to prompt terms and descriptions within the prompt. Most notably students would use references to genres and font families that had specific characteristics found in the prompts.

#### 5 TESTING THE RESULTS, EVALUATING THE PIPELINE

During the last stage of the processes completed the triple diamond testing and evaluating the proposed designs with potential audience members. At this stage, students were asked to start from the beginning of the process with a new client and proposed communication with multiple touch points promoting the same product or service. This could be done using product tie-ins, or new communication materials in different contexts such as a movie poster, a 3D cut out for the same movie and its collector cup. Students reported that shifting from one generator to another was an inconvenience and proposed one software to locate all their work rather than fitting together the different parts of prepared material (design brief, prompts for each generator and assets for the project). Composition layouts were done using software enhanced with AI tools but required the students to actively contribute to the final designs. Each student found participants to provide feedback from simple split tests of three different versions of all touch points within the project. The participants were asked to compare individual products as well as the collection of tie-in items. An evaluation of the final design's effectiveness was not possible due to the limitations of the course and replicating incentives which better reflect user motivations. However, the

analysis of participants responses does provide some insight into their likelihood of purchasing or behaving because of the communication material.

The following questions and answers are from a survey given to all students of which 13 responded. They offer insight into how students who have completed the course now see the role of AI in the process, their work, and the industry. Comments similar in terminology and phrasing were grouped as well as sentiment analysis using text2data [7] for relevant question and compared to our assessment. The scale for the sentiment is ranked between -1 negative and 1 positive with neutral ranging from -0.25 to +0.25.

# Question 1 - Describe the process you followed, how is it different from what you have done or knew before class?

The class is typical for a design course however, many of the students in the class are not design students in the contemporary sense. The focus of their program is directed toward print production and less on design concerns such as user-centred approaches and process driven strategies. All the answers were identified as positive using the text2data tool despite many of the students not having experienced a design course of this kind. "The process I followed for this class was a way more in-depth version of the design process I've used for other projects in the past." (student 3)

#### Question 2 - What do you know about AI generators now that you did not know before?

Although the sentiment analysis appears to be generally negative (7 negative, 2 neutral, and 4 positive responses) the majority was a criticism students had of their own abilities to work with AI or their current understanding of how to design. "Something I pride myself in is being able to visualize something and then turn it into a physical design. All that pride was demolished in this class because rather than designing an image exactly how I wanted by combining various design elements I had stored in my head, I had to write each individual thought out as a prompt and hope AI saw my vision." (student 7) The emphasis shifts to articulating what the student wants encouraging a thought process they previously did not exercise. "Unlike my usual method of visualizing and translating ideas directly into designs, I had to articulate each concept as a prompt for the AI, leading to extensive refinement through prompt adjustments. While this process was time-consuming, it provided valuable insights into phrasing and AI manipulation." (student 13)

# Question 3 - What was the most difficult part of the process or AI or solution you created for the projects?

Overwhelmingly, the issues students struggled with the most was writing prompts to get AI tools to produce what they wanted. Eight of 13 indicated writing or communicating to be the difficulty but made them think about describing their ideas in detail. The benefit using AI tools similar to a creative director not only encourages a clear vision but also managing the project throughout the process. The remaining 5 responses discussed issues with details or correcting small portions of an image. One student struggled with the design brief that was detailed enough for them to develop their prompts.

#### Question 4 - How do you see AI influencing or changing design in the future?

Of the students in the class there are three perspectives that formed around the idea of AI's influence on design: diminished, mixed, and enthusiastic. Five students attempted to diminish the impact that AI would have and only saw modest advantages, "I don't think AI will be able to change design overall since it's reliant on existing concepts." (student 3) Equally, five students hedged to admit AI's advantages but suggested humans in the process would still be needed. This limited their view on the impact AI would have on the industry and their future career. Only three students were enthusiastic about AI and its ability to more than a human designer could do alone. They all stated it would take over the role of designer in the future. "I see it drastically changing design in the future, hopefully creatives will be able to embrace AI." (student 10) Using the sentiment analysis tool, text2data [7] only 2 neutral, and 3 negative responses were found in question 4 with the remaining 8 identified as positive.

# Question 5 - How would you change the process, pipeline or course to take advantage of AI more fully?

Most students focused on the course and the changes they would make however, a clear pair of concepts regarding speed of results, and frustration concerning their own ability to 'talk' to the AI generators arose. "a potential "workshop/playground" type of project at the beginning of the year could help new users of AI (such as me) understand what kind of images will be resulted from the key words that they are using," (student 5) This translated into the projects being run too quickly but the pipeline was of value in understanding the designs they were creating more fully. "I would change the course by possibly including a small project utilizing the entirety of the design process at the beginning of the class. Then, throughout the course, learn and implement each of the steps of the design process more fully. Finally,

as is being done currently, incorporate the entirety of the design process AGAIN, but with a better understanding of each of the steps." (student 2).

One of the most challenging parts of teaching design is for students to be truly critical of their own work. AI boosts the willingness to do this because it puts the work outside of their personal space even though they are directly guiding the project. The process was perceived as a collaboration according to students, outsourcing some of the responsibility. More than half the class indicated they, "can be more critical because [their] collaborator has no feelings". All but 1 student reported a shift in thinking about the design process placing more emphasis on the user rather than the aesthetic qualities of the project in part because they perceived the output to be 'good or better quality' than they could produce. All the students reported the AI tools to be 'extremely fast' much faster than they can work. The overall efficiency of the process was reported to be 'slow' or 'average' in terms of getting the projects done. This may be due to the fact it is an unfamiliar process but with time could be shortened. All the students reported the process to be more thorough an investigation of the problem however, over half the students felt less satisfaction with the result indicating they disliked AI 'creating' the design with one student reporting a feeling of 'cheating' using the AI tools.

#### **6** CONCLUSIONS

The integration of AI into the design process can enhance efficiency, clarify creative objectives and critical evaluation. Initially students faced challenges writing prompts, and they felt a loss of creativity autonomy, but by the end of the course they developed a more precise and critical approach to design. The incremental process of developing design with AI assistance enabled deeper understanding, and rigorous critique among students, highlighting AI's potential to transform design education. The evaluation of the design effectiveness was also new to students and revealing to their understanding of what design communication could and could not do. A more direct line connecting their thoughts to the interpretation of the audience was clearly drawn tying designers to the audience. By developing best practices for AI-human collaboration, we can further enhance both the educational experience and professional application of these fast-approaching technologies.

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### EXPLORING CHATGPT'S IMPACT ON STUDENT-TEAM IDEATION OUTCOMES FOR NEW PRODUCT DEVELOPMENT: A PILOT STUDY

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#### ABSTRACT

Ideation techniques such as associative-thinking methods are commonly used to explore design proposals. However, limited experiences and knowledge in young designers can constrain diverse and meaningful design solutions. Emerging artificial-intelligence technologies, like ChatGPT, provide easy access to a global knowledge base which could inform associative-thinking outcomes. ChatGPT excels at generating lists of user-specified topics to accelerate learning with access to decades of gathered online experiences and insights. This study hypothesised that using ChatGPT to inform associativethinking techniques would improve student idea generation compared to analogue methods in a new product development workshop. Product ideas were represented on Post-it notes, and outcomes were measured by fluency, flexibility, and originality. Thirty-five undergraduate students (first-year freshmen to fourth-year seniors) from Brigham Young University participated in two innovation workshops. One utilised ChatGPT in team ideation efforts, and the other used analogue methods. Over 75 percent of students had engineering related majors of study while less than 25 percent were non-engineering disciplines. All students were equally taught associative thinking techniques, and the ChatGPT group had additional training on software usage. Results show that fluency and flexibility outcomes were slightly lower in the ChatGPT group. In originality, the analogue group averaged twice the ideas of the ChatGPT group. Self-reported performance of flexibility and originality were lower in the ChatGPT group, but higher for fluency. Ideation effectiveness, enjoyment, and empowerment were all lower in the ChatGPT group. Observations revealed that ChatGPT-assisted teams had increased team interactions. Future research might benefit from longer ideation sessions and visualisation training.

Keywords: Product design education, associative thinking, design process, generative AI

#### **1** INTRODUCTION

In the early stages of product design, ideation techniques such as associative thinking methods are commonly used to explore design proposals within a target problem space [1], [2]. Associative thinking connects ideas, words, or experiences across different areas of knowledge, industries, or geographies [1]. This can be done spontaneously as "free association" by connecting random ideas together to make a new solution to a design problem or, strategically as "goal-directed association" by connecting related ideas with a specific goal in mind [2]. This process may be constrained by a young designer's limited experience and knowledge, thus restricting the ability to generate diverse and meaningful design proposals compared to experienced designers.

ChatGPT technology provides easy access to a global knowledge base and experiences that potentially inform associative thinking outcomes [3], [4]. ChatGPT's simple conversational interface excels at quickly generating lists of user-specified topics beyond the speeds humans can generate. This technology accelerates learning by providing access to decades of gathered online experiences and insights [3], [4], potentially allowing design students to generate idea content, and judge quality and appropriateness [5], [6]—a capability that artificial intelligence tools struggle to achieve [7].

This study explores ChatGPT's impact on students' new product ideation outcomes from two design workshops utilising two associative thinking techniques. One workshop utilises traditional analogue methods, and the other incorporates ChatGPT into the workflow. We expected that inexperienced design students incorporating ChatGPT into their ideation workflow would improve their ideation outcomes by

utilising ChatGPT's abilities to (1) quickly produce lists of relevant subject-matter topics for new idea generation and (2) provide access to unfamiliar knowledge or topics.

To assess ideation outcomes, methods from Divergent Thinking tests were used to measure: (1) fluency, the number of ideas generated by each student; (2) flexibility, the diversity of idea categories proposed; and (3) originality, the number of novel, unexpected, or unique ideas within the relevant context of the idea [8]. Given the subjective nature of ideation evaluation, techniques from the Consensual Assessment Technique (CAT) to appraise ideation outcomes were employed [8]. A post-workshop survey gauging participant perception of the study experience was administered to help interpret quantitative and qualitative results.

#### 2 METHOD

A pilot study was conducted with two sections of a product development class, taught at Brigham Young University (BYU). The class occurs several times each semester and takes place during a single seven-hour day. Data was collected from classes taught one week apart. Students worked together throughout the day, learning and practising design exercises and techniques, such as SCAMPER, associative thinking, 5-whys, and mind mapping, to design new product proposals for self-identified product problems [9].

Free and goal-directed associative thinking were taught to both classes and selected as vehicles to explore the impact of analogue ideation versus technology-assisted ideation. Classroom instruction is performed in real-time by an instructor; however, for the associative thinking segment of the class, students viewed videos explaining associative thinking techniques, ensuring consistency across both classes. The class utilising ChatGPT (version 3.5) had additional video instruction demonstrating how ChatGPT could assist with free and goal-directed association techniques and a computer workstation to facilitate ChatGPT explorations. Each team's ChatGPT session was displayed on a wall-mounted television, allowing students to contribute questions or prompts and see live ChatGPT output.

#### 2.1 Participants

Thirty-five students participated in the study. Sixteen students (4 teams of 4 students each) participated in the class focused on analogue ideation. Nineteen students (3 teams of 5 students and 1 team of 4 students) participated in the ChatGPT-assisted class. Approximately 75 percent of participants were manufacturing, mechanical, or technology engineering students while 25 percent of participants were students outside of the engineering college (e.g., accounting, communications, cybersecurity, human development, or physics). All participants were undergraduate students ranging from freshmen (first year) to seniors (fourth year). Participants received no extra credit or compensation.

#### 2.2 Study Procedure

#### 2.2.1 Analogue Ideation Group

Participants in the analogue-ideation class were taught associative thinking approaches for ideation through an instructional 2.5-minute video about free-associative thinking. Next, they were instructed to collaborate with their team to generate as many ideas as possible for their design problem using techniques described in the video. Participants used markers and Post-it notes to document ideas using sketches and text descriptions with enough detail so that someone unfamiliar with their problem could understand the concept. Participants had 8 minutes to ideate and document their ideas; at the end of the ideation session, each team's Post-it notes were collected. Immediately following the collection of ideas, a second 2.5-minute video about goal-directed association was presented, and participants were again instructed to generate as many ideas as possible in 8 minutes using the techniques described. Post-it notes were collected at the end of that session, and the class proceeded to the next course topic. At the workshop's conclusion, students were asked to complete a 9-question survey about their associative thinking experience from the class.

#### 2.2.2 ChatGPT-assisted Ideation Group

Participants in the ChatGPT-assisted class followed the same procedures as the analogue-ideation class; however, two additional 1.5-minute videos of ChatGPT instruction and demonstration for free and goal-directed associative thinking were presented. The video demonstration for free association showed how ChatGPT could generate a list of random words and explore associations and connections about ideas or concepts related to a hypothetical design problem. The goal-directed associative-thinking video

demonstrated how to use ChatGPT to explore new associations and unfamiliar ideas through questionand-answer chat prompts similar to a conversation with a subject-matter expert for the same hypothetical problem. Participants in the ChatGPT session also generated as many ideas as possible in their teams, documented them on Post-it notes, and collected them after the ideation sessions. Students were asked to complete the same post-workshop survey at the end of the day.

#### 2.3 Synthesis

#### 2.3.1 Ideation Outcomes

Both groups' ideas were sorted and assessed by two instructors who teach new product development classes and categorised the outcomes. Fluency was measured by quantifying the number of total ideas generated by each team. Unclear and incomplete ideas were eliminated from the study results. Flexibility was measured by categorising each team's ideas through affinity mapping and quantifying the resulting idea groups [10]. Originality was measured by quantifying the number of novel, unexpected, or unique ideas not commonly used in the relevant domain.

Each team had different colour Post-it notes, easily distinguishing separate team outcomes. An example of organised and quantified ideation outcomes are shown below in Figure 1.



Figure 1. Affinity mapping of ideation outcomes: fluency, flexibility, and originality

#### 2.3.2 Post-workshop Survey

An internet-based survey was administered to participants at the conclusion of the class. Questions gathered insights into participants' self-perception of the effectiveness of analogue or ChatGPT-assisted associative thinking using a Likert rating scale from 1-5. Questions 1 and 2 asked about the perceived effectiveness (i.e., 1 = not effective, 5 = very effective) of free and goal-directed associative thinking. Question 3 explored fluency by asking how often the student felt "stuck" when generating ideas for their design (i.e., 1 = often stuck and 5 = rarely stuck). Question 4 uncovered how original they thought their team's ideas were (i.e., 1 = not original to 5 = very original). Question 5 asked how diverse (flexibility) their ideas were (i.e., 1 = not diverse to 5 = very diverse). Questions 6 and 7 asked how enjoyable and empowering associative thinking was for their teams. In the ChatGPT group, the wording asked how enjoyable and empowering using ChatGPT was to aid associative thinking (i.e., 1=not enjoyable/empowering).

The participants' discipline and team designation were also gathered. The survey took, on average, less than five minutes to complete.

#### 2.3.3 ChatGPT Prompt Analysis

Incorporating ChatGPT into the ideation process was a new experience, and exploring its utilisation was important. Student-generated input prompts were saved and analysed thematically to observe student interaction use. Prompts were categorised by type and quantified.

#### **3 DATA ANALYSIS AND RESULTS**

#### 3.1 Ideation Outcomes

The quantifiable data from the two classes for ideation outcomes, post-workshop experience surveys, and ChatGPT conversations are outlined below.

Table 1 summarises the total fluency, flexibility, and originality results for all teams for each class. Ideation outcomes have been calculated per student because of differing class sizes between the analogue-ideation class (n = 16) and the ChatGPT-assisted class (n = 19).

Class Fluency		Flexibility	Originality	
	(ideas per student)	(idea groups per student)	(original ideas per student)	
Analogue $(n = 16)$	5.6	2.8	0.8	
ChatGPT $(n = 19)$	5.1	2.6	0.4	

Table 1. Ideation outcomes for associative thinking idea generation

#### 3.2 Post-workshop Survey

The post-workshop survey was completed by 30 of 35 students attending as it was not a mandatory requirement of the course. Results for self-perception of fluency, flexibility, originality, and overall effectiveness for free and goal-directed associative thinking from both classes are shown in Table 2. Results are reported on a scale from 1 (lowest) to 5 (highest).

Table 2. Self-perceived ideation outcomes and associative thinking effectiveness

Class	Fluency	Flexibility	Originality	Effectiveness of	Effectiveness of Goal-
	Rating	Rating	Rating	Free-Associative	Directed Associative
	_	_	_	Thinking Rating	Thinking Rating
Analogue $(n = 15)$	3.3	4.1	3.9	4.1	3.9
ChatGPT $(n = 15)$	3.7	3.5	3.4	3.7	3.5

The post-workshop survey results for self-perception of enjoyment and empowerment of associative thinking activities are shown in Table 3 on a scale from 1 (lowest) to 5 (highest).

Table 3. Self-perceived enjoyment and empowerment rating in associative thinking activities

Class	Enjoyment Rating	Empowerment Rating	
Analogue $(n = 15)$	4.4	4.2	
ChatGPT $(n = 15)$	3.9	3.7	

#### 3.3 ChatGPT Prompt Analysis

Participant ChatGPT prompts were individually assessed and coded into categories of: (1) "unknown knowledge questions," (2) "analogous concept exploration," (3) "random words," (4) "previous output elaboration," and (5) "solve my problem." Table 4 presents the summary of prompt types by quantity and frequency percentage.

Table 4. ChatGPT prompt type, count, and frequency percentage

Prompt Type	Prompt Count,
	Frequency (%)
Unknown Knowledge Questions: "Can zippers be waterproof?"	22, (37%)
Analogous Concept Exploration: "Tell me some unique ways to store food on the go"	20, (33%)
Random Words: "Create a list of random objects"	9, (15%)
Previous Output Elaboration: "What are more ideas around item #8"	6, (10%)
Solve My Problem: "Create 'adaptive technology' for removing ice from a windshield"	3, (5%)

#### **4 DISCUSSIONS**

#### 4.1 Ideation Outcomes

Ideation outcome results summarised in Table 1 show evidence that ChatGPT-assisted ideation yields slightly lower fluency, flexibility, and originality outcomes than for analogue ideation. Comparatively, fluency and flexibility outcomes were only slightly lower in the ChatGPT-assisted class; however, the originality outcome was larger. Students in the analogue-ideation class produced, on average, twice the number of original ideas compared to students in the ChatGPT-assisted class.

#### 4.2 Post-workshop Survey

Results summarising self-perceived ideation outcomes in Table 2 indicate that fluency was perceived as higher, while flexibility and originality were perceived as lower in the ChatGPT group compared to the analogue group. Even though the ChatGPT-assisted group produced fewer ideas per student, they reported a higher perception in fluency. One possible reason for this result comes from anecdotal observations of the two classes. The ChatGPT-assisted class engaged in more team discussion, design exploration, and new knowledge investigation compared to the analogue class. It's plausible that ChatGPT output (i.e., lists of related ideas, topics, and expert knowledge surrounding a design problem) stimulated more verbal idea explorations and conversations in a team environment. The time spent searching for an optimal design solution through engaged team discussions may have taken precedence over using time and effort to document interim ideas. Conversely, students in the analogue-ideation class rated their team's ideas with higher diversity (flexibility), originality, and free and goal-directed associative thinking effectiveness than the ChatGPT-assisted group. This may be attributed to students having a stronger sense of self-efficacy and ownership of their own ideation efforts compared to technology-assisted efforts. Additionally, students in the analogue-ideation class may have a clearer understanding of how their own design ideas may emerge or be developed. In contrast, the ChatGPTassisted design ideas may seem less familiar to students as these ideas may come from domains where students have less knowledge and experience.

The enjoyment and empowerment ratings, as shown in Table 3, indicate that ideation activities in a team environment without ChatGPT have higher enjoyment levels compared to using ChatGPT. This result seems contradictory to anecdotal observations of higher student engagement among team members but may be a result of other factors such as the additional task of using a computer together as a team instead of just using team members alone without ChatGPT.

#### 4.3 ChatGPT Prompt Analysis

Results from the ChatGPT prompts, as shown in Table 4, support the notion that ChatGPT can be used as a tool to inform inexperienced design students in ideation activities. The most common prompt type (1 out of 2.5 prompts) was the "unknown knowledge questions" prompt. These are prompts used to gain more information or learn about unknown topics. These prompts demonstrate that students investigated idea content unfamiliar to them. The second most common prompt type (1 out of 3 prompts) was the "analogous concept exploration" prompt, providing ideas specific to the prompt topic. "Random words" were used approximately 2 times per team (1 out of 6.5 prompts) in practising the free-associative thinking activity. One out of ten prompts were "previous output elaboration" prompts used to elaborate on previous conversation output, demonstrating the utility of a conversation-like interface for design explorations. Lastly, only three prompts were "solve my problem" prompts. These prompts explore more complex and solution-specific ideas related directly to a design problem. These types of prompts reflect a student's intent to have ChatGPT directly generate associative thinking connections rather than having it produce lists of topics that the students must associate on their own. There were 60 prompts in total for the two ideation sessions, averaging 8 prompts per team for each 8-minute session. Therefore, on average, students input prompts into ChatGPT at a rate of approximately one prompt per minute.

#### 4.4 Limitations

Introducing a new technology-assisted ideation method into an existing course curriculum, rather than a stand-alone experimental study, limited the time available for ideation activities. Gathering data within a classroom setting offers valuable real-world perspectives; however, conducting longer ideation sessions could enhance ChatGPT's effectiveness in idea generation. It is possible that two 8-minute sessions may not fully exhaust a student's design ideas, while a longer session could better showcase the impact of using ChatGPT on ideation outcomes compared to analogue ideation.

The class does not focus on teaching rapid design communication, yet assessing ideation heavily relies on clear design communication. As student ideas were collected and evaluated for ideation outcomes, it was evident that some students articulated design concepts more effectively than others who lacked clear design communication skills. This may be attributed to student experience and training in visual communication based on their disciplinary pedagogical norms. Since unclear or incomplete ideas were excluded from the study results, for future studies it is important that ideas are properly conveyed to avoid being disregarded due to ambiguity or confusion. Even though less than seven percent of student ideas were excluded because of unclear or incomplete designs, the overall communication of ideas should be improved for a study like this that relies heavily on clear communication.

#### 4.5 Future Work

Future research allocating more time for extended ideation sessions may prove more effective in enhancing creativity outcomes for ChatGPT-assisted idea generation. Previous studies on creativity utilising ChatGPT conducted ideation sessions averaging 30 minutes [4], which demonstrated improvements in individual creativity outcomes.

Additional research should include training to improve rapid idea communication with sketching, text description, and visualisation practice. Performance differences between disciplinary backgrounds and skills in visual and written communication should be addressed. Alternatively, advances in artificial intelligence for image generation from text descriptions might prove useful to bridge the gap between inexperienced visualizers and clear ideation communication.

While anecdotal observations of higher engagement with ChatGPT-assisted student teams were insightful in this pilot study, subsequent studies could benefit from implementing in-class video recordings to capture student behaviours that would further validate the anecdotal observations of higher team engagement with using ChatGPT.

#### **5 CONCLUSIONS**

ChatGPT was predicted to improve ideation outcomes because of its ability to rapidly generate topical lists and provide insight to inexperienced students; however, initial results of this study do not confirm this prediction. For short-duration ideation sessions and limited experience with ChatGPT, it may not be useful to incorporate in the ideation process if maximising ideation outcomes is the desired result. However, ChatGPT technology shows promise for improving student engagement and assisting inexperienced students in knowledge exploration. Given more ideation time, ChatGPT may impact idea generation and associative thinking, serving as a valuable tool to complement traditional analogue ideation methods among designers.

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### HOW COULD REGENERATIVE FRAMEWORKS STIMULATE STUDENT'S CREATIVITY: A CASE STUDY OF A WORKSHOP ON ORAL HYGIENE

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#### ABSTRACT

In this paper, we investigate the potential of regenerative frameworks as a starting point for students to explore diverse futures within the context of design development. We review related works on regeneration, environmentally responsible design, and enlivenment to come up with seven regenerative frameworks in the context of product design. To test the frameworks, we conduct a case study reflecting on a two-day design workshop with students from the product design department at the Academy of Fine Arts in Sarajevo. The goal of this workshop is to design a "regenerative toothbrush". The students worked in groups and explored concepts of regenerative design within each theme. Through the workshop, we found that students' approach towards design differs: Human-nature reorientation and embedded experiences activate the possibility for inner exploration. Students are inspired to formulate unconventional approaches to the possible role design can have in enabling futures for common good.

Keywords: Regenerative design, transition, design framework, future design, design education

#### **1** INTRODUCTION

Regenerative design is an emerging research field addressing the global ecological crisis, following sustainability and circularity. It aims to replenish and restore, rather than doing less harm (sustainability) or designing out waste (circularity) [1]. The concept of regeneration has its origin in agricultural practices such as permaculture, which recognises patterns in natural and human systems to weave them together as a dynamic whole [2]. It focuses on the natural metabolism of the ground and seeks a partnership with nature where we could achieve a diversified and holistic harmonious state. In the context of architecture, regeneration is linked to the concept of living systems thinking by Steve Larrick and is capable of resisting entropy increasement, capturing energy and resources from the environment to facilitate further growth and development [3]. Within the field the concept developed further to be applied as "placemaking" strategy looking to foster the interactions among people; their consciousness, habitat, infrastructure, etc., all aspects contained within a "place". Regeneration acts as a storyline revealing the narratives behind a place, where it becomes a living organism [4]. In architectural practices, a number of strategies have been put forward. While the implementation of regenerative building practices on a big scale has not reached its full potential yet, multiple visions have been formulated.

Within the field of product design, the question of how to achieve harmony both in ecology and society utilizing regenerative thinking, however, is not yet clearly formulated. One direction is to rethink and reframe the bond and relationship between human and non-human species, the environment, the planet, for example, the pioneering exhibitions *Broken Nature* (Triennial Milan, Italy, 2019) and *Eco-Visionaries* (Royal Academy of Art, UK, 2019). In the latest design exhibition at the Museum of Modern Arts New York *Life Cycle* (2023), the material circulation in the ecosystem is highlighted, shifting the focus of design towards a more collaborative relationship with nature. This wave of regenerative thinking continues in education. The University of the Arts London opened a new department named *Regenerative Design* exploring design in a more-than-human world. Also, the Systemic Design Lab at ETH Zurich opened an advanced study program in 2023, aiming to hybridize science, design, and transformative practices. This shows that universities are contributing to the discourse on regenerative

design. Another direction is calling for locality, searching for design vernaculars (materials, techniques, etc.) as the exhibition BIO27 (Ljubljana, 2022) proposed. Moreover, curators explore aspects of regeneration in different areas of people's everyday lives, like consumption (*Critical Consumption*, MAK, 2023), clothing and housing (*Planetary Boundaries*, Royal Danish Academy, 2023), contextualising human lifestyles as part of the problem, while suggesting the tools towards regeneration be accessible to everyone, so that small actions can gather to create change. Aiming at reorienting design in a world marked by numerous crises, Institute of Design Research Vienna (IDRV) interprets the definitions and principles of regenerative design from Andreas Weber, Daniel Christian Wahl and Regenesis Group [5-8] and curated the "learning travelling" exhibition *Imagine Coral Reef: Regenerative Design*. As a part of the exhibition, IDRV organized a regenerative design workshop collaborating with a local university. During the workshop, the students were encouraged to discuss definitions of regenerative design and the related concepts.

In this paper, we present the potential of the seven regenerative frameworks to inspire a different understanding of our embeddedness in natural systems and of the design process and outcome when working with students. Our hypothesis is that by presenting students with an approach to design thinking that proposes an engagement with the ecosystem in which they as designers and the objects they create are embedded, new visions for the future of design will emerge.

#### **2 REGENERATIVE FRAMEWORKS**

We position the regenerative frameworks as the roadmap, leading designers and students to reflect on their current position and envision a path to move on in order to achieve the next step of design for all, i.e., environment, other species, and future generations. We reference the trajectory of environmentally responsible design from Bill Reed [9], where he points out that environmental rating systems and other mechanisms entitled sustainability could only solve the problem of efficiency at best. Herein, Reed called for a holistic, living systemic thinking in the reconciliation and regeneration level, asking the ultimate purpose of sustainability. In his tone-setting paper, he defined the trajectory into five phases: Conventional, Green, Sustainable, Restorative, and Regenerative. The five-phase diagram from conventional to regenerative is widely referenced in further developments of regenerative design, where the definition of each phase is continuously reformulated (see Table 1). In order to generate a regenerative vision for the field of product design, we formulated each phase specifically in relation to this context.

authors	Conventional	Green	Sustainable	Restorative	Regenerative
B. Reed	"one step better	relative	neutral, 100%	humans doing things	humans are an integral
[9]	than breaking the	improvement.	less bad	to nature – assisting	part of nature,
	law"	eco-efficient		the evolution of sub-	participating as nature -
		design		systems	co-evolution of the
					whole system
D. C.	compliance to	relative	neutral point of	humans doing things	appropriate participation
Wahl	avoid legal	improvement	not doing things	to nature	and design as nature
[6]	action		to nature		
W.	achieving	performance	towards net-	reversal to pre-	human and natural
Craft	minimum	improvement	zero carbon	development	systems actively co-
[10]	standards	sustainability	neutral	environmental	evolving as one
		ratings		conditions	

Table 1. Explanations of five phases in trajectory of environmentally responsible design

In our process of exploring these strategies, coral reefs serve as inspirational metaphor to create a bridge towards product design. Coral reefs are referred to as the rainforest of the ocean. The symbiotic relationship between corals and zooxanthellae (algae) makes the ecosystem vibrant even in waters with only few nutrients available. We consider the coral as one of the "products and infrastructures" shaped by nature, and we start to question: If *Regenerative* is the phase when humans can co-evolve with nature, then how could the logic of nature apply to principles of product design?

In his text *Enlivenment* Andreas Weber calls for economic commoning, "Besides producing and distributing resources, economic commoning is about constructing meaningful relationships with a place, with the Earth, and with one another [5]." There is no separation between humans and nature. Everything is connected, and only a mutually dependent relationship can support continuity of life [12]. He listed seven guidelines of reciprocal productivity: Local rules, Interbeing, You are the commons, Resources

are meaning, Reciprocity, No copyright, and Gift exchange [5]. We use the coral reef to help us illustrate the philosophical meanings behind each of the seven principles (see Figure 1).

mes.	A CONTRACTOR	S.		A Com	A.C.	
Distribution of Canals: consta are scattered in the troppical and subtroppical area where the area lacks numbers that the numbers by State, Cherwin Sparadou affective recycling: know the place make test use of n	Food Chain / Pyramide cycle. every specie in hithred to other specie, they compare and coopenies in the same time, their censitiarios, parthe- hip and hostily creates productivity in the assignment production-consumption disculation, chosely rid; so each other	Pastolitah acci Cocala: partolitah apendi about 00% of their dee eating algoe of cocal neeh. This constant eating performs the exactrial task of cleaning the need which heigh the docata stay healthy and thriving. Interdependence of species, commons to both disposition and nocultariant	The besutprisiveneous of the caratis. The experience of besulty is a necessary ingredient of a commoning processes. Locking into the gestime of aliveneous. patterns of dynamic balance offers a sense at belonging and connection. appreciate the besulty: individual serviceric connection	Ecotons: a handbom area between, like the timpe, areas of breas zones. Two systems my to self-subilizing, while in the molder, here is a area to streas bleach and the whithe feasibly atimutus the smaller instancing could appear. healthy dynamic equilibrium	International and the second and a second a seco	Whate Fait: when the while cless, different species, will corre to sack its firsts, so nothing is wasted, dying for one species becomes gring for other species. The selections of the whate sums the foundation for coral to the on. no waste, simp of giving and taking
Local Rules 9	Interbeing	Your are the commons	Resources are meaning	Reciprocity	No copyright	Gift exchange
design starts from the locality, tradition, securitype, material, inhastructure, designs are receively adaptative, responsive design culture, restorative of themsel knowledge and expension. total incohesitype and expension become global potential.	plorpoly; highly diversified, localized and shared participants in an open system	design in dialogue with natural eco- systems. design is shaped by the needs of all participants; design is adoptable and changeable; design is adoptable and changeable; design is shaped by to use.	the production and cultivation of materials lood, ex. is diversified according to the capacity of exception: finde resources are extrated from the strate only.	dension is astaphildre, upgradiable, responsable and neurable, densign is analyzed by the conditions and needs of the excerption; design needs bridges between human and non-human beings; design relates to the dynamics of eco- acytering.	knowledge is openly and globally shared bi, knowledge enables a multitude of developments and solutions, knowledge adlegate to local contexts.	al products are mano-material, all products are disastembiable; all materials are biodegatable; all materials are biodegatable; recycliate; the systems for return, sorting and appropriate recycling are in place.

aphor illustration drawn from coral reef B explanation ciples referenced from enlivenment (Weber, 2019) C extend the

explanation how does the phenomenon from nature links to the principles from enlivenment (Weber, 2019)
extend the natural principle into the field of design

Figure 1. Each card represents a theme drawn from Andreas Weber's seven principles<sup>1</sup>. Image source: IDRV, 2023

In a future where regenerative becomes the minimum standard for every product design, all seven aspects need to be fully considered so that the design responds to the complex network it is situated in. Every principle works as a theme for later navigation (see Figure 2). The cumulative as well as iterative process show the evolution of design practices from conventional to regenerative<sup>2</sup>. For example, in conventional practices, design is driven by standardization and globalization. Numerous problems appear, like homogenous products, the mismatch in production and consumption, and vanishing local production. With Local Rules, the regenerative framework explores paths articulating how product design could be practiced as place-based (see Figure 2), embedded in local cultures, traditions, and resources; how the distribution between local and global could be optimized, making systems adaptable. Also, local rules consist of place-based knowledge and techniques existing in memories and folk stories passed down through generations.



Figure 2. Left: regenerative framework trajectory format; right: interpretation of Local Rules (one of the seven regenerative frameworks), image source: IDRV, 2023

We perceive the seven regenerative frameworks as a tool to expand the paths students explore during their design process, creating the space to explore with whom [6] and with what to work with. The frameworks offer a different perspective to examine current and potential metabolisms surrounding design objects to then implement design (system) functioning as a living organism, as part of nature. In Plumwood's words, "all bodies are food, all food is souls, and all souls get recycled, so all of nature and life are thought of in gift exchange terms [13]."

<sup>&</sup>lt;sup>1</sup> Seven theme card explaining the adaptive process from biology and philosophy to design © 2023 by <u>IDRV</u> is licensed under <u>CC BY-NC-SA 4.0</u>. Attached with corresponding design examples used as exhibits in Imagine Coral Reef: Regenerative Design in Tirana, Albania (2024.3.12-4.1).

<sup>&</sup>lt;sup>2</sup>Seven regenerative frameworks in product design © 2023 by IDRV is licensed under CC BY-NC-SA 4.0.

#### **3 THE WORKSHOP ON ORAL HYGIENE**

Within the context of the exhibition *Imagine Coral Reef: Regenerative Design*, we conducted a workshop on oral hygiene and the prototyping of a "regenerative toothbrush" at the University of Fine Arts, Sarajevo, allowing us to test the potential of the regenerative frameworks. The toothbrush as an everyday object offers us a wide network of relations. In the Middle East, Africa, and India, for example, a natural toothbrush called miswak is used. The miswak comes from the roots of the tree (Salvadora Persica), which, according to scientific research [14], could suppress the bacterial redox system. This place-based toothbrush has its unique way of "production" – growing, gathering, and harvesting, which harmonizes with the cycles of nature.

In the workshop, the participating students were mostly from the product design department, two students were majoring in architecture. The workshop consisted of a lecture on our previous research on regenerative design and the seven regenerative frameworks, inputs from a local entrepreneur, group discussion and collaboration, tutoring, prototyping and an oral presentation. Students were randomly divided into seven groups corresponding with the seven principles. Due to time limitations, every group focused on one of the principles as their steppingstone, to find the unique as well as the overlapping perspectives in the process. Before the workshop, we encouraged the students to see the exhibition and engage with the reading materials<sup>3</sup> to better understand the context of regenerative design.

We took this workshop as the testing ground for the regenerative frameworks, the research questions we aimed to explore are as follows: (a) How do the regenerative frameworks resonate with the students? (b) How do they interpret the key concepts of the frameworks and further develop their design proposals? (c) Which aspects of the regenerative frameworks enable the students in their thought process? We used participatory observation to document the group discussions, tutoring, and presentation. We also took on-site notes to help us better reflect on the workshop.



Figure 3. Schedule of the regenerative toothbrush workshop in Sarajevo. Image source: IDRV, 2023

After the lecture on regenerative design, we opened the room up to a discussion during which a student critiqued "*I don't think design can solve the problems we are facing now, it's more like the business for economists, politicians.*" Other students argued back focusing on two main topics: (1) The possibilities of what design is capable of. (2) Why they think regenerative design could differentiate from green, sustainable, and circular design. The spontaneous open discussion among students made the understanding towards regenerative more concrete and accessible. Students found common ground in the perception that the current state of design is conventional, or green at most; that regenerative design is bonded with future design centred on the issue of how we imagine a future that could achieve human living as part of nature. We challenged students to think how design could work as part of nature. How can design processes, actions, practices be thought to imagine a productive (non-extractive) practice of making together with multi-species living systems? Each of the group brainstormed departure from the one of the seven regenerative themes, in the other day, each group managed to use the local materials they could access to prototype and give an open presentation to the whole class. From theory to real practices, students kept reflecting on the regenerative theme and found their own approach to build logic and complete prototyping.

<sup>&</sup>lt;sup>3</sup> <u>Regenerative Reading Materials</u> © 2023 by <u>IDRV</u> is licensed under <u>CC BY-NC-SA 4.0</u>.

#### **4 RESULTS AND DISCUSSION**

In the end of the intensive two-day workshop, every group presented their "final" toothbrush prototype, introducing their iterative process of developing with mind maps and sketches. More than half of the prototypes went beyond form, function, material, and involved other participants in their concept for the future of oral hygiene. Proposal included: Local Rules – A "chewing gum" made from woollen fibres, utilizing left over materials from local sheep farmers, different textures could be achieved employing local knitting, crocheting and felting techniques. Gift Exchange – A gummy brush with a bio-chemical process which dissolved in user's mouths after use. You are the Commons - A toothbrush using natural materials (sand, clay, limestones) from the local river, involving algae and spores to complete the hygienic purification at the same time.

One of the interesting phenomena we saw is how students use the premise of "there is no waste in nature". One supportive quotation asserts that: "One of the biggest problems we are facing today is that humans are not incorporated in the ecosystem. ... We use sand, clay, or limestones to make the toothbrush, after our use, we could throw it back to the river, creating more nutrition and oxygen." Another group resonated with this: "You can bury it (the toothbrush) in your backyard, in your closest park... make an aquarium out of it." Here, the proposal involves communal herbal plant patches as participants in the circulation of the design. The students demonstrate how they leverage nature from private to public spaces and from ecosystems on land to those in the water.

Also, the meaning of key terms shifted. Like in this context, "waste" had multiple ways of understanding: (1) our input: there is no waste in nature. (2) interpretation to "less waste, less design". focused on the core issue of "*how to design life after use*". They came up with the idea of replacing the bristles with composite hygiene gummy (the third image, Figure 4) with a chemical effect on the teeth, the gummy will dissolve eventually in the mouth. (3) As in the group You are the Commons, they started to involve disconnected sub-ecosystem, to turn the "waste" in one system (toothbrush) to the sparkling part of another system (riverbed).

Throughout the workshop students were referencing their own and others' experiences as inspiration for their creative ideas on reimagining oral hygiene. One member from Resources are Meanings shared an observation: "children chew things because they want to understand surroundings. I think in a philosophical way, it links with regenerative design. We design society because we want to understand our position in nature." This group also shared: "(My grandpa) uses salt to clean the teeth, he rubs his teeth with the salt", "(Brushing the teeth is) like smoking, people smoke in their head out of habits." The students started to reflect on their environments and to rethink the everyday routines they're used to (see Figure 4 far left for the chewing kit from the group Resources are Meanings) The group working on Reciprocity expanded the participants to the fringes between bacteria and mouth, trying to engage all different life forms and to achieve zero waste on a molecular level. They envision their oral hygiene device could function as a container gathering bacteria which help the mouth get cleaned. Taking the human metabolism as one part of the hygiene system, the pomegranate (see right in Figure 4) enables production and use at the same time.



Figure 4. Selected prototypes from students. From left to right: Group of You are the commons, Resources are meaning, Gift exchange, and Reciprocity. Image source: IDRV, 2023

#### **5 CONCLUSIONS**

Based on the research on regeneration, environmentally responsible design, and enlivenment, we use coral reefs as metaphors to come up with seven regenerative frameworks for product design. They specify the characteristics each stage has and the trajectory towards regenerative design. At the same time, they unify our vision for the future of design and the ecosystems we are living in. The workshop in Sarajevo field tested the effect of the regenerative design frameworks in an educational context. The immediate resonation students react to our inputs is learning from nature, thinking in the phase of

regenerative, where design functions as part of nature. They used key concepts in natural systems to expand their ideas. The references and expansion of key concepts put design thinking in a connected position, where neglected relationships are enabled. In this paper, we used the keyword "waste" to showcase the expansion process, how students start from our input, "there is no waste in nature", and develop their multiple directions for interpretations. The intuitive response of the students to the frameworks allowed them to freely imagine a design, which involves not only humans as active agents. The students used their prior experiences and knowledge to relink the relationship between humans and nature, bringing new entities into the design ecosystem. The focus on locality, natural resources, and the logic of mutual exchange pushed the students to create unconventional understandings and imagine diverse futures for design.

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## WHO OWNS ARTIFICIAL INTELLIGENCE?

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#### ABSTRACT

This paper explores the complex landscape of AI-assisted and AI-generated work, examining the pressing concerns and issues regarding Intellectual Property Rights (IPR) and ownership in the future. AI presents unprecedented opportunities and challenges, potentially influencing every global citizen in profound ways. Against a backdrop of the historical evolution of disruptive technologies the paper navigates the current discourse and legal frameworks around AI and IPR. It underscores the pivotal role of authorship and ownership in shaping the intersection of AI and IP. The paper also considers the challenges faced by authorities grappling to regulate its application. Acknowledging the disruptive and contested nature of AI outputs in the context of IPR, the narrative raises ethical concerns around how AI is deployed and exploited. As AI becomes more ubiquitous, questions arise about its potential impact on the ecosystem which protects creative production and innovation, potentially posing a threat to established intellectual property norms. The paper considers the potential for a new AI/IP ecosystem as well as the intriguing possibility of AI itself being granted intellectual property rights, a development with far-reaching implications for global IP policy. The concluding focus underscores the profound implications of these issues on both Engineering and Design Practice and education, urging a careful consideration of how to harness the benefits of generative AI while preserving the integrity and motivation of human creative endeavours.

Keywords: Artificial Intelligence (AI), Intellectual Property (IP), ownership, authorship, innovation

#### **1** INTRODUCTION

This paper considers AI as it has evolved in recent years and its paradigmatic potential to reshape the way we think, operate, and interact with both the natural and artificial world. Researchers have been interested in how to use computers to carry out intelligent tasks since the 1940s. Indeed, computer scientist John McCarthy coined the term "Artificial Intelligence" as far back as 1955 [1]. In attempting to define AI, Seaver, describes it as a diffuse term that corresponds to a web of human actors and computational processes interacting in complex ways [2]. In fact, there remains no clear definition of what AI actually is [3][4][5]. What is clear is that AI is a technological innovation that is set to shape and reshape our collective futures. Society has consistently made technological advances, achieving incremental breakthroughs leading to new capabilities that benefit humanity. These advances began almost 2 million years ago with the hand axe and evolved slowly over time. However, in recent history there have been three paradigm shifts often referred to as industrial revolutions, which have reshaped how we think, operate, and interact [6]. These paradigm shifts have created conflicts around authorship and ownership of these technological breakthroughs. Consequently, an IP ecosystem evolved to assign rights to this type of property. AI follows this pattern, however, the delineation of authorship and inventorship roles may become less clear [7].

The foundations of copyright and patent laws are being challenged by AI's rapid growth. The modern copyright system evolved in response to technological disruptions like the printing press [8] which revolutionized the way information was produced, disseminated, and consumed from the late 15th century. Previously, books and documents were painstakingly copied by hand, making them scarce, expensive, and often prone to errors. The printing press transformed the way information was created, shared, and consumed, leading to profound social, cultural, and economic changes in societies around the world [9]. The question is whether AI is just another disruptive technology or something more transformative and perhaps more profound. While section 8 of this paper considers the impact of AI on Education, sections 2 to 7 address some of the emerging discussions that our students and programmes need to engage with in order to be prepared to navigate a changing world.

#### 2 AI AS DISRUPTIVE TECHNOLOGY

Klaus Schwab, founder of the World Economic Forum, coined the term Fourth Industrial Revolution describing the current technological revolution as 'characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres' [10]. This Fourth Industrial Revolution has evolved out of the three earlier Industrial Revolutions. The first utilized water and steam to power machinery and enable innovative structures, the second harnessed electric power to enable mass production, and the third enabled a 'digital revolution' which introduced personal computers and the internet. The Fourth Industrial Revolution builds on these, particularly leveraging digital technologies and supporting a vast, interconnected ecosystem, which dynamically shaped interactions between humans and the world around them [11]. With its roots in the mid twentieth century, it has been informed by the emerging technologies in engineering, science, computing and medicine. The foundations were established for the internet of things (IoT), virtual and augmented reality, AI, nanotechnology and robotics. AI has already significantly impacted human lives, extending its influence across diverse industrial, business and medical applications by analysing data for predictive insights. Disruptive technology is a signature of this Fourth Industrial Revolution and presents humanity with both great challenges and great opportunities. A comprehensive and expanding literature on disruptive technology places AI at the forefront of this disruption [12].

However, AI may be more than disruptive with Schwab [13] suggesting that we are now standing at the edge of a transformative technological revolution, where we face an unprecedented shift in technological innovation which is set to redefine 'our daily lives, professional landscapes, and interpersonal dynamics'. This transformation distinguishes itself through its vast scale, far-reaching implications, complexity and embeddedness, presents a significant departure from any historical precedents. This Fourth Industrial Revolution is unfolding at an unprecedented pace which is disrupting industries on a global scale and reshaping the nature of manufacturing, distribution, administration, governance and education. The increasing deployment, ubiquity and invisibility of AI, should prompt a collective refocus on personal and societal values. Creating a future that prioritizes the well-being of all requires placing people, not machines or tools, to the forefront both in application and ownership. While the Fourth Industrial Revolution carries the potential to mechanize and therefore dehumanise humanity, in its most pessimistic manifestation, it also harbours the capability to enable the positive qualities of human nature and to develop a new collective moral and ethical consciousness where AI technology can enable us to co-create a sustainable and resilient future. However, managing the evolution of our technological innovations and their transformative potential presents many challenges.

#### **3 THE INTELLECTUAL PROPERTY ECOSYSTEM**

IPR, including patents, copyrights, designs, trademarks, and trade secrets, provide legal protection to individuals and corporate entities for their intellectual creations. The two core categories of copyright and patent, represent legal rights for the creators and inventors who generate the content which generates both creative culture and technological innovation as outputs of the human mind.

The technological revolution marked by the invention of the print press, which enabled the mass dissemination of information [14], was the catalyst for one of the earliest pieces of IP copyright law which was passed into the UK statute books in 1710 [15]. This initial law set a precedent for the development of a comprehensive global IP ecosystem. By 1948 intellectual property rights were enshrined as human rights by the United Nations under article 27 of the Universal Declaration of Human Rights [16].

The original purpose of the patent system was to promote innovation by granting exclusive rights for a period of time to inventors in exchange for making their inventions available to the public. These exclusive rights were guaranteed by government and protected through national and international legal systems. Overall, IPR aims to strike a balance between providing creators and inventors with the incentives and protection needed for their endeavours while supporting a climate of innovation that benefits society as a whole. Wills reminds us that 'IP's core function is promoting innovation and not preserving tradition... [17], with the intention being a better societal future. The disruption to IPR presented by the very nature, scale and pace of AI will require establishing a new balance between stimulating, generating and protecting IP and the IP ecosystem.

#### 4 AI DISRUPTION TO THE IP ECOSYSTEM

The challenge of AI in the realm of IPR is complex, stemming from the unique nature of AI-generated creations and the emergence of blurred ownership positions. Key issues include determining authorship and ownership of AI-produced works within existing IPR frameworks designed for *human* creations. Concerns extend to data ownership and access, especially considering the use of diverse datasets in AI training, which potentially pose challenges to intellectual property provenance.

The evolving nature of AI challenges patent law, necessitating increasingly complex definitions of inventive steps and non-obviousness requirements. Further challenges result from the pace in AI developments and questions around human/machine collaborative. Addressing these challenges necessitates an increasingly nuanced approach, potentially incorporating new AI-specific categories or regulations within IPR frameworks. International agreements and standards are proposed which would aim to harmonize AI and IPR practices. The intention would be to continue to promote innovation while safeguarding both creators and the interest of society in general.

The intersection of AI and IPR also raises ethical concerns, particularly regarding the concentration of power in the hands of advanced AI technology processors and owners, potentially leading to economic and societal inequalities. The autonomous nature of AI in creative endeavours challenges traditional authorship concepts and prompts questions about fair compensation for human creators of content. This emphasises the need to strike a balance between innovation incentives and ownership if we want to continue to encourage human creativity. Ethical and legal questions increasingly arise from AI's role in both accidental and intended intellectual property violations, resulting in production of illicit output. In addition, biased algorithms and discriminatory AI practices may result in social injustices and exploit IPR to protect questionable content. Responsible AI use within IPR bounds requires ethical considerations in both development and application. Therefore, IPR frameworks may need a comprehensive overhaul to remain credible in the face of questions and challenges.

#### 5 AUTHORSHIP AND OWNERSHIP

Given the economic significance of these AI innovations, there's an inclination to 'control' such intellectual creations through IPRs. A pivotal question arises regarding how to interpret the notions of 'authorship' in the realm of 'copyright,' and 'inventorship' in the realm of patents, when AI systems generate creations and inventions [18]. Authorship is central in copyright law, raising questions about AI's role in the creative process. International treaties, such as the Berne Convention, lack explicit definitions of 'author' or 'authorship,' leaving room for interpretation at the national level. [19]. Ginsburg argues that the person who conceptualizes and directs the development of the work is the author, rather than the person who simply follows orders to execute the work. Most national copyright laws agree that mere execution does not make one an author. Ginsburg goes on to suggest that the "author" conceives of the work and supervises or otherwise exercises control over its execution. [20].

Within patent law Abbott [21] challenges conventional notions of inventorship and advocates for recognizing AI as a 'co-creator'. The absence of legal clarity prompts a call for adaptive frameworks that balance innovation encouragement, human creators' rights, and AI's unique contributions. In the European Union, most Member States lack a specific definition of 'inventor,' relying on the presumption that inventions are solely made by natural persons [22]. While patent ownership may include legal persons, only humans typically qualify as 'inventors'. The collaborative nature of AI-human interactions raises issues of both authorship and ownership. The lack of clarity on policy has been prompting discussions on updating legal frameworks to accommodate AI-generated works, which argue for recognition and protection for both human and AI contributors. As technology advances, collective agreement becomes crucial for fostering a fair and adaptive intellectual property ecosystem.

#### 6 NEW IP/AI ECO SYSTEM

Questions of accountability, copyright, and patent rights become challenging when discussing AI. The notion of creativity and authorship is entwined with human emotion, intuition and experience, characteristics that AI does not possess. While AI can evaluate and optimise data sets, it arguably lacks the depth of understanding, meaning, and personal experiences that define human creativity. As AI becomes increasingly prevalent in society, it becomes important to assess how ethical responsibility is tied to developers and owners of AI systems. As more sophisticated AI raises fundamental questions about the roles of authors and inventors, blurring distinctions between human and machine-generated

content. AI's capacity to autonomously create types of content, can appear to challenge conventional definitions of creativity and invention. Collaborative efforts further complicate the attribution of authorship, raising legal challenges in intellectual property frameworks that often assume a human creator. AI will inevitably disrupt labour within the creative industries. Understanding the potential impact on existing professional pathways in these industries is essential as AI continues to shape this sector [23]. As AI systems evolve to produce more complex content, the question over whether machines can be considered authors or inventors becomes an increasing discourse. Legal frameworks surrounding intellectual property are grappling with these challenges. Current IPR assumes a human creator or inventor, which poses difficulties in assigning ownership to machine-generated works. Striking a balance between acknowledging the contributions of AI tools in the creative process and preserving the unique aspects of human authorship and invention remains a complex and evolving challenge. Inevitably the existing IP ecosystem needs to evolve to recognise and acknowledge the changes and potential impacts to protect the richness of human culture and innovation while embracing the co-creation potential of AI as a transformative technology.

#### 7 REGULATION AND CONTROL

The World Intellectual Property Organization (WIPO) acknowledges the growing impact of AI on IP and has been actively monitoring developments in this field. WIPO recognizes the need for a balanced approach that fosters innovation while addressing ethical, legal, and policy challenges associated with AI. WIPO has engaged in discussions and forums to explore the intersection of AI and IP, seeking to emphasize the importance of ensuring that IP systems effectively accommodate and incentivize AI-related innovation [24]. WIPO has encouraged member states and stakeholders to share their experiences and insights on the challenges posed and highlighted the significance of a global dialogue to develop guidelines and frameworks that align with the evolving landscape of AI technologies.

WIPO's stance underscores adapting IP systems to cater to the unique aspects of AI creations, promoting innovation, and safeguarding ethical considerations. The European Commission recently published a proposal for regulating AI detailing definitions and uses of the technologies, with important sections on the prohibited uses of AI and what are referred to as high-risk activities, requiring that the latter go through an approval process much like medications or vehicles would before being made available to the public [25].

Many jurisdictions are addressing challenges as they arise and navigating between existing IPR, legal judgement and contract law in the absence of a global guidance or policy. The resulting uncertainty has the potential to disincentivise using AI tools to develop works which may not be guaranteed protection and also a fear of liability as a result of unwittingly infringing the IPR of others. [26].

#### 8 EDUCATION AND AI

Al's has enormous potential to transform educational practices and enhance learning experiences. [27], however, it is not without concerns. There is now a critical discourse happening around AI and education which is appropriate to those of us who are educators. This discourse influences the ethical and integrity contexts of our graduates as they permeate through their professional careers. Their position is being influenced and shaped by the current debates, debates which they need to be part of. Regardless of concerns, doubts or fears from many within the education community, AI continues to open up new possibilities for innovations in education [28]. Spennemann [29], outlines some of the educational questions which we might reflect on, proposing Integration, Integrity and Equity as critical criteria. Integration focuses on how we should integrate AI tools like GPT-4 into education in a way that enhances learning outcomes without compromising the development of critical thinking and analytical skills. Integrity focuses on what policies should be implemented to ensure the use of AI in education upholds academic integrity, particularly in core courses and examinations. Equity focuses on how we should address the potential for AI tools to disproportionately benefit certain groups of students over others, ensuring equitable access and benefits from these technologies.

Careful consideration needs to be given to the nature and pace of integration of AI tools within education to ensure we appropriately maximise the benefits without compromising the integrity of educational practice itself. Responsible innovation while exploiting the potential of AI tools underpins the nature of Engineering and Product Design Education.

#### 9 SUMMARIES

While AI has the potential to enhance creativity and innovation, there are concerns that its implementation may also pose challenges and inhibit certain aspects of these processes. AI systems are often trained on existing datasets, which might inadvertently reinforce biases present in the data, limiting the diversity of ideas generated. Moreover, the reliance on algorithms to predict trends or optimize solutions might result in a narrowing of creative exploration, as AI tends to favour patterns and existing knowledge. The justifiable fear of job displacement due to automation by AI could also impact the willingness of individuals to take creative risks or explore unconventional ideas. The inherent emphasis on predictable outcomes and efficiencies of AI systems, may undermine the tolerance for failure, which is a characteristic element in the creative process. Furthermore, there is a risk that overreliance on AI-generated solutions might reduce human involvement and intuition, eroding the unique, serendipitous, and emotionally driven aspects of creativity that AI tools might struggle to replicate.

While AI holds immense potential to augment and catalyse certain aspects of creativity and innovation, careful consideration and human oversight are crucial to ensure that its implementation does not constrain the very qualities it seeks to enhance. Balancing the strengths of AI with the unique capacities of human creativity remains a key challenge in maximizing the synergies between the two. Perhaps the emphasis should be taken off the distraction of attempting to recognise AI as an independent creator and realise that it itself is a creation of the human intellect and that it presents us with a powerful tool for co-creation. Perhaps too much of the discussion on AI focuses on the 'intelligence' and not on the 'artificial.' AI is a powerful new tool, which in the right hands can enable and expand human intelligence. However, it is just a more advanced stone axe, a complex tool which we are still trying to figure out how to deploy appropriately.

AI has the potential to assist in solving existing and future challenges across many fields. It is incumbent upon us to find a framework that enables its potential to be truly universal in a fair and equitable way. Evidence would suggest that AI can be used for the generation of human-like creative output, however this is based on the existing limited definitions of creativity. Perhaps the greatest distinction between AI creativity and human creativity lies in its primary purpose, the making of human culture through human creativity. This paper is not an interrogation of creativity but yet its context is central to most debates on AI/IP. The IP system has been primarily formed to protect the economic benefit of human intellectual and creative output, however, there is much more to the human experience and creativity than an economic output. Perhaps the questions raised around authorship and ownership point to an opportunity to re-evaluate the nature of a new AI/IP ecosystem which captures and reward the best of human creativity and imagination.

So, to answer the question, "Who owns AI?" we realise there are many elements to the term own. There is the patent ownership of those who create the AI algorithms and tools; the natural ownership of those who create the content and data on which AI is trained; and those who create new content while using AI tools. It is clear however that we need to address the relationship between AI and IPR to enhance and improve the legal and ethical frameworks that support innovation and ensure fair reward for all those creators. On attempting to interrogate the subject of the paper new questions emerge? Is the blurring of ownership just a distraction? Who benefits from the tool being granted rights?

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### DIGITALISATION – IS HAPTIC UNDERSTANDING OUTDATED IN THE TEACHING OF GEOMETRICAL PRODUCT SPECIFICATIONS (GPS)?

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#### ABSTRACT

For the creation of standard-compliant drawings, the international standards system of Geometrical Product Specifications (GPS) is fundamental. This paper provides a current perspective on the teaching of GPS. What teaching approaches currently exist? And do these meet the requirements of educators in vocational schools and universities? Particular attention is paid to the use of commercial learning kits. Is learning through haptic models as well as learning by doing outdated in the age of digitalisation? What are the learning contents and teaching objectives of such learning kits?

To get to the bottom of these questions, a hybrid learning kit, which combines physical models with digital applications, is used and evaluated in a case study with mechanical engineering students as part of a lecture in the field of ISO-GPS [1]. Finally, the findings are presented in an optimised teaching/learning concept. The aim of this study is also to evaluate simple haptic models in the context of teaching GPS content in an increasingly digital society. Can such simple haptic objects still be convincing and help to understand complex issues? Or do students expect the use of technological visualisations from the field of computer vision?

*Keywords: Haptic understanding, Geometrical Product Specifications (GPS), teaching approaches, learning kit, engineering design* 

#### **1** INTRODUCTION

When a component is manufactured, the technical product documentation serves as a means of communication between different stakeholders such as design or development, the customer, production and quality assurance [2]. The technical drawing and/or 3D CAD model should therefore clearly define all the information required for geometrical description and verification [3]. For the creation of standard-compliant drawings, the international standards system of Geometrical Product Specifications (GPS) is fundamental. The primary objective is to describe the function of the component and to minimise the ambiguity in the translation of this function into the technical drawing and the metrological verification.

#### 2 STATE OF THE ART

The fact that the range of possibilities in the description leads to challenges in the application and teaching of the standards system is explained below. An introduction to findings in the field of digitalisation and haptic models is also given and linked to the requirements of educators and learners.

#### 2.1 GPS

Creating technical product documentations in consideration of GPS can be seen as state of the art. But the voluntary nature of the application of standards is undermined by the need to prove, particularly in the event of disputes, that one has acted on the basis of recognised rules of technology. Current figures on ISO standards and standard revisions show the extensive scope, but also the topicality of the GPS standards system [4].

#### 2.1.1 Teaching approaches

An overview of teaching approaches is given in [5]. The approaches are briefly described below, categorised as literature, e-learning, courses at universities and seminars, and more recent approaches are added. Approaches in the field of e-learning include, for example, a multimedia application, a virtual

laboratory for verification or a newer educational application using machine learning and short videos [6, 7, 8]. In courses at universities, 3D CAD (with model-based definition), a 3D printed assembly as well as augmented and virtual reality (AR/VR) are used in teaching [9, 10, 11, 12]. Teaching can also cover the use of a learning kit such as [1], which is described in more detail in Chapter 3. In addition to GPS seminars, AUKOM [13] also offers international seminars for training in production measurement technology with certification in companies and at universities. Schuldt et al. [14] developed an approach for the integration of the GPS system in companies using agile methods and a maturity model. However, even with the more recent approaches, only a few can be identified for the teaching of GPS.

#### 2.1.2 Current challenges in application

As a result of the contrast between the characteristics of the standards system, namely its scope and dynamism, and the gap in existing teaching approaches, challenges arise in the application of the standards. Studies around the world, in Bulgaria [15], Poland [16], China [17] and Germany [18, 19, 20, 21], have shown that the main problem is a lack of expertise and skills based on the current state of standardisation.

#### 2.2 Digitalisation vs. haptic models

Some examples of haptic models in STEM subjects are presented in the review by Fouad et al. [22]. In addition, the advantage of using haptic devices to transform previously passive learning into active learning is emphasised. In the area of spatial abilities, Montag et al. [23] shows the positive effects of direct touch-based and dynamic tasks on the success rate and mental effort of students. In particular, the results of the study indicate a significant increase in intrinsic motivation and a decrease in frustration for women in the dynamic/interactive version of the tasks. Visual and visual-haptic models have been developed by Sykes [24] to support the understanding of dimensional magnitude values and tolerance fits. In this paper, the haptic model is defined by an assembly learning kit with physical parts, assembly tools and a digital device user interface, which is described in detail in Chapter 3.

#### 2.2.1 Requirements of educators and learners

The requirements of educators and learners were also part of past surveys [18, 19]. For example, teachers at technical vocational colleges asked for literature with reduced content and clear illustrations, and for support in developing practical examples [18]. University lecturers wanted their teaching to be more interactive, with feedback, better links to other courses and more interaction with other experts and lecturers [19]. Both lecturers and students asked for vivid, practical and up-to-date teaching examples.

#### 3 METHOD

As part of an elective course in the field of GPS (5<sup>th</sup> semester of the bachelor's curriculum), 25 mechanical engineering students were given a group task involving the standard-compliant creation of a technical drawing on a voluntary basis. A course in fundamentals of engineering design with a focus on technical drawing is mandatory in the 1st semester. A basic knowledge of GPS standards is therefore assumed. The age of the participants, two of them female, ranges between 20 and 35 years. During their one-hour work, they were divided into three groups and subjected to a short knowledge test. This test used multiple select questions to assess their knowledge of concepts, principles and rules, datum system, dimensional tolerancing, envelope requirement and surface texture. Group size was planned so that four to five people would work together at random. Depending on their group assignment, the students then received the following tools, partly from a hybrid learning kit "lever press" [1]: technical drawings, technical drawings and 3D CAD model or technical drawings and a haptic model. All in all, the learning kit contains a physical functional model designed primarily as an assembly exercise. It is also possible to access various digital media within the learning kit. These are technical drawings in accordance with GPS standards, namely drawings of individual components and assemblies as well as an exploded view. Assembly instructions (as a video or PDF), the full 3D model with the option of exploded view and component name identification, a document with basic knowledge on technical drawing and worksheets with solutions can also be accessed. Finally, the three tools were evaluated. On the one hand, it was possible to assign points between 1 and 4 to the tools for the different purposes, so that a maximum score of 20 points could be achieved in each case. How do you rate an "assembly drawing" or "3D CAD model (incl. exploded view)" or "haptic model" as a tool ...

• ...to describe the required functions?

- ...to determine the datums/datum system?
- ...to determine the tolerances of size, form, orientation, location and run-out?
- ...to determine the envelope requirement?
- ...to determine the surface texture?

On the other hand, students could indicate which tool they liked and which other tools would have been helpful.

#### 4 RESULTS AND DISCUSSION

At the beginning, the raw data for this case study [25] was checked and processed. Two of the 25 data sets to evaluate the tools had to be removed due to incompleteness. Thus, 25 data sets for the knowledge test and 23 data sets for the tool evaluation could be analysed as they are independent of each other. The number of correct answers within the knowledge test for the three main groups (green = technical drawings; blue = technical drawings and 3D CAD model and red = technical drawings and haptic model) is shown in Figure 1. As the three main groups exercises were each carried out twice, this resulted in a total of 6 groups. Overall, a range of 3 to 5 correct answers is identified. This results in mean values of 4.4, 4.3 and 4.1 for the individual groups. The mean value of 4.3 for all students is close to the individual mean values, so that a similar level of knowledge in the lecture can be confirmed.



Figure 1. Number of correct answers within the knowledge test for main groups

Looking at the results by subject area (see Chapter 3), the subject of datum systems stands out. With only 17 correct answers, this seems to be the issue where students have the most uncertainties or gaps in their knowledge. In contrast, the question about two-point sizes in the field of dimensional tolerancing was answered correctly in 24 out of 25 cases. In between this minimum (17) and maximum (24) number of correct answers are the scores for the other subject areas: concepts, principles and rules (23), envelope requirement (22) and surface texture (21).

In the next step, students were given the opportunity to rate the three tools, regardless of whether they had used them or not. The results of this rating are presented in Figure 2. For example, the "assembly drawing" receives the lowest average value from the group that had technical drawings as the only tool available during the group work (left in green). Among the groups that used a combination of technical drawings and 3D CAD model or haptic model, the assembly drawing was considered to have more potential. Within their evaluation, the three main groups give the "haptic model" the most points (right). The students' wishes would reflect a similar picture. All the students who had the technical drawing as a tool would have liked to have had the haptic model. In the 3D CAD model group, 13 % of the students were satisfied with their tool, 37 % wanted the haptic model and 50 % wanted a combination of the two. The haptic model tool was considered sufficient by approximately 66 %, 22 % would have preferred the 3D CAD model and one student indicated a desire for a combination. When asked about additional tools, the following were mentioned: a video about the production and usage of the assembly, reference literature, a parts list and a discussion during the exercise.



Figure 2. Average of points per main group for the evaluation of "assembly drawing" (left), "3D CAD model" (middle) and "haptic model" (right)

Whether the students' preferred tool, the haptic model, is sufficient and/or should be combined or supplemented, depends on the GPS content to be taught, the desired competences/competencies, and the requirements of the educators and learners. Figure 3 shows the relationship between these four factors in the development of a learning kit or rather an optimised teaching/learning concept.



Figure 3. Factors in the development of a learning kit

The content of the GPS standards system can be allocated to various subject areas. The knowledge test (concepts, principles and rules, datum system, dimensional tolerancing, envelope requirement, surface texture) covers these not completely. A more comprehensive proposal for GPS content can be found in [18]. Tools that can be used alone or in combination with the concept include, for example: Measuring equipment and gauges, AR/VR, videos, (learning) games, 3D printing, simulations and model-based definition. It is also necessary to consider the competences/competencies that are to be acquired through the teaching/learning concept. In addition to the competences of the six categories according to Anderson et al. [26], the broader definition according to Heyse et al. [27] in terms of competencies must also be taken into account. What are the requirements for the learning kit and which groups define them? Findings on educators' and learners' wishes have already been presented in Chapter 2.2. Further requirements could be modularity, but also the broadest possible coverage of GPS content. A level structure of the learning concept (as in [28]) or a consideration of prior knowledge may also be required. Based on the students' evaluation, it was shown that haptic models are preferred as a tool for learning GPS, especially for understanding the subject of datum systems. However, the investigated learning kit does not focus on GPS, but on the assembly. Therefore, an optimised teaching/learning concept is presented, which features a combination of different tools. A connection with the verification of GPS is created by enclosing gauges. This will help students to understand the envelope requirement and to carry out a gauge check. By incorporating measuring machines like the Keyence XM-2000 [29] into the concept, the students' competences can be expanded. The previously named measuring machine, shown in Figure 4, is a mixture of coordinate measuring machine (CMM) and hand-held measuring device. Associated features, tolerance zones and deviations can be visualised with the help of AR and the 3D model. After completing this practical training, students will be able to apply their knowledge of measurement methods to the measurement task at hand, understand tolerance zones, evaluate deviations, and be trained in teamwork and digital applications.



Figure 4. Geometrical measurement with a hand-held CMM with AR visualisation

By adding multiple parts produced with different processes to the learning kit students can be sensitised to different manufacturing methods and their deviations in dimensions and surface textures. Due to this component variations students can understand their effect on the functionality and the concept of fits by using punches with different fit sizes. Incorporating videos on topics such as manufacturing, usage of the assembly and measuring equipment and technical drawings can make even more subject areas of the GPS standards system easier to understand and more accessible to students, regardless of time or location. These videos can be made available on a digital learning platform. In this case, a self-assessment could help to individually recommend the digital content that is needed in advance.

Limitations of the case study are the small number of students participating in each group and a similar previous knowledge predetermined by the curriculum at the University of Wuppertal. Results may vary with a larger sample size and the composition of the groups in terms of prior knowledge, i.e. training in a technical profession or core areas in other universities' curriculum.

#### **5** CONCLUSIONS

Student evaluation as part of the case study provides evidence that haptic learning still has potential. In combination with digital teaching and visualisation techniques, the complex field of GPS can be made more accessible. The teaching concept described above now needs to be developed in detail and tested for the examples mentioned above. This also requires further scientific analysis of the proposed concept in terms of feasibility on the one hand and the requirements for the underlying didactics on the other. As a first step, it is necessary to determine the desired competences and competencies for each individual subject area of the GPS standards system. The next step is to identify the present competences and competencies of the individual students. In the long term, implementation may require changes to the overall teaching and learning environment and to the module handbook. This has the potential to link with other engineering subjects and thus improve engineering education in general.

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### CO-DESIGN AND ARTIFICIAL INTELLIGENCE: A METHOD TO EMPOWER END-USERS IN VISUAL COMMUNICATION

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#### ABSTRACT

Co-design brings designers, end-users, researchers, and other pertinent stakeholders together to forge meaningful design solutions. It dismantles traditional barriers between professional designers and endusers by fostering collaborative, participatory design development processes. This paper explores using an AI visualisation tool, Vizcom, in a co-design workshop. The tool helps participants without visualisation skills to convert their rough sketches into refined visual representations. Thirty-six undergraduate students from Brigham Young University across ten disciplines participated in the study. Participants were introduced to the principles of co-design and the functionalities of the Vizcom, including how to create accounts, craft effective textual prompts for AI, and adjust the drawing influence parameter to optimise the visualisation of their ideas. Participants worked in pairs, designated as "users" and "professionals." Prompted to reflect on their campus lunch food heating experiences, users shared insights with professionals who conducted interviews to pinpoint specific problems. Following this, professionals and users brainstormed solutions together. The users then sketched the proposed solutions, guided by the insights and ideas discussed during their collaborative session. After completing their sketches, they used their mobile phones to upload their sketches and detailed prompts into Vizcom, generating visual representations of their concept.

The study collected feedback from both professional and user roles through separate surveys, assessing the effectiveness of the AI in capturing and enhancing their conceptual solutions. The findings suggest new avenues for co-creation in product design, emphasising the potential of AI tools to bridge the gap between rudimentary sketches and sophisticated visual outputs.

*Keywords:* Collaborative product development methods, Vizcom research, product visualisation, sketching with AI

#### **1** INTRODUCTION

Co-design focuses on dismantling the traditional barriers between professional designers and end-users by fostering collaborative, participatory design development processes [1]. The goal is to democratise the design process, ensuring that end-user perspectives shape the outcomes of a design process [2]. In turn, this practice promotes an inclusive design environment, focusing on participants' collective creativity and insights, emphasising contributions from those without formal design training in product development [3]. A prominent co-design researcher, Liz Sanders, has significantly contributed to promoting participatory design and co-design principles. Her methodology transforms users from passive informants to active co-creators through accessible and engaging tools such as drawing, modelling, and manipulating tangible materials. These tools encourage participation and serve as concrete reference points that aid in discussions, guide direction-setting, and support decision-making processes [1].

Designers are trained in sketching as a visualisation method essential to the design process [4]. Recent developments in artificial intelligence (AI) tools in visual communication, particularly in design sketching, introduce new possibilities for co-design methods by providing untrained sketchers with a tool to help them visualise their ideas [5]. These AI tools serve as intermediaries, enabling individuals who may not possess formal design or visualisation skills to communicate their concepts effectively. AI

enables rapid generative visualisation of a participant's abstract ideas into coherent visual forms, thus expanding the co-design process in new ways [6].

In product design, "product visualisation" refers to various graphical representations to conceptualise and convey design concepts, solutions, and product features throughout the design process [7]. Visualisation involves techniques and media tailored to meet the needs and capabilities of individuals involved in product development, including industrial and engineering designers. These visualisations can range from basic analogue sketches to sophisticated 3D CAD models that facilitate clear and effective communication between designers and stakeholders [7]. Visualisations enable design explorations, assess feasibility, and ensure ideas are conveyed accurately to technical and non-technical audiences [8].

Incorporating sketching by users, even those without formal training in visualisation, at the early stages of the co-design process significantly enhances their engagement, allowing them to actively participate in shaping the initial design concepts [9]. This paper explores the relationship between participants with rudimentary visualisation skills and an emerging AI visualisation tool called Vizcom in a co-design workshop. Vizcom provides non-sketchers with a tool to visualise their roughly drawn ideas rapidly. We expect this will uncover new methods of co-creation activities that could evolve traditional product design processes. Our research focuses on the participants' viewpoints regarding the value of this process on collaborative concept creation and design process effectiveness.

#### 2 METHOD

#### 2.1 Participants

Thirty-six undergraduate students from Brigham Young University, comprising eight females and twenty-eight males, participated in the study: twelve from Industrial Design, six each from Computer Science and Mechanical Engineering, two each from Electrical and Manufacturing Engineering, four from Entrepreneurial Management, and one each from Philosophy, Machine Learning, Economics, and Information Systems. Participants received no extra credit or compensation and were free to withdraw from the study.

#### 2.2 Procedure

#### 2.2.1 Co-Design Process

Participants were presented with the concept and process of co-design through a short presentation. Students were put into pairs, taking the role of "professional" or "user." While the professionals may have varied levels of visualisation training, the critical factor was that the 'users' lacked formal training in visualisation techniques.

#### 2.2.2 Vizcom Al Sketching Guidelines

Participants were taught effective sketching practices for the AI tool to interpret. They were instructed to draw clean, bold lines, including key product features, one idea per page, fill the centre of the page, and not lay marks near the page edges. The emphasis on clarity and scale aimed to mitigate common issues associated with AI processing, such as the misinterpretation of text and poorly defined sketches.

#### 2.2.3 Prompt Construction and Influence

Participants were introduced to the nuances of crafting textual prompts for the AI. The instruction highlighted the impact of word order on the AI's output, advising a strategic arrangement of descriptive terms to guide the AI towards the intended visual outcome. Additionally, participants were advised to adjust the drawing influence parameter (a slider tool in the software), ideally between 60-70%, to balance the authenticity of the original sketch with AI-generated enhancements. This iterative adjustment process encouraged participants to experiment with and refine the AI output.

#### 2.2.4 Interview and Ideation

Initially, the professional conducted a comprehensive interview with their user counterpart to gather indepth insights into the users' experiences and specific requirements regarding the prompt, "heating food on campus". The professionals were advised to use open-ended questions and probe further into brief responses from the user to acquire a deeper understanding.

#### 2.2.5 Collaborative Sketching

Following the interviews, participants began a collaborative sketching session to solve an issue identified in the interview phase. The professionals used notes from the interviews to prompt the user while they sketched a product concept. Participants were provided paper and black markers to complete their sketches, Figure 1.



Figure 1. Selected user sketches of an on-campus food heating product concept

#### 2.2.6 Al Integration

Participants uploaded their sketches and detailed prompts using their mobile phones to the Vizcom AI, which then used its algorithms to generate visual representations of the solutions envisioned by the users. Participants were encouraged to adjust the prompt language and influence settings iteratively until they were satisfied with Vizcom's output, Figure 2.





#### 2.2.7 Reflection and Feedback

Each team presented their rendered outputs and the original idea sketches to the class, who provided feedback on the projects. The workshop moderators also solicited input from the class regarding their experience.

#### 2.3 Data Collection

Professional and user participants completed separate surveys, provided their interview and sketch session insights, and wrote notable observations during the AI visualisation process. Additionally, participants were asked twelve questions to assess the degree to which they believed the AI-generated visuals reflected their concepts. They used a five-point Likert scale for quantifiable measures and open-ended questions for qualitative insights.
## 2.4 Analysis

A mixed-methods analysis was used to assess data. Qualitative inputs such as interviews, sketches, and reflections were thematically analysed to identify perceptions and outcomes of the AI-assisted design process. Quantitative data from user feedback ratings was analysed to assess overall satisfaction with the AI-generated representations.

## 3 RESULTS

## 3.1 Analogue Sketching Effectiveness

A rating of 3.72 out of 5 indicates that participants viewed sketching as somewhat effective for visualising ideas. While sketching is generally seen as beneficial, there is variability in its perceived effectiveness across participants, and the efficacy of sketching was not uniform across all aspects of idea representation. Some participants reported that while conventional elements were captured well, the ideas' more innovative and abstract parts were not as successfully communicated. One participant pointed out that "The microwave part [was captured the best by my sketch] ... The innovative parts were not captured well by my sketch," implying that while certain conventional elements were effectively depicted, the more innovative aspects of the idea were not as successfully communicated. Further, respondents noted that sketches effectively depicted "The general shape, little features I thought of adding," and "The essence and spatial placement of entities," indicating that sketches were particularly adept at capturing basic shapes and the spatial relationships between different components of an idea. These responses underscore the strength of sketching in conveying the foundational elements and spatial dynamics of ideas, even as it may struggle with more abstract or innovative aspects.

## 3.2 Collaboration Effectiveness

The co-design session received an average effectiveness rating of 4.6 out of 5 from participants, indicating successful collaboration. This high score reflects the session's inclusive and structured nature, which enabled active engagement and shared decision-making, resonating well with the participants.

User participants felt a strong sense of belonging and contribution to the process. One participant's feedback illustrates the session's impact: "It was super valuable! I felt heard and that my problem was being addressed by someone who wanted to help me." Such expressions underscore the personalised and attentive approach of the session, diving deep into individual concerns and facilitating a meaningful design process. As another participant noted, the ability to articulate personal experiences and challenges, "Talking about my experience helped me find the pain I had," enhanced collective understanding and provided individual insights, demonstrating the transformative potential of collaborative design practices.

Professional participants reported the session presented a unique set of challenges, particularly in guiding participants without imposing on their creative autonomy. The delicate balance required in the facilitation process is captured by one professional's reflection on the difficulty of "Jumping into the interview - pushing a concept while also just wanting to get their insights," demonstrating the struggle to encourage independent thought and creativity while resisting the urge to lead their thinking. Another participant noted "the challenge of prompting participants to start drawing without suggesting specific ideas further," emphasising the professionals' endeavour to reduce their bias in the co-design process. Moreover, the transition from closed or leading questions, " highlights the shift required in their approach to communication. The session environment served as a pivotal learning experience for professionals, teaching them the importance of maintaining an unbiased stance, crafting open-ended questions, and adeptly guiding participants through the design process.

## 3.3 Al-Render Effectiveness

Vizcom scored a 3.7 out of 5 for accurately conveying user ideas. This moderate level of satisfaction indicates areas for improvement. Qualitative feedback from participants cited instances where the tool missed crucial contextual elements and struggled to interpret abstract design elements, highlighting the need for improved algorithmic understanding of user inputs. Additionally, participants desired more lifelike and detailed visualisations in the tool's rendering capabilities. One participant noted, "The render looks impressive, but some of the details are off, like heating bread- the wavy heat lines were interpreted as cables."

### 3.4 Varied Discipline Response

The study evaluated students who were trained in visualisation and others who were not. Industrial Design (ID) students rated themselves more comfortable than the other disciplines presenting a Vizcom render. Of the other disciplines, 18% stated they were "uncomfortable" to "very uncomfortable" presenting their ideas with Vizcom. In contrast, none of the ID students stated they were uncomfortable presenting the AI-rendered image. All disciplines generally recommend Vizcom as a tool for co-designing sessions in the future; however, Industrial Design students are a more likely scoring 4.5 out of 5.0.

# 4 **DISCUSSIONS**

## 4.1 AI Performance and Integrity

Participants stated that although Vizcom could capture the general idea of their concepts, it missed specific details or original elements. We expect that as AI technology improves, its ability to interpret and visually represent user-generated ideas will become more precise. The emergence of AI in the design realm presents opportunities and challenges regarding performance and conceptual integrity. AI algorithms will need to discern and translate the nuanced intentions behind user sketches and prompts while ensuring that the essence of the original idea is amplified, rather than lost, through the intervention.

### 4.2 Al as a Co-Design Partner

The increasing use of generative AI in design is introducing a new era of collaboration where AI is seen as a partner rather than just a tool. This partnership requires human input to prioritise design aspects such as empathy, intuition, and subjective judgment. AI can potentially provide valuable insights and connections that can be easily accessible. When designers treat AI as a partner in the design process, they can use its computational power and data-processing abilities to explore a broader range of design options, fostering a collaborative partnership where human creativity and AI intelligence complement each other to achieve potentially superior outcomes.

### 4.3 Balance in AI & Designer Partnership

Using AI as a tool for co-creation between users and designers raises concerns about its long-term efficiency and effectiveness. While AI has the potential to streamline the design process significantly, there is a threshold to its utility, particularly if the input of ideas and information from users does not yield productive concepts. This scenario prompts a critical examination of whether AI's usefulness in the creative process is finite, especially considering the time invested. It brings to light the possibility that a designer adept in research methodologies and rapid visualisation techniques might offer more value in specific contexts. This comparison prompts the creative industry to weigh the benefits of AI against the nuanced and irreplaceable human touch that a skilled designer brings to the process.

### 4.4 Improvements to the Co-Design Vizcom Process

To enhance the co-design process with Vizcom, AI users should be given more time and opportunities to engage with the tool than our one-hour workshop allowed. As users become more familiar and comfortable with AI-assisted design, they will utilise its capabilities more effectively. Additionally, facilitators leading co-design sessions should refine their skills to foster an environment that encourages open dialogue and unbiased exploration of ideas, explicitly training facilitators to ask open-ended questions and minimise their influence on the creative direction of the session. Extending the co-design experience beyond the classroom and involving real-world users can provide invaluable insights and feedback, grounding the design process in user needs and contexts.

## **5 CONCLUSIONS**

According to the study, incorporating AI tools such as Vizcom in the co-design process presents potential benefits but notable limitations that require attention. The findings expose the necessity for significant enhancement in AI's capacity to comprehend and visualise intricate human inputs. Nonetheless, as AI tools advance and improve their accuracy in response to the complex output of human imagination, our design processes and interactions with AI will inevitably evolve.

It is crucial, however, to ensure AI tools complement rather than replace human creativity. One participant noted, "The AI tool is a great addition to our toolkit, but it must support rather than override the creative process." Introducing AI into the co-design process can allow designers, end-users, and AI

to work together to develop innovative, user-centric solutions that reflect collective input. This study exposes opportunities and issues in implementing this method in future co-design practice.

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# CO-DESIGN WITH PERSONS WITH DISABILITIES AS AN INNOVATIVE RESOURCE SET FREE BY AI

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## ABSTRACT

UN's Convention on the Rights of Persons with Disabilities (CRPD) states that persons with disabilities should be allowed to develop their creative and intellectual potential, not only for their own benefit but for the enrichment of society. It means the right not to consume what others have created but to share one's own ideas, aesthetic expression, and intellectual work. Our thesis is that there is an unused potential in persons with disabilities. What if designers saw the world of a person with disabilities as a resource of diversity rather than a lack of normality? What if designers would tap into this resource of perspectives on everyday life to the innovation of technology? We would like to understand if AI could unleash the potential of persons with disabilities, by visualising and translating between people and technology. We discuss conversational and multimodal AI used for persons with learning and language disabilities, including AI visualization techniques. We aim to prepare for software re-design, translating between text-based services and symbolic language, the so-called Augmentative and Alternative Communication (AAC). Our case is a family with a young adult with learning and intellectual disabilities using AAC for social activities such as hiking. We find both barriers and potential. Barriers to harnessing the unused resources are due to traditional Co-Design methods, excluding persons with other languages than verbal and text. It is weighed up by the potential of AI to democratize through a certain lack of prejudice and norms, which make it easier to interpret, create, visualise, and share.

Keywords: Inclusive design, AI, co-design, alternative and augmented communication, innovation

# **1** INTRODUCTION

## 1.1 "For the enrichment of society"

The right to share with others what you have created, is written into the UN Convention on the Rights of Persons with Disabilities [1]. The rights to share have two benefits:

- 1) For the individual, the benefit of sharing is increased Health Promotion [2] and wellbeing through increased self-efficacy expressing yourself creatively and in a social group [3].
- 2) It benefits the community to recognise everybodies' work, ideas and expressions as valuable resources, "for the enrichment of society" [1]. When designed thoughtfully, design for one particular user in mind, can be turned into commercially successful Universal Design, reaching a diversity of persons in different groups [4]. An example is the magnifying glass, made for a visually impaired person, that is used by elderly persons and at night with poor lighting by everybody. That is an innovation process of expanding design for an individual's needs to a universal design for the many.

## 1.2 Co-Design and Innovation through Diversity

Participatory Design and today's development into Co-Design has since the 1970s been part of a Scandinavian design tradition [5] to develop a democratic and socially sustainable technology. The traditional design process of products and services is often linear and divideded into phases of insight, defining and development. It is led by professional designers and engineers and tested with users. A Co-Design process, with focus on democratic values and social sustainability, is much more fuzzy. In Co-Design tools and methods are avilable to everybody, including expert, designers and users. Co-Design uses: *1. probes* to involve users early on in pre-design phase, *2. toolkits* involving all in generative processes of making and relating, *3. prototypes* in an evaluative phase to create and test concepts in real

life settings [6]. There is, however, a gap between vision and reality. Many persons with limited abilities to communicate verbally and to read and write are not included in traditional Co-Design and brainstorming sessions. It is because most Co-Design work is based on text on post-it notes and verbal discussions in groups or online [7]. However, based on research findings in the prototyping of multisensory Co-Design projects, we know that it is possible for persons with learning and language disabilities to share their creative and intellectual work with others in a design session [8]. The consequence of exclusion from sharing ideas, intellectual work, and expression is the individual's loss of power over the own life situation. It is also the loss of a diverse resource and to learn from people that experience the workd differently and that could benefit many others. The "Co" of the Co-Design is reduced to empty words.

### 1.3 Case: Co-Design Use-stories with Family and Young Adult with Disabilities

"Linda" is a young adult with learning and intellectual disabilities, with limited verbal language and reading and writing skills. We have been following Linda and her family, her mother and father, for a year, and helped facilitate two Co-Design workshops and participated in outdoor hiking activities with the family and their community in Norway. We have also developed new Co-Design methods with Linda and her family. Throughout these activities, we have investigated how we can learn from Linda and her family's experiences. The work has resulted in Co-Design method development, presented earlier in a master thesis in Interaction Design by one of the authors of this paper [8], also as part of the EU-project RurAllure report [9].

Up to the age of 18, all Norwegians have access to learning technologies, tools, and leisure activities, sports and cultural events, through their local schools. When leaving school, many persons with disabilities loose connection with friends and social life and are not anymore included in processes where they are asked to participate, also outside of school. Only a select few are offered jobs and gain entry into new networks in society. This is the case for "Linda", who still lives with her parents and is dependent on their goodwill to meet with people and get involved in activities. Linda uses Augmentative and Alternative Communication (AAC), symbol language, both physical talking cards (fig. 1) and an interactive tablet, TD Snap [10]. With the tablet and the way the symbols are built up as a natural language with the possibility to choose verbs, nouns, adjectives, etc., Linda speaks in full sentences, expresses herself and her opinions, creates new concepts and ideas, and shares those with her family.

To be able to connect with the world around her and to be able to choose what activities to do, she needs to know about the activities and be able to express what she wants. Linda's parents have founded a software company called SmartCognition [11], with the purpose of translating text to other multimodal outputs such as sound and symbols. So far, the texts about activities Linda and her peers can access have been manually typed into the application by personnel working at the local municipality and by Linda's mother, resulting in delays due to lack of time. The parents expressed that they wanted more involvement from Linda and that she needed to be able to make decisions concerning her own life and how she spent her leisure time. We explored various options and recommended that Linda plan a hike along lake Mjøsa, heading to a location she wanted to visit, engaging in activities she enjoyed, such as having picnics, and more. Based on the principles of participation and Co-Design, we suggested arranging Co-Design workshops accessible to Linda and the whole family.

In a physical workshop with the parents, we tried out Co-Design and how to replace and complement some methods. We brainstormed and prototyped how a narrative would look based on the talking cards (fig. 1) made in a series of two workshops with Linda, her parents, and design researchers [7].



Figure 1. Talking cards are used in hiking situations to express meaning and communicate what you want in full sentences. From workshop with experts, parents, and designers, created by Cecilie Eide [7] based on the TD snap software[10]

Linda used the talking cards, combined them with hand-drawn pictures, and played out scenarios as a role play with all of us as her actors. Linda even put on music and staged a dance with all of us. Linda ended with a picnic and a snack together at one of the tables full of drawings, symbols, and talking cards.

## 1.4 Augmented and Alternative Communication and Artificial Intelligence

Artificial Intelligence AI has long been integral to AAC systems, enhancing communication for individuals with disabilities. Evangeline et al. [12] underscores the impact of AI-driven AAC tools through their systematic literature review. They point out a notable gap, highlighting the lack of AAC solutions that seamlessly combine speech recognition and reconstruction within a single device, catering to partially and fully speech-disabled users. This gap, however, is not a barrier but an opportunity for inclusivity. Complementing this, Valencia et al. [13] suggest that AI technologies, specifically large language models (LLMs), can significantly enrich AAC by improving the quality and diversity of textual suggestions provided to users. These concepts aligns with the potential of generative AI to empower people with disabilities, enabling their active participation in co-creative activities.

# 2 METHODS

We searched for relevant literature and built further on the case based on workshops with a family with a young adult with learning and intellectual disabilities. Finally, in Table 1, we compared the different technologies' innovative potential qualities to be health-promoting for individuals, enriching for others and society and their individual degree of diversity, and based on culture and social values.

## 2.1 Literature Describing AI with Persons with Disabilities

The last time AI was popular in 1986, Dreyfus and Dreyfus wrote about how computers «...radically have increased the abilities of seriously disabled children to function in normal school environments, by allowing, for example, students to work on microcomputers equipped with special input devices. Reading machines for the blind are already available, as are machines that help the deaf learn to speak, and artificial vision systems which translate TV signal into tactile images on the user's back, are in development.» [14] We believe that AI, 38 years later, could be used to empower persons with disabilities to communicate and taking part in planning, expressing ideas, and all the Co-Design processes of pre-design in *probes* with users, *toolkits* for generative processes and *prototypes* in real life testing [6].

We made a search in the databases ACM and PubMed for the combination of the terms Artificial Intelligence AND Disability (OR Accessible) AND learning (OR intellectual) for the years 2019-2023. We did another search, also including AAC. We found eight relevant papers and articles describing the innovative uses of AI together with the target group. Three of the papers are described in Table 1 and

the main concepts in each lifted up and compared with the concepts of the physical card and the SmartCognition software.

## **3 RESULTS**

### 3.1 Al-fying Language Models and Multimodal Interaction for Diversity

The innovative concepts for AI-based large language models (LLMs) and conversational agents in the papers were mapped and compared to the existing software and the physical Talking cards used in the two workshops with the family and the young adult Linda (see Table 1).

In describing the different innovations in Table 1, we include both technologies and theoretical concepts. We have rated *Diversity*, *Health Promotion*, and *Enriching Society* from 1 to 5, where 5 is the highest rating. Cecilie Eide's [8] physical Talking card (fig. 1), used in workshop one and developed further in workshop two, is in its simple form, easy to understand and view as long as it is relevant to the situation and task you will perform. The fact that the card is printed on paper and not possible to change makes it static and eventually obsolete as the situation changes. On the card in Figure 1, the symbols are all to be used in a hiking situation out in nature. Some may be relevant in a walking situation in the city, but much will be irrelevant in, let's say, a choir practice situation. It is easy to master the talking card and therefore Health Promoting for an individual as it promotes self-efficacy and the feeling of accomplishment and mastery [2, 3]. In its physical form, it is slow to use and distribute and is not enriching for many more than the person using it.

Technology (AI, Physical, SW)	Diversity (1-5)	Health Promotion <i>Individual</i> (1-	Enrich society by <i>sharing</i> (1-5)	Innovation (technology, theory)	Reference
Physical	2 (static)	3 (easy to master)	3 (slow)	Talking card, mobile	Eide 2023 [8]
AI	4	4	3 (individual focus)	HCAI – human computer AI	Shneidermann 2022 [15]
AI	5 (social, prototyping)	3 (master for limited group)	5 (potential for social interaction)	Tinkerable AAC	Yang 2023 [16]
AI	2	5 (master for limited group)	3 (individual focus)	Speech recognition & reconstruction	Evangeline 2024 [12]
AI	4	3 (master for dialogue)	5 (potential for social interaction)	LLMs Speech Promts AAC	Valencia 2023 [13]
Software	3	2 (delay)	3 (local, manual)	Database text, symbol, sound	SmartCognition [11]

Table 1. Al-fying Co-Design technology for sharing

Ben Shneiderman's [15] theoretical concept of Human-Computer AI (HCAI) wants to ground AI in Human values (rights, justice, dignity) and individual goals (self-efficacy, creativity) and threats for the individual. However, it is less focused on society and sharing with others. It would need to be tested further in the development of software for sharing to see if it works outside a single-user situation. Boyin Yang's [16] Tinkerable AAC is a concept that scores highest on Diversity and Enrich society because of the potential in Co-Designing and sharing during participatory workshops with users with diverse backgrounds [8]. The idea that prototyping is made social and that we open machine learning training for users to participate in is fundamentally democratic and based on the principles of Participation and Co-Design [5, 8]. To be truly participatory, the user should be offered to participate in rule-making and policy-making activities, as well as in the execution and playing out of the rules. For individuals with speech deficiencys Evangeline [12] want to see more AI-based AAC solutions in speech recognition to speech recognition and reconstruction with contextually relevant outputs in speech and pictograms. Valencia [13] successfully used AI to design and test Interactive

Speech Prompts to extend short conversation prompts, written by a person with disabilities, into full sentences, to add biographical data and to quest for more feedback. They also included Pictograms in combination with written text to speed up and motivate to a seamless and smooth conversation between persons with and without disabilities. Compared to the other options, Smart Cognition's traditional software without AI capabilities is a straightforward database with a rule-based system for selecting symbols, sounds, and texts [11]. Because it is manual labour, it is also vulnerable to delays based on the person who types the text and makes the connection. It is the least rewarding option.

### 4 **DISCUSSION**

We think that the future development of an AI-fyed SmartCognition software for translating between text and symbolic language and multimodal communication (AAC) should be Tinkerable [16]. Tinkerable in the *pre-design* and *generative* phases of Co-Design [6] in the sense that you are motivated to participate in Co-Designing the rules for how the AI should learn and operate. AI should also involve the individual mastery of physical and multimodal interaction, such as with the talking cards, expanded with sensory input, and also be flexible for social play, with possibilities to detect and include activities such as Linda's staged and improvised dance and role play from the workshops.

As our case was a family with a young adult with learning and intellectual disabilities using AAC for social activities such as hiking, we will still find both barriers and potentials. This will also be the case in future automated AI applications. We think the potential of AI is to democratize through a certain lack of prejudice and norms that make it easier to interpret, create, visualise, and share. What innovative resources could designers and engineers tap into if we invited persons with disabilities to Co-Design future machine learning algorithms for AI?

In all the Co-Design phases (*pre-design*, *generative* creative, *prototyping* and evaluating real life testing), we believe AI could healp spead up dialogue, e.g. with Valencias [13] use of speech prompts and the possibility to speed up the response time for the person with disabilities.

The main take away is that AI-based Augmentative and Alternative Communication (AAC) is in an early stage of development, in need of more explorations, but with many promising possibilities. Possibiliteis for school, learning and other context sensitive use-situations. The main finding from the literature study is that the AI-technologies miss case studies in all areas, for all tasks, users and contexts. We suggests thet these explorations and case studies involve users with disabilities in Co-Design processes, to get as much relevant knowledge as possible.

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# BRIDGING THE RELATIONAL GAP: SYSTEMIC DESIGN AND AI, SPARC-ING SUSTAINABLE EDUCATION IN UNIVERSITIES

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## ABSTRACT

This paper gives perspectives on the use of systemic and product design methodology combined with AI as a tool to facilitate an inward examination of university organisational structures. The paper attempts to provide a deeper understanding of the existing challenges and the necessary adaptations to contribute to the development of a sustainable society within the university system. This research is derived from SPARC, 'Sustainable Partnerships and Research Collaborations', a student-led research pilot owned by Arbeidsforskningsinstituttet (AFI - Work Research Institute) and Oslo Metropolitan University. SPARC was created and led by three product design students collaborating with research assistants and research professors at AFI. The research seeks to design innovative approaches that address the complex interplay of elements within the stakeholders at fragmented organisational structures in the university. In the pursuit of this objective, the students shape AI using qualitative data gathered through explorative workshops involving various stakeholders at the university, which is at the core of the research. The article speculates and suggests the potential of design students to shape existing systems by utilising this approach in their product design education. This initiative is allocated to the following Sustainability Development Goals of the United Nations; 17. Partnership for the Goal and 4. Quality Education. Design approaches, along with advancing AI, provide a holistic examination of sustainable solutions by cultivating awareness and capabilities for action, developing partnerships, and improving educational quality within the university ecosystem.

*Keywords: Systemic design, product design, AI, partnership, stakeholders, systemic change, sustainability, universities, research, interdisciplinarity, social innovation* 

## **1** INTRODUCTION

In a contemporary context, the university has evolved into a dynamic living system, providing a habitat for a multitude of institutional entities and stakeholders. This includes students, faculty, researchers, as well as a varied array of academic and administrative departments. Universities have tried to adapt and respond to the evolving needs of a developing society whilst the academic community helps apply focus on what should be taught and researched. However, in their outward gaze, universities sometimes neglect to examine their internal dynamics, leading to a potentially static and hierarchical organisational structure in a rapidly evolving society.

The triple Helix presents a model which relies on industry, governments and universities, as the entities with the power to create innovation based on their interactions [1], with universities being the main actors for knowledge production and delivery. Moreover, Elias G. Carayannis and David F.J. Campbell (2010), develop the Triple Helix into the Quadruple Helix [2], by adding the societal sphere, media-based and culture-based public, and further, the Quintuple Helix [3] including the dimension of natural environment, acknowledging socioecological interactions [4].

While recognising government, universities, society and environment interactions as the driving core for innovation, analysing this system through a magnifying lens is crucial for their understanding. Micro-relationships are the ones making the system operate, and their value is being increasingly perceived [5], after all, micro-relationships between individuals are the ones making the systems function.

This paper puts the scope on the micro-relationships of universities, believing in universities as innovation houses of "knowledge intermediaries, knowledge gatekeepers, knowledge providers, and

knowledge evaluators" [6]. Showcasing SPARC's activity, Sustainable Partnerships and Research Collaborations, the research explores system-oriented methodologies, as a groundwork to study universities own practice, and is designed to empower micro-relationships between multi-stakeholders; trusting, that a change at the university level can impact the quintuple helix interaction. Hence SPARC recognises sustainable values as essential for an operative interaction system, aligning with the 17th of the Sustainable Development Goals of the United Nations, Partnership for the goals: Strengthen the means of implementation and revitalise the Global Partnership for Sustainable Development. In addition, SPARC, a student-led research project, aims for the change for the 4th SDG, Quality Education, which is incorporated not only in the aim but also in the research methodology.

## 2 LITERATURE BACKBONE: SYSTEMIC DESIGN AND AI

Tame problems are stable problems which are defined to have a single aim to be solved and which can be objectively evaluated [7], however, when trying to look deep into gaps and barriers within the systems, we find the 'Wicked' problems [8]. Wicked problems are those ambiguous issues whose root is tangled in different systems, for example, in cultural, political and economic systems. Hence, clear definitions and procedures of wicked problematics is often as complex as finding their solutions. In response, the practice of systemic design or system-oriented design, offers design-based methodologies for holistic analysis and knowledge creation. Systemic design can be defined as a "design-led practice that integrates dialogue in co-creation for sensemaking and decision-making" [9] In this case, the wicked problem that we're designing interventions for at SPARC is the issue mobilising higher education to take on stronger roles and adjust their structures to work towards the SDG goals [10].

Due to technological advances and the launch of open AI sources such as ChatGPT, the edge of Artificial intelligence (AI) has now been unlocked and popularised. AI is mostly being developed to function independently from human intelligence for task fulfilment; however, even with AI's efficacy when facing tame problems, the use of AI on its own, is often not feasible to respond to the complexity of the "open-ended nature problems" we are facing, problems we could once again refer to as wicked problems.

Although, nowadays Artificial intelligence can't completely substitute human intelligence unassisted for the solution of wicked problems, AI tools could be highly beneficial for their research. Intelligence amplification (IA), also known as Augmented intelligence, is a type of AI that aims to enhance human intelligence by working alongside it, thus, it doesn't want to replace humans but assist them. For instance, generative AI can create content and ideations, which in collaboration with human experiences, could help to address actual challenges in decision-making processes [11].

Furthermore, Hybrid Augmented Intelligence (HAI) [12], is born from the synergy between human cognitive capabilities and AI models, acknowledging the need for human comprehension in problematics that machines cannot unfold. There are two main models of HAI: 'Human-in-the-loop', an AI and human-collaborative model in which artificial intelligence provides the analytical information, while human intelligence is intuitive and empathetic, and 'Cognitive Computing-Based' IA, an AI with a designed cognitive model mimicking humans [13].

## **3 CONTEXTS OF THE CASE STUDY**

SPARC is a student-led project created in collaboration between Oslo Metropolitan University, and AFI, Work Research Institute. SPARC's platform consists of researchers, scientific assistants and students, researching OsloMet's practice and strategies in the area of social environment, communication and collaboration. Research on the already existing practice for collaboration at academic grounds internally and also externally is included in its objectives together with the exploration and the design of new collaboration formats in education. With the diverse transdisciplinary skills and academic backgrounds of the team members, various outcomes are designed, such as the design of concepts for collaboration, based on the experience from conducted workshops, and the needs of students and staff employed at different units and departments of the university; design for the implementation of OsloMet's strategy goals and frameworks; and the holistic location of concepts about border systems of the university.

SPARC was ideated from a pilot project by researchers at Arbeidsforskningsinstituttet in unison with a team of students majoring in Design and Complexity at OsloMet in 2023. This pilot opened an arena for a student-led exploration of the systems at university, thus, students were invited to explore the ecosystem they were part of, aiming to find and shift, the barriers, silos and gaps OsloMet faces.

Using systemic design methodologies and analysis, students from SPARC have designed different practices for sustainable collaborations among different stakeholders at the university: this research showcases "SPARC AI", an AI-generated persona whose knowledge gathers all the collected data through the previous workshops led by SPARC.

## **4 METHODOLOGIES**

Using systemic design methodologies and analysis, such as stakeholder mapping, and participatory workshops, students from SPARC have designed different practices for sustainable collaborations among university stakeholders over a year, including workshops such as "What does sustainability mean?" giving voice to students, "Research-ship" an activation for researchers-students collaboration, and a pre-conference involving researchers, students, and professors as part of Storbykonferansen 2023. As follows, this research adopts an innovative methodology by using the collaborative qualitative data analysis gathered from previous workshops and processes in the collaboration between stakeholders, to generate the knowledge of the designed SPARC AI avatar. Furthermore, the AI avatar has been tested and evaluated by OsloMet's researchers, students and administrators for the ideation process on the possibilities of AI implementation at university systems.

# **5** IMPLEMENTATIONS

SPARC AI is an avatar that holds the co-created knowledge between stakeholders at OsloMet. For the creation of this avatar, students used 'Inworld AI,' [14] an advanced AI software designed for creating and shaping non-player characters within customised virtual environments, and 'Unreal Engine' [15], a game engine that can allow for real-time interaction and experiences. To develop the AI's 'brain' - how it talks and behaves logically - the process involved providing the character with a fundamental description that imbues the avatar with contextual awareness and gives them the needed knowledge to respond to the user needs for each service. Additionally, users can tailor the AI's personality by adjusting its default emotions and responsiveness to player input, allowing a precise design of the interaction dynamics.

SPARC AI was provided with anonymised knowledge and data collected through earlier workshops and activities conducted in the research pilot. The AI's goal was to provide users information about the SPARCs' pilot project data collection processes, methodologies, and the data sets of results through discussion. For example, the AI should be able to tell you all about a 'Research-ship' workshop that SPARC conducted. - The design of the workshop, what happened, and the conclusions and feedback gathered. Qualitative data had to be formatted into easily digestible facts for the AI to read, line-by-line. As the workshops that SPARC conducted involved innovative, co-creative exercises, such as developing posters and artwork in group settings, all data had to be converted into readable text form manually.

The AI character was then given a visual anthropomorphic body through Unreal Engine's 'Metahuman', allowing easy creation of a 3D, photorealistic digital human which can be fully integrated with InworldAI's 'brain', complete with lip sync and audio output. Using a realistic human appearance was decided as a tool to invoke deeper discussions, visualisations and interactions with stakeholders. Recent research suggests that using a more anthropomorphic design can lead to a higher degree of social presence with users [16], which would be advantageous when we want to discuss and ideate upon this AI with stakeholders.



Figure 1. SPARC AI service

## **6 DISCUSSIONS**

in a manner informed by the workshop data it was fed.

Universities are complex systems driven by the force of students, professors, research institutes, libraries and other actors and divisions making the organisation work. Hence, based on the strategies of OsloMet, the university states the importance of collaboration between stakeholders to improve sustainability and innovation. However, for these interactions to happen, SPARC advocates for a need to study and design new forms of communication that enable the system to be dynamic and flexible, increasing the efficiency of the existing resources, believing that; "In this new paradigm, the importance of knowledge is determined not only by competitiveness and productivity but by taking into account the creation of social welfare, the impact on quality of life, and the co-creation of knowledge as part of a partnership" [17]. SPARC's AI was tested with stakeholders within the university system, in particular, researchers, students and administrative staff. They were presented with the AI and encouraged to interact with the software and discuss their thoughts in a roundtable format. Stakeholders initially asked the AI about what it represented, finding more information on SPARC and what workshops the project did throughout the year. Afterwards, stakeholders began to ask broader questions on how to approach sustainable partnership, how to organise a workshop, or why the workshops were effective, and the AI replied back

For example, when asked why a 'speed dating' networking event between students and researchers went well, the AI responded with "... because it allowed them to find common ground and develop research questions together, leveraging their shared interests and expertise. This collaborative process fostered a sense of ownership and engagement, leading to meaningful and impactful outcomes." When more broadly asked for advice in developing sustainable partnerships, the AI responded with: "Sustainable partnerships can be fostered by creating spaces for dialogue, promoting shared values, and identifying common goals. By engaging stakeholders and building trust, we can work collaboratively towards a more sustainable future."

These answers prompted further discussion, however directed in a more universal fashion rather than the current form of AI investigated. During testing with stakeholders, new ideas arose on how AI could be integrated into the university system. Stakeholders discussed how a form of this AI could be utilised on a more macro level, having data from multiple research projects, so that students and researchers could communicate with the tool, ideate and gather connections on existing research projects. There was discussion on how this type of AI tool could be used at the administration level, to gather meeting notes and strategies from different departments at Met and disseminate the knowledge in a more digestible way. It could also encourage connections and related topics between different departments and at different levels of OsloMet's structure. Thoughts on multiple instances of this AI tool in various environments were examined, and how it can be used to ensure good quality education for students and an engaging workplace. Stakeholders noted the way in which the chatbot spoke, and the notion that there were no power dynamics when asking and receiving information. Stakeholders could discuss freely their thoughts and opinions on SPARC and spoke about how this sort of chatbot would be useful when asking questions you're normally too embarrassed or worried to ask. Questions arose on how an AI chatbot could be given 'neutral' data, as even things such as meeting notes can be biased depending on the person writing them. During testing and presentation, the AI could be seen using 'empty phrases', language which extended sentences, but didn't really provide more detail. Part of this is due to the amount of data inputted, and also due to the strict censorship settings, meaning the AI would try not talk about topics it had no data about. Thoughts followed on the importance of the data input into the AI, how many ideas should the AI be allowed to generate on its own, compared to reflecting the data, and if that could be different depending on the needs of the user. Could this AI chatbot be seen as a reflection tool, an ideation tool, or a relational one? Could it be hybrid?

Through the discussions, it can be noted that stakeholders viewed this AI software as a form of *Intelligence Amplification*, designed to enable users to understand a complex system and ideate alongside them, rather than *for* them. It could be argued that this prototype can impact the Quintuple Helix model by generating understanding and connections at a micro-relationship level, as the AI prompted a discussion between stakeholders on potential future systemic changes at OsloMet. There is large potential in this prototype to address the systemic wicked problem of transforming higher education structures towards the SDG goals, as seen in the discussion about the potential of this AI connecting amongst different levels at university. AI's such as this one, informed by qualitative, creative workshops towards sustainability, could help advise and inform educators and students on sustainable and design-informed ways of creating workshops and discussions that they may have otherwise not thought of.

The aesthetic design of the AI was not covered in discussions, however, may be seen as an important aspect of how users interact with the software and should be examined in future studies. The discussions and testing phase, whilst fruitful, could have involved more stakeholders in the university system, such as educators, course coordinators and librarians, to provide a much more holistic view. Whilst discussions naturally shifted towards a systemic and future perspective, there could have been more conversation targeted towards what makes this current AI iteration relevant and useful to stakeholders. The next steps for this AI would be more testing and development with researchers, educators and students to see how well of a tool this could be for those wanting to develop design-informed and active projects, workshops and research.

# 7 CONCLUSIONS

SPARC is a multi-stakeholder team that proposes new paradigms to re-arrange decision-making structures and processes at the university, providing arenas for co-creation through collaborative practices. These arenas require the participation of different stakeholders for their operation since diverse perspectives are essential to generate a common value. Highlighting the importance of micro relationships within university as innovation drivers, this paper showcases the latest approach of this research pilot that is driven by students utilising systemic design and AI as a tool to bridge stakeholders through a divided educational system.

SPARC AI offers a visualisation of how AI could potentially be used for service development at universities, even if this prototype is still an early model of AI as a facilitator in our relational and communicational systems, its design provoked new ideations and understandings among the stakeholders about how AI could be utilised beneficially.

Accordingly, this approach advocates for Hybrid Augmented Intelligence technological devices to foster solutions encompassing human cognitive intelligence and AI, understanding that AI cannot work independently to face wicked problems.

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# IMMERSIVE LEARNING IN AGRICULTURE: XR DESIGN OF ROBOTIC MILK PRODUCTION PROCESSES

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# ABSTRACT

During the confinement of COVID-19, learning about virtual and augmented reality grew exponentially; universities were the accelerators of this knowledge. Distance learning was the trigger to consolidate emerging technologies in education and professional life [1], including virtual reality (VR) and augmented reality (AR). Given the rising interest in virtual simulations, this paper targets authentic design challenges and how distributed collaboration may enhance the immersive learning potential by utilising network resource efficiency. According to the Institute for the Future of Education of the Tecnologico de Monterrey, in the Tec21 educational model, the most important part is the challenge, which is defined as a problematic situation posed by the partner trainer, and when analysed, a problem is defined by mutual agreement. The project is defined on this problem. One of our most essential training partners is CAETEC, where we carry out challenges ranging from precision agriculture to data science, experiment design, and forecasting [2] [3].

To 3D model this robot, we need to work with the former partner, whose headquarters are in Sweden, through a collaboration agreement between universities that pursue the same educational purpose. We will work with the University of Mälardalen on the design of the lessons and with the University of Mondragon on the interaction between humans and robots.

This research results from joint work between three educational institutions with a multicultural and multidisciplinary project approach.

*Keywords: Immersive learning, agriculture, XR Reality, Industry 5.0, higher education. educational innovative* 

# **1** INTRODUCTION

Due COVID-19 confinement, universities were the driving force for the surge in virtual and augmented reality adoption for education and professional use [1]. This paper explores how distributed collaboration enhances immersive learning and optimises network use in virtual simulations. In the Tec21 model, challenges set by partner trainers, like CAETEC, guide problem-solving and shape projects in areas ranging from precision agriculture to data science [2, 3]. The implementation of virtual reality (VR) is a growing concern in order to improve data visualisation for education and industry. The use of virtual flows and simulations through digital twins has shown importance for enabling new forms of interaction and efficiency, presenting a high correlation between its use and the increase in quality indicators and productivity [4].

## **2 BACKGROUNDS**

In recent years, the Tecnologico de Monterrey, through its new Tec 21 educational model, started in 2019, brought a new opportunity for the rise and use of new and emergent technologies globally. With these new technologies, it was possible to implement and train the current student population with our partner CAETEC (Experimental Agricultural Field from Tecnologico de Monterrey, Spanish acronym) to analyse and identify new efficient solutions. Doing so, it increases the range of opportunities for the

university and our partners to collaborate, share knowledge, and apply new current technologies to controlled study grounds allowing for the development of more complex projects regarding precise agriculture, data science, digital twins emulation, and create better design of experiments using current milk production processes.

CAETEC, despite being the largest laboratory at Tecnologico de Monterrey, has different restrictions on bringing entire groups to its facilities. So, one among the institutional projects is the development of a virtual plant, in this case, a virtual experimental agricultural laboratory to provide access to students, international & national collaborators, private companies, among others, to the facilities. The robots that are being used for milk production at CAETEC are manufactured by DeLaval, which is a Swedish company that currently is the world leading provider of solutions to enhance food producer farms. The company has had more than 125 years of experience in milk production innovation [5]. The term robotic milking system refers not only to the use of an articulated hydraulic arm but also to the concept of global automation of a facility and the voluntary assistance of the cows to the robotic milking module, also known as VMS for its acronym in English: Voluntary Milking System.

This interdisciplinary project has allowed academic collaboration between three universities to achieve the established objectives where the University of *Mondragon* will work with the impact between users and robots, thinking in a future context in which Mexican and other livestock farmers can replicate this technology. And both Tecnologico de Monterrey and Mälardalen University, collaborate to designed the digital twin for the VMS system and virtual reality lessons for the training of DeLavals Latin America employees and for students in the area of mechanical engineering, mechatronics, and digital systems, which all this areas are members of Tecnologicos de Monterrey School of Engineering and Sciences (EIC) Figure 1.



Figure 1. Process to interaction between universities and the process to get the project's findings

# **3 DEVELOPMENTS**

Through a digital twin that simulates the complete process of the milk production data is generated; starting from when the cow is in the stable, showing the station where the robot is, how the milking process is carried out, and the final moment when the cow returns to the stable. Data can be used for learning different topics, such as Design of experiments, Forecasts for decision-making, Inferential Statistics, Statistical Engineering, Data science, Engineering in the robotic milking system, and Integration of bio productive processes.

This digital twin consists of the simulator and the virtual reality practices, where students from campuses located in different sites can interact with the VMS system without the need to travel to CAETEC. If the students belong to the Tecnologico de Monterrey system, they can practise within the VR Zone of their own campuses, better known as Mostla. CAETEC currently receives applications to be a training partner of training units, mainly from the Engineering and Science schools of the Tecnologico de Monterrey's different campuses, specially form Querétaro campus, from the departments of Industrial Engineering, Mechatronics, Robotics, Agronomy, and Biotechnology. Nonetheless, it also receives requests for visiting CAETEC from other universities and research centres. It has experimental fields for extensive agriculture (open sky), mainly corn, where different precision agriculture technologies are applied. The

main objective of planting corn is for it to become the basis of the cows' diet, which are of the Holstein breed, and the milk produced by these cows is sold to the Alpura Cooperative for human consumption. Other activities of CAETEC are intensive agriculture (in greenhouses), vineyards, fruit trees, and pumpkins. Using soft systems methodology, the current situation of CAETEC was described. The rich picture reflects how CAETEC operates from a systems point of view and the problem has been defined. With this, the best solution proposal is the design of a digital system for the milking part. Figure 2



Figure 2. CAETEC Systemic map and Rich Picture to show the milking system

A problematic situation is that CAETEC does not have the infrastructure in human resources and facilities to receive large groups that want to learn about the milk milking process and satisfy the demand for challenges requested by different teachers. One of the objectives of CAETEC is to be a living laboratory for Tecnologico de Monterrey students, serve as a research centre, and be a reference to other educational centres, private companies, and researchers. Unfortunately, this has not been achieved.

Based on known information and using the Kepner and Tregoe methodology [6, 7], the problem has been defined as follows: CAETEC needs to have the capacity in human resources and infrastructure to receive students who request to visit the VMS facilities to learn about its functioning and the daily performance.

To solve this problem, a digital twin model of the milking robot was designed based on virtual reality and augmented reality technology for remote learning. The academy and the company worked together to ensure that said design meets the needs of the student's knowledge and the needs of the company regarding marketing its product and maintaining and using the robot by its employees. The design we are working on consists of the following milestones: the digital twin will be an interactive solution and it must show the technology devices involved in the CAETEC milking system. It is worth mentioning that the application will guide the user step by step during the operation.

Two development phases were defined for the interactive stable:

**Phase 1:** Interactive map of the stables where the general system of the milking area and the milk cycle is explained, Figure 3; here, the user interacts with the virtual world and the elements are mainly selected with the click of the mouse. The user will be able to select up to 10 elements in the scenario, for example, VMS, cows, feeding area, rest area, sensors, and doors, to name a few; the information of the selected elements (statistics and relevant information) will be displayed on the screen.

The design of the solution also includes a dashboard with the operation's strategic KPIs [4]. The user will also be able to view and analyse the cow control panel, where there is a list of cows and view data of research interest such as age, milking time, milk produced, last milking, and calving number. The user will be able to select all the components. The application will have a tutorial that guides the user to perform the following actions:

- Select all components of the interactive map.
- Select the cow panel.
- View the information on three different cows.

**Phase 2:** A general panel has been designed where the general statistics of the entire stable will be displayed, accompanied by dashboards such as graphs of (e.g., Average milk production, Average milking time, Amount of food consumed per day). The user will be able to design the cow diet (food generation). At this point, the user can modify the food formula by changing the percentages that make it up. For the cow simulation module, the system is designed for the user to manipulate the behaviour of

the cows going executed through the following four phase commands (1-Send to a veterinarian, 2-Send to feeding, 3-Send to milking, 4-Send to rest) Figure 3.

For the virtual reality lesson, the design has been thought to have a prospective and concurrent approach since the lesson is being built in standard modules, to later derive the application for students (academic) and for the robot manufacturer in these lessons.

The application will guide the user step by step during the operation. The scope and design of the lessons have been made for HTC Vive headsets. We aim for the user to interact with the virtual world and the elements mainly by selecting them with the control. There will be narration in Spanish and English; subtitles can be activated for this narration. In the same way, the design has considered deploying signage on those elements relevant to the learning process.





The simulator and VR lesson have been a work of progress for many hours in a multidisciplinary and international cultural project that started a year ago with the proposal to the Institute for the Future of Education through the Novus funds, where we won the competition to access financial funds to develop virtual reality lessons. The first design phase was carried out through video calls, and in October 2023, a representative of the University of Mälardalen visited to intensively work on the design of the practices and the simulator. The second phase was to incorporate the vision of interaction between the robot's management and the human with the help of the University of Mondragon.

## **4 METHODOLOGIES**

To evaluate the current stage of development of the virtual reality lesson and the milking process simulator, an augmented reality lesson was applied in the IN2006B training unit, groups 501 and 502, with a sample of 39 Tecnologico de Monterrey students and 25 CAETEC employees and Tec de Monterrey professors, in which the challenge is carried out in the stables using the robots.

A survey was carried out to analyse human interaction with robots based on a 5-point Likert scale developed regarding the relationship between human and robots [4].

It is worth mentioning that at the beginning of their professional studies at Tecnológico de Monterrey, students sign an agreement in which they consent that their responses and/or interactions during class may be used as evidence to analyse the impact of technological applications focused on educational innovation. This evidence can include tests, exams, surveys, among others. Thus,

## **5 RESULTS**

The analysis was guided by a series of questions, answered by students and users of said robot. The survey aimed to understand the impact of the robot on the work performance and productivity of the users; it was designed to evaluate aspects such as the user-friendliness of the robot, the ability to use the robot without written instructions, and the level of trust and confidence users have in it. The results provided insights into how well users can adjust the robot to assist them in their tasks and whether the robot helps in completing tasks in a shorter time; it was observed that majority of the sampled individuals agreed that the robot can enhance their work performance, help them complete task in shorter time, said that it's easy to use without instructions and they can adjust it to their needs, and that it increase their confidence when using the robot. On the other hand, the majority strongly agreed that they trusted the

robot so that it would not harm them. And finally, it was observed that the majority neither agreed nor disagreed that the robot could help them be more productive and is user friendly. Figure 4.



Figure 4. Survey results applied to students and users of the voluntary milking system. Q1: The robot enhances my work performance. Q2: The robot helps me to be more productive. Q3: The robot helps me to complete the task in a shorter time. Q4: The robot is userfriendly. Q5: I can use the robot without written instructions. Q6: I trusted the robot would not harm me. Q7: I am very confident in my ability to control the robot. Q8: I can adjust the robot so it will help me carry out my tasks

The results show that the use of the robot has not only allowed the users to learn about the automation of the milk milking process, but it also has provided valuable information for decision-making in the daily operation of CAETEC. Based on the data provided, daily handling and interaction with the robot is simple. And the use of digital twins for distance learning shows good acceptance by both students and professors.

## **6** CONCLUSIONS

Digital twins are a more efficient and democratic gateway to knowledge. The construction of this design has allowed us to be at the forefront of the Tec21 educational model in terms of generating remote learning experiences. The interaction and collaboration between academics from the three universities has also been an experience worth sharing. It has shown how different visions can converge in designing high-value learning activities through educational innovation. The project will be released in May and will be fully implemented before the end of the school year in June 2024. The research group will show the final results during the E&PDE conference.

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# DEVELOPMENT OF A FULLY FUNCTIONING ARTIFICIAL DESIGN TUTOR – A QUEST FOR REFRAMING INTELLIGENT TUTORING SYSTEMS

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### ABSTRACT

This paper presents a scrutinising attempt to design an artificial design tutor (ADT) that can specifically support development task throughout the phases of product development. In the format of a conceptual paper, it is arguable important to consider how artificial intelligence can support task related aspects, and more complex process-oriented design processes, not as an immediate substitute but as a supplement. With the purpose to present the founding principles of an ADT, the full paper adds insights through a series of interviews with academics and professionals working in the field of AI. The ADT is designed based on generative AI protocols and follows the escalating trend of utilising more and more areas with AI tools to facilitate and improve existing processes. From Newsweek magazine alone, it has been stated that numerous fully functioning AI apps are released every week, exceeding a growth rate of 38% in 2023. The AI components in an ADT can contribute to improved decision-making processes, where machine learning algorithms may be used to improve the ADT's ability to recognise and capture user preferences, emerging design trends, and successful design strategies. Consequently, given the range of scope, we still have not faced any ADT, which probably is connected to the complexity of the process itself. This paper hopes to inspire the cross-disciplinary efforts that advance the community of designers, and design educators, involving computer scientists, IT specialists, AI consultants, systems developers, and beyond, to further explore potential and risks of AI-enabled design support.

*Keywords: Artificial design tutor, generative AI, design process, intelligent tutoring systems, ITS, LLM* 

## **1** INTRODUCTION

The thought about having a computerised tutor supporting the design process is far from new. Actually, very similar reasoning to the evolvement of the modern generative language modelling, e.g., ChatGPT, Wolfe and McDonald presented 40 years ago, a programming guide for establishing a user-centred approach in the interaction process [1]. While society is today overwhelmed with advanced algorithms capable to both, predict, intercept, activate, analyse, and evaluate any given data set, the normality of human-to-human interaction is by far the only given way for reaching new insights. Considering the capacity of AI, the major interest of its capability is witnessing the same exponential interest as when internet became present to all, fundamentally altering our way of life from that point forward. Eroding practices, or replacing actions? Depending on how we frame our point of view, the way AI may change and impact our living is ultimately affecting how we anticipate and allow this to get into our daily life. For establishing new design, the quest for progression is always present. Recently, Open AI announced that their new focus is to develop AI Agents, this was followed almost immediately by Microsoft introducing an AI Agent Foundation Model, which is a substantial step toward what is referred to as Artificial General Intelligence, or simply AGI [2]. While the impact of foundation models in AI transcends the realms of efficiency and resource management, establishing new capabilities, earlier considered to be exclusively within the realm of human intelligence. Still, research presents scepticism to how the potential role of an artificial generative agent may be. In a recent study determining barriers for AI in product development [3], the value of an intelligent system is based on data collection, data conditioning, algorithms, and human-machine collaboration. This, paper tries to explore what an artificial design tutor is, and what role it may have for supporting design education. Design education is characterised by dealing with complex situations, that are marked by an abundance of elements or

variables. This necessitates the processing of vast amounts of information, to reassure proper, and accurate progression. AI provides a speed beyond what the cognitive capabilities of even the most intelligent human tutor, senior lecture, or professor would be able to process. In recent years, AI, with its superior quantitative, computational, and analytical capabilities, has outperformed humans in handling complex tasks. Research has proposed partnering with AI to materialise the synergistic relationship between AI and humans combining the processing speed of AI in collecting and analysing information with humans' superior intuitive judgement and insight, captured in AI analytics or bots [4]. Human presence and interaction, in form of tutors are frequently regarded as the benchmark for fostering learning gains, yet with the precision of AI and possibilities to even render human tutoring this is posing a highly concerning topic for debate. As such, what has escalated in interest, also for learning purposes are Intelligent Tutoring Systems (ITS), capable to deliver adaptive guidance and instruction, evaluate learners, provide a specialised format for how to improve learning, and cluster and categorise learners based on level of expertise [5]. One strong reason for why ITS is a good starting point for further exploration is that these systems target to facilitate the learning process. However, these systems have not yet been explored in more complex experimental courses [5], which focus on problem-solving and decision-making, two foundational pillars of design education. ITS are capable to use multiple agent based computerised conversational experts, personalised to match both language and individual preferences, embodied in animated avatars [6]. Several questions arise based on the arguments and practices hitherto, yet to what extent is generative AI and ITS capable of transforming the design process and the objects exposed to design actions. For example, which decisions can be automated, and which ones cannot? These questions address the impact of AI on the principles of design. If AI induces significant changes in design practice, does it challenge the fundamentals of design? Is usercenteredness, for instance, questioned in the age of AI, and is design practice informed by significantly different principles? AI has the potential to assist individuals in integrating information, analysing data, and utilising the resulting insights to enhance decision-making. This causes the interest to further investigate the challenges and complexities that arises as AI and tools enabling interactions is gaining increased impact. This paper examines relevant research and share perspectives on application possibilities from AI experts to determine what it takes to establish and realise a fully functioning ADT.

### 1.1 Impact by AI tools

Numerous AI tools are rapidly being commercialised and made available for consumers and industry practices. This paper, inspired by management concerns, explores how AI is poised to change the way design is practiced, influencing decision-making and unfolding processes. AI drastically removes limitations in both design and learning, leveraging the performance of machine learning algorithms to achieve unparalleled levels of people-centeredness [7]. Designed to help find answers and establish new insights from vast data sets, IBM Watson presents a cognitive, problem-solving supercomputer, capable of processing data with a logic and precision of a superhuman. AI tools like Watson presents how context-specific decisions can be mastered at an unrivalled speed, transforming the ways in which students, instructors and other actors can influence how learning is intercepted, spurring new educational services [8]. Several unknown variables come in to play as interaction and tutoring modes radically emphasise processing aspects such as timing and accuracy. However, individuals require different means for interpretation and learning, depending on their preferred learning style. This poses more efforts to be directed towards exploring the potential customised features that can be provided.

### 1.2 Al tutoring potential

In recent years, ITS have progressed and evolved rapidly [5], positioning AI tutors as operators that have garnered attention as virtual teachers offering personalised learning approaches. While AI tutors aim to enhance learning progression and review learning plans, they utilise their experiences to categorise the academic status of a specific learner and design suitable actions [9]. An artificial design tutor serves as a computer-based system designed to assist and support individuals in the field of design education, capable of offering personalised, adaptive, and technologically enhanced learning experiences. Serving as a tool for both students and educators, an AI tutor enables a range of ways for deepening the understanding of design principles. Improving teaching processes by reducing and eliminating repetitive tasks, allows for increased precision, and a balanced way for connecting and interacting. The idea to enhance cognition through collaborative visualisation and iterative prototyping steps has long existed in the forefront for engineering design practices [10]. Still, AI can provide and

utilise a new form of advanced personalised and collaborative learning, featuring a digital tutor prototype and opportunities for a new educational model that offers integral learning activities for students [11]. Specifically, in this context, AI is employed to empower an ITS to produce accurate solutions for specified problems, and enable effective negotiation tactics [12], and supporting design phases [13]. The ITS incorporates mechanisms that enable students to request explanations about the solution process, serving as a means to facilitate learning.

### 1.3 Al biggest challenge

While being objective in format of a machine, that despite the risk of coloured "biased" coding, the advantage of being a mere object is also its immediate disadvantage. Reading peoples intentions, could yes probably be solved with sophisticated techniques eye-tracking, sensory systems and so on, yet the maturity level of how adoption and practice of this technology is still very uncertain, especially in the ethical concerns of how it may affect students being supported by a machine rather than a human. One alarming danger with AI tools in general, and with popular tools like ChatGPT in particular, is their propensity to be used for deceit, making misuse and abuse the important potential fear that argues for improvement of detection and transparency to end-users [14]. While AI may infuse more doubts and information conflicts, humans' perception is far more than what we currently grasp about coding, the sensations are simply difficult to replicate. But is this really a concern for content learning? If being factual, which teaching and learning so desperately try to focus on, precision is not something negative. It is precision with a nuance, or fake precision, meaning that the submitter unconsciously, and in very detailed ways, have been trying to humbly direct its extraction of data to what could potentially be right. However, as even a simple LLM example from ChatGPT may address, Figure 1 provides a snapshot that ridicules a system attempting to provide support, while lacking adequate fundamentals to do so properly. Essentially, it performs proudly, yet with the insecurity of a baby providing diapers.



Figure 1. Beyond a training data challenge for ChatGPT 3.5

## 1.4 What motivates an artificial design tutor?

As AI increases its capabilities in refining and updating its capacity, already now, there are far more advanced systems, capable to mirror sophisticated in-depth and realistic conversations with humans. AI is a self-learning system exploring and mastering bigger and bigger challenges. Suggesting that we are

moving towards a dynamic and adaptive design capability to handle varying levels of complexity. Learning and progressing in ways that were once destined for persistent humans is now intercepted in the age of generative AI, seen as nothing else than a suitable match, framed as:

### "You never fail until you stop trying."

### - Albert Einstein

What is conceptually showing a fitting description to the perceived elements of the ADT is captured by the ITS. Both ADT and ITS build upon computerised learning environments that integrate computational models from domains such as cognitive sciences, educational sciences, computational linguistics, and generative AI. The relationship between ITS and cognitive learning theories plays a crucial role in their design in the explanation functionality and the results impacting students' learning and perception [9]. Extensive mapping by past research provides indications of the stage-by-stage distribution of how AI could critically benefit designers' actions [13], by supporting design tasks and further examining process steps that require extensive use of various methods and processing capabilities. Several perspectives in how AI can support the design, scrutinising expansion efforts that evaluates the designer's role provides a link towards deepening AI and human interaction [15]. However, rather than focusing solely on AI-integrated interaction patterns to emphasise the importance of an ADT, there is a shift towards a more grounded, human-centred perspective. This perspective prioritises validation and reliability checks by tracking, monitoring, and enhancing human efficiencies.

#### 2 RESEARCH DESIGN

This explorative study, exposing theoretical paths not directly connected to design education, but given the immediate potential and together with the empirical investigation is made in alignment with to optimise clarity, consistency, and ease of reading. Web of Science was used with the search string 'artificial design tutor'. Notably, ITS showed high thematical relevance when no paper explicitly mentioned the term, 'artificial design tutor'. Furthermore, a mere handful of articles targeted any of the phases of the design process [13], [16]. These exemplified, discussed and provided perspectives on application design content relevance could be moderated and improved. Semi-structured interviews with three respondents were carried out. Respondent all had more than 20+ years expertise in the area of AI, currently operating in the Sweden with "Expert 1" being an independent IT consultant and "Expert 2", a R&D manager in a MNE dealing with process procurement, product development, and manufacturing support. The responses from these respondents, referred to as AI expert interviews within the paper, are presented in the findings as expert insights. One additional professional expert was interviewed, yet the coverage of this interview was not deemed eligible to provide enriching answers to properly relate to an ADT. Following the guidance by design science research methodology, the use of open-ended questioning is deemed particularly suitable for exploring new domains [17]. This contributed to understanding the in-depth influences and aspects related to an ADT, still the interviews provided neither narratives nor insights that could clarify distinct practices. To enhance transparency and establish conceptual beliefs on systematic grounds, an analytic process was used to extract key narratives related to the design process. Adopting a structured approach for transcript processing aims to improve the credibility for interpretations, enabling a more purpose-oriented screening process.

#### **3 FINDINGS**

AI were presented to have a galvanising overall support. There are despite the general enthusiasm also a few concerns that were raised related to algorithm bias, due to training limitation, and the difficulty to comprehend the design environment and inherent complexities. This may cause unpredictably due to personalised practices by individuals, especially for the uncertain outcomes when dealing with complex design tasks. One key concern was more to get programs and courses willing to test and integrate the potential of an ADT, because without systematically looking at pedagogical and practical concerns, simply ignoring it, will not benefit anyone. Experts shared the belief that an ADT should not be used as a substitute, blindfolding the human creativity, but rather as a mean for broadening the critical thinking and to develop the design practice. To organise the influences and aspects of AI as captured by the narratives from the two experts, Table 1 presents a summary of the interviews.

DESIGN PHASE	INFLUENCE/ASPECT	EXPERT 1	EXPERT 2
Research and Discovery	Generative AI and LLM Use	Access to tools for information search, extraction, and presentation.	ADT can support learners by identifying key concepts, trends, and gaps.
	Systematic Practice in Learning	Underutilised for learning despite immense opportunities.	Supports in early phase idea generation, iteration conceptualisation and need analysis.
Concept Development	Text-Based and Text- Image Analysis.	Enables perspectives, compiles research domains, connects image and text in different forms of presentation.	Generates ideas for projects and exploration.
	Creative Suggestions and Challenges	Generates creative solutions and alternatives, challenging existing ideas and beliefs.	Enhances idea generation and exploration.
Design and Prototyping	Data Analysis and Improvement	Breaks apart existing data points to improve the fitting and existing processes.	Functions as a mediating cost-efficient step for institutions and companies.
Evaluation and testing	Practical Applications and Pilots	More emphasis on validation and process refinement to address conflicting suggestions.	Demonstrates potential in pilot programs, fostering creativity, critical thinking, and practical skills.
Implementation and Production	Support for Teachers	Can enrich and support depth and authenticity of design projects.	Facilitates evaluation without being an immediate substitute for human tutors.
Feedback and Iteration	Validation and Process Refinement	Targets to improve refining processes, triggers feedback iterations, and output validation.	Supports continuous improvement and iteration based on data-driven feedback and insights.

Table 1. Summary of experts' beliefs about potential influences by an ADT

The experts highlight the in-built knowledge capacity that supports the iterative use of an ADT and the proper utilisation of its potential. Additionally, they explain how an artificial design tutor could improve design by providing personalised feedback, identifying critical aspects, patterns, trends, and needs. By offering data-driven insights an ADT can potentially enhance learning outcomes, imposing a mediating and new format for optimising the design process.

### 4 **DISCUSSIONS**

This paper makes no claim that AI is new in any ways to the design community. However, the rapidly improved availability of AI tools, for end-users with no prior expert skills in programming, makes access and availability very interesting adoption consideration. To perceive cost-efficient value benefits of ADT and how such as a phenomenon can promote design processes, current concerns for adoptions goes beyond the potential, and sometimes get stuck at existing constraints, which may limit the ADT potential. Although generative AI shows compelling results, they also show vulnerability and obvious flaws [14]. From LLM like ChatGPT, and other similar tools as Google Gemini, Bing AI, and OpenAI Playground they comprise a convincing, yet somewhat a dubious power mean. While new AI-enabled tools are continuously being improved in precision and processing capacity [6], [9], they keep flourishing communication through improved interaction capabilities. This allows for improved user engagement while queries and operations are processed at more complex cognitive levels. Meanwhile, users, are strive for adopting tools that smoothen the interactive prompting. To enhance the practical benefits of an ADT, users need explore value benefits at different phases and increase validation and refinement strategies. Similar to recent research [13], an important design awareness is not about "if" a certain tool should be applied, but "what" tool should be applied, and "when". The conceptual idea behind the ADT is to emulate the chosen AI application, resulting in various user-oriented, interactive, and attentive tutoring agents. Similarly to how ITS can create personalised challenges and quizzes for students [5], [6], [8], an ADT may generate practical questions, that need deep level explanations and educational content tailored to individual needs. While early examples have shown so-called "hallucinations," where services have created an incorrect response due to limitations in the LLM model, an ADT is expected to value the input received throughout the interaction, and thus deemed critical to make a self-review assessing and critically evaluate the information provided.

### **5** CONCLUSIONS

This paper is set out to challenge existing forms, and think outside the box, introducing a crossbreed element of the ADT, combining LLM, with ITS and even given the technology format a simulated robotic presence. When trying answer questions on how an ADT could be designed and on the desired

criteria for how to utilise this format, literature offers a wide range of methods and approaches overlapping with ITS, generative AI and LLM. Ultimately, the paper is a framed conceptual reasoning attempt that has concentrated on what experts experienced and literature revealed. Indications provided state that an ADT is not at all far away, as complexity capacity increases so does generative AI solutions. Reframing ITS, this attempt hopes to direct further attention towards the design process and opening up a new path for inspiration within the community of Design Society and E&PDE. Potentially even a new research trajectory for design research and design education where ADT attempts can merge an obvious need for cross-disciplinary overlaps enabling future design education initiatives.

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# THE ETHICAL USE OF ARTIFICIAL INTELLIGENCE IN HIGHER EDUCATION IN TEC21 MODEL

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## ABSTRACT

Artificial Intelligence (AI) has grown exponentially in the last few years, and has presented opportunities and challenges in several sectors, including Higher Education. AI's potential to engineering companies is significant, nevertheless, there are concerns about the abuse of AI in decision making. In an educational context, some universities have forbidden the use of AI because it directly affects the understanding and learning process of students. Other universities, such as Tecnologico de Monterrey, promote the use of it as a tool to help students and teachers in the process of teaching-learning. It is important to understand the benefits, risks, and ethical concerns of the use of AI. This paper examines the implementation process of AI at the Tecnologico de Monterrey form learning and teaching approach, exploring the student and teachers' vision in the context of Tec21 Educative Model.

Keywords: Artificial Intelligence, teaching-learning, higher education, ethics

## **1** INTRODUCTION

Artificial Intelligence (AI) has grown exponentially in the last two years. This has had a significant impact in education, especially for Engineering teaching. It is important to educate future professionals to have a strong knowledge and foundations in their respective area; this education must be updated to understand and train students to new technologies, which will allow them to integrate into a future of work that requires this knowledge. The possibilities of empowering students of Engineering with specific AI tools are exponentially beneficial.

Nonetheless, design education now has a new challenge, "The establishment of rules and guidelines for the use of AI." The use of this technology is controversial, a lot of universities have been working to overcome this challenge, but on the other hand, AI has been forbidden in some universities because it affects the understanding and learning process of students. However, the progress cannot be stopped; hence, the present paper aims to lay the ethical foundations and unify the principles to be followed in the integration of AI in education.

Some efforts have been made to establish ethical principles, such as 'Ethical Guidelines for Trustworthy AI' published by The European Commission in 2019 [1], 'The Call for an AI Ethics' signed in 2020 by The Pontifical Academy for Life, Microsoft, IBM, FAO, and the Italian Ministry of Innovation [2], 'The Artificial Intelligence Act' released by the European Commission in 2021 [3], and the 'Recommendation on the Ethics of Artificial Intelligence' published in 2022 by UNESCO [4].

## 1.1 Depiction of Artificial Intelligence

To use AI as a tool, it is essential to first understand the definition of AI. According to UNESCO [5], AI refers to machines that imitate some aspects of "human intelligence", such as perception, learning, reasoning, problem-solving, language interaction, and creative work. When setting AI in education, multiple types of AI that can be considered, nonetheless all serve different purposes and will fall under one of two categories: AI based on capabilities and AI based on functionalities. Examples of those are search algorithms, languages processing, machine learning (ML), deep learning (DL), etc.

### 1.2 KEY principles of artificial intelligence

As mentioned before, educational institutions must establish guidelines to direct how to start using AI in a responsible, ethical, efficient, and clear way for different educational scenarios [6]. This is a great challenge due to the importance of shielding and strengthening the responsible and ethical use of AI tools, while simultaneously bringing benefits to accelerate and increase learning experiences. Multidisciplinary efforts involving different perspectives of scientists, philosophers, engineers, and stakeholders are necessary to implement AI in a beneficial and conscious way [7].

AI developments must incorporate human-centred ethical principles and embracing diversity, designing future-proof systems, periodically re-evaluating ethical compliance, and simplifying the concepts employed for a clearer, overall understanding [8].

Moreover, another key aspect is the respect for the autonomy of the person which is essential in the design of AI systems. AI systems should not unjustifiably subordinate, coerce, or manipulate; it should be designed to augment and enhance human cognitive, social, and cultural abilities [1]. Harm prevention, or non-maleficence, is an aspect of harm prevention that is fundamental. Systems must not cause harm or aggravate existing damage, and must protect human dignity, physical and mental integrity; as well as consider the environment and life in general [1].

Equity and explainability are principles that must be considered in the development and use of AI systems to make them fair, ensuring an equitable distribution of benefits and costs and avoiding discrimination or bias, ensuring transparency about who makes decisions and how they are made [1].

### 1.3 Benefits of artificial intelligence

Some of the advantages of the use of AI are that AI has the capacity to automate cognitive functions by establishing patterns, processing huge amounts of data, and making improvements with experience. In education AI provides a variety of options for the creation of written content, computer coded, images, video or audio; all of this can enhance traditional activities for the better understanding of students [9].

### 1.4 Risks of artificial intelligence

On the other hand, AI could represent a risk factor for humanity, to try to avoid the risks the AI Act in 2024 presented the first legal framework on AI, which addresses the risks of AI and positions Europe to play a leading role globally [10]. The framework defines a four-level risk scheme category: 1) Unacceptable, in which AI violates fundamental rights by declaring threat to the safety, livelihood. And right of peoples; 2) High Risk, in which AI must be subject to strict obligations prior to commercialisation to prevent adverse effects on people's safety and fundamental rights; 3) Limited Risk, where AI have transparency obligations to inform users of machine interactions; and 4) Minimal Risk, where AI has a low- or no-risk and has an free access. Education is positioned on the high-risk level [10].

### 1.5 Ethical use of AI at universities

In the case of education, the Office of Educational Technology [11], in its publication "Artificial Intelligence and the Future of Teaching and Learning: Insights and Recommendations" provides a framework to start including the use of AI at the organisational level in the educational field throughout the teaching-learning process. It gives recommendations according to different stages of how to align certain tasks to open a gap and facilitate adoption.

- Teaching: Implement AI to improve teaching work, manage risks, and provide relevant information for close teaching and generate empathy with students.
- Learning: Use of educational technology to make recommendations tailored to each one. It is essential to have a process for identifying biases and to secure equity in learning.
- Evaluation: Implement AI-led assessments to guide training on a broader spectrum of skills, with a focus on learning optimization. Educational decisions should focus on students, teachers, and the community.
- Research: Use to personalise learning resources, to facilitate the adaptation of materials to neurodiversity students and cultural and community requests.

### 1.6 Ethical AI at Tecnologico de Monterrey Educative System

The University has already published the rules and guidelines for the use of AI at the institution, Figure 1, and has shared several documents and courses so the teachers, students, and collaborators can learn

about the different available AI tools and understand the ethical implications of their use. Some examples of this are AI tools as the ones that are shown in table 2 [12].



Figure 1. Ethical AI guideline of Tecnologico de Monterrey

A pilot study was conducted during the spring semester of 2023 in Digital Education courses at Tecnologico de Monterrey, exploring the integration of generative artificial intelligence tools, mainly ChatGPT, in the educational field. The study was carried out by teachers, together with pedagogical experts, to design innovative educational activities that incorporate AI in an ethical and responsible way in the teaching-learning process. The results mention favourable acceptance by teachers and students, a positive assessment of the development of critical and ethical skills, as well as the promotion of a responsible use of these tools in the educational environment. The groundbreaking pilot study highlights the importance of ensuring a responsible use of these tools to ensure their effectiveness in the teaching-learning process, thus offering enriching and high-quality educational experiences [13].

Since the breakthrough of AI into everyday life, Tecnologico de Monterrey has provided resources dedicated to effectively integrating AI into educational practice.

Actions using AI	AI tools	
Image generation	DALL-E, Midjourney, Pollinations.	
Text generation	ChatGPT, Perplexity.	
Video generation	Genmo, CharacterGPT, Artflow, FILM, EbSynth, Fliki.	
Presentation generation	Tome, Beautiful AI.	
Audio generation	ElevenLabs, Azure text to speech, Rifussion.	
Fostering creativity	Plaito, QuillBot, Brainly.	
AI online courses	IA for everyone, AI chatbots without programming, AI applications with Watson, How to use AI responsibly, Elements of AI.	
More AI tools	Video Playlist: AI Tools, AI Tools for Teachers by Christiam Mendoza, AIFINDY, Elements of AI.	

Table 2. Al Tools used at Tecnologico de Monterrey

Artificial intelligence (AI) has been incorporated within the institution to optimise operations and enrich service experiences in multiple ways:

- In 2021, TecBot was designed to make it easier to connect students, teachers, and collaborators to different systems within the edtech ecosystem. TecBot in 2023 was upgraded to different service modules to have more personalised and accurate capabilities [14].
- Professor Atom 2.0 is an academic assistant, a reference within the institution for the use of artificial intelligence. Specialised in guiding professional students in Intelligent Physics content by offering explanations of concepts, giving examples of problems with subject procedures to support learning, and resolving doubts at any time in a personalised way [14].

• The TECgpt initiative represents the spirit of the institution in the search for innovation and educational excellence. Offering a generative platform for the institution's community, which has its own AI model capable of synthesising, generating ideas, creating images, carrying out procedures and searching for information within a secure technological environment while safeguarding data privacy [14].

## 1.7 Tecnologico de Monterrey Al Ethical guidelines

Tecnológico de Monterrey has shared with its teachers and collaborators the guidelines to adopt artificial intelligence in a responsible and transparent manner during the educational environment. These include a series of concrete actions and protocols to ensure AI understanding and positively contribute to student learning. They reflect Tecnológico de Monterrey's commitment to academic excellence and ethics in the use of emerging technology.

In addition, it highlights actions to be followed to address any breach of academic integrity and inappropriate use of AI. Moreover, it also emphasises the importance of continuous training and access to specialised resources through the Center for Teaching Development and Educational Innovation (CEDDIE) and Teaching Hub.

It is essential that the use of AI is deliberately integrated into activities that encourage critical thinking and is explicitly stated in curricula. The combination of AI with other technologies and pedagogical strategies enriches the learning experience. Furthermore, teachers are reminded that they are models of academic integrity and must ensure quality and transparency in the use of AI tools in their own educational practice. It is important to reflect on the interaction of human beings and AI systems, since technology will become increasingly active, immersed, and powerful in the relationship with us, human beings [15].

# 2 CASE STUDY: AI DURING CLASSES

After the publication of the academic rules for the Tecnologico de Monterrey there was a need for analysing some teachers and students' aspects. The objective was to identify patterns of use, to learn about perceptions of the veracity of the outputs and whether there are concerns regarding its ethical use. A random sample of 58 individuals was taken among students and teachers to ascertain how they interact with AI technology. From which 34 were students and 24 teachers.

The response was observed through surveys, which was focused on ascertaining how they interact with AI technology, if they had preferences of certain AI systems and their context of use; the assessment of reliability, the measures in place to verify the information and to identify any biases thereby, and the most important to us was to identify if IA was used in unethical way. It was expected that with the survey, it would be possible to detect whether AI systems are being used to solve exams, in order to identify certain anti-bias mechanisms and initiatives to reinforce academic integrity. Hence, with the assessment of the results, we would be able to see if it's possible to determine if the tendency is prone to educational innovation.

## 2.1 Results

The survey showed that the percentage of teachers that had used AI in the teaching-learning process is 95.8% and 43.5% of them use Apps to detect the use of AI being Turnitin the most common. It is important to note that Turnitin is a tool that is currently integrated on the Canvas educational platform used by the university. Also, 12.5% answered that they did not know that there exists a tool for verifying plagiarism. On the other hand, the percentage of students who have used AI to solve school tasks was 94.1%.

The most common app that has been used by both groups was ChatGPT, with a percentage of 26.3% for teachers and 42.3% students. Teachers had used also Turnitin (15%), Grammarly (8.8%), DeepL (6.3%), MindMeister (6.3%), Research Rabbit (2.5%), WeVideo (1.25%), ReMarkable (1.25%), among others. Students have used Wolfram Alpha (18.3%), Grammarly (16.9%), DeepL (5.6%), MindMeister (2.8%), ReMarkable (2.8%), Turnitin (2.8%), WeVideo (2.8%), Copilot (1.4%), Sway (1.4%), among others. As we can see in Figure 2, teachers found more sources of bias in the AI applications, being the most common found gender bias for teachers and educational level for students. Nevertheless, in both groups



Figure 2. Bias percentage of Tecnologico de Monterrey teachers

In terms of reliability of the information 91.7% of the teachers and 85.3% of the students validate the reliability of the information. Also, 87.5% of the teachers and 82.4% of the students do a reference check. The results of the survey showed that 17.7% of the students claimed that they had used AI for exams resolution while 16.7% of the teachers have found the use of AI for exams resolution by the students. Only 1 teacher asked for the use of AI in the exams, 8.3% of the teachers found more than 2 students per group that had used AI for exams resolution.

## **3 CONCLUSIONS AND RECOMMENDATIONS**

The use of AI in education in Engineering can be positive and offers potential to enhance teaching and learning experiences, but it is essential to have a pedagogical strategy perspective, with an intentional instructional design linked with disciplinary objectives, competencies and ethical values. AI allows the student to have a diversity of exercises, cases of analysis, knowledge practice, simulation of operations, and creative processes by exposing them to varied learning experiences. Care must be taken for the unethical use of AI as for cheating in exams, and more effort has to be done to encourage students to verify the quality, reliability and validity of the information.

AI also provides educators direct benefits in their work process, AI can optimise routine tasks, administrative matters or creation of evaluation instruments. Active exploration of AI tools, encouragement of critical thinking and creativity, establishing rigorous ethical guidelines, boosting digital literacy, and continuous training and support are few recommendations for the integration of AI into daily activities. In conclusion, by following guidelines, educational institutions can leverage AI to enrich the learning experience while maintaining ethical standards and enhancing educational outcomes. Nevertheless, still a lot of students are not aware of the existence of the rules and guidelines for the use of AI (only 2.8% know the existence of it). A lot of work must be done to inform students about the regulations at the university. For future work, it should be interesting to analyse if those tendencies have changed and compare the two findings in order to know if the ethical behaviour improves in students.

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# AESTHETICS OF CARE AND SUSTAINABILITY IN TECHNOLOGICAL EDUCATION: IMPLEMENTING A GAME-BASED METHODOLOGY

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## ABSTRACT

Introducing the notion of Aesthetics of Care (AoC) when teaching sustainability studies and/or sustainability related modules, might be an appropriate way to rethink the role of technology(ies) in human development. Such an approach is a valuable opportunity to reconsider the way we produce, and consume, not just the objects we interact with but also our perception of reality in such a moment of ecological and social crisis. We propose a game-based Teaching Training Programmeme (TTP) for technological higher-education to assess work, behaviour and choices of the participants. We tested three games that could be used to introduce participants from different backgrounds to mobilise the ideas of AoC and Regenerative Sustainability (RS) within their practices, by encouraging teamwork, critical thinking and self-evaluation. These games are: 'Atlas of Weak Signals', 'In The Loop', and 'Revolt'. They serve as educational tools that prompt questioning of decisions, actions, and attitudes concerning ecology, AoC and RS. Results show that such a game-based methodology has the potential to promote and teach AoC and RS in technological higher-education milieux.

*Keywords: Aesthetics of Care, technological education, regenerative sustainability, game-based methodology, relationality* 

# **1** INTRODUCTION

There is a wide agreement that Sustainability has failed [1]. Planetary resource exploitation and the capitalist call for short-term planning and quick profit (often at all costs) have, arguably, been undermining efforts for a sustainable economy. The most prominent trend insofar as the latter is concerned, is on how to constrain immediate needs (or desires) to serve future ones, rather than seeking regenerative long-lasting strategies. Furthermore, the bridge between the theory and practice of Sustainability has contributed to the acceptance that human beings have decisively altered the atmosphere and have set in motion inevitable drastic changes to the Earth system over geological time.

Fortunately, Sustainability has been undergoing serious changes helping not only to deconstruct the humannature divide, but also to create bridges between the theory and the practice of the so-called sustainable practices. In this paper we discuss how the notion of 'Aesthetics of Care' (AoC) helps to raise awareness on the development of a Regenerative Sustainability (RS) [2] as well as on its implementation in various contexts. Together with such related notions as "body aesthetics" [3] and "care aesthetics" [4], AoC has become an object of interest in recent times, building on the insight that "human relations can be considered for their aesthetics" and that "care is an important source for ethics which can be understood as an embodied sensory practice" [4]. We define AoC, following work carried out within the European Culture and Technology Lab + "Aesthico" project, as a process aiming ethically responsible action, informed/activated by sensory experience, and shaped by knowledge and aesthetic consciousness; this entails caring for ourselves, others, and the planet<sup>1</sup>.

We propose AoC as a suitable approach to rethink the role of technology(ies) in human development. This idea was firstly addressed by a feminist Ethics of Care, where care is treated as a central value in the society, becoming "everything we do to maintain, contain, and repair our "world" so that we can live in it as well as possible" [5]. As to Sustainability, AoC conceives of it as a matter of relationality where the "care" element also comprises "generalised relational and affective elements" that go beyond caring about or for specific objects or beings [6]. Hence, a concern with the environment that places the AoC definition in close proximity to the recently proposed concept of Regenerative Sustainability (RS) and its three meta-principles of working towards "Wholeness", "Change" and "Relationships" [7].

## 2 AIMS AND APPROACHES

Many courses are moving toward an integrated model of sustainable education within their programme frameworks rather than relying on standalone sustainability modules [8]. This allows for education systems to not only educate students on the technical aspects of sustainability theory but also the underlying social realities. The approach also encourages a deeper understanding of the challenges of the paradigm of sustainability, including reflections on ecological ethics and issues aligning closely with the Aesthetics of Care (AoC). For this reason, our Teacher Training Programme (TTP) was developed as a mechanism to help teachers to integrate these concepts into diverse curricula and into courses being taken by students of different backgrounds. The programme aims to function as a means of testing how successful the integration of these concepts actually is, and how well students respond to questions around the AoC and sustainability. The TTP was developed by analysing existing approaches to integrating related concepts into education and considering what aspects of the Aesthetics of Care (AoC) were critical for learners to assimilate. As this is a programme aimed at teachers, it is important that it delivers on communicating the core conceptual ideas, but also on providing a pedagogical methodology that learners can employ in their own classrooms. The chosen methodology in this respect was game-based learning [9][10], which employs games as educational tools in order to encourage learners to actively engage in the subject matter and, in our case, question decisions, actions, and attitudes concerning ecology, AoC and RS. A set of learning outcomes of the TTP was developed and these fall into three categories each of which correspond to key desired outcomes of the programme.

### 2.1 Understanding the Aesthetics of Care

The first part of the programme is oriented towards introducing learners to the basic principles of the Aesthetics of Care (AoC). The relevant learning outcomes state that the learners will "understand the principles of the aesthetics of care and appreciate the importance of integrating this into their teaching practice" as well as knowing how it "applies within their own disciplines". There is also an emphasis on developing an understanding of the "responsibilities of students, teachers and practitioners of these disciplines to themselves and others", this speaking to the central notion of care within ecological and sustainability education as introduced in the previous section. The recommended activities involved here include a presentation of the Aesthetics of Care itself that encompasses a definition, some theoretical resources and consequent discursive elaboration with/by the tutor(s) and learners.

### 2.2 Teaching with the Aesthetics of Care

The second part of the programme is aimed at providing examples of the use of the game-based learning methodology and serves both as a means of delving further into the conceptual and theoretical ideas of the Aesthetics of Care and also as a way of testing different game-based learning approaches that the teachers might subsequently employ in their own practice. The learning outcomes specify that the learners will know how to use games and role play in their teaching, understand how to "act as facilitators" and know how to use speculative scenarios as a means of communicating the principles, and exploring the implications, of the AoC. A number of games have been tested and proposed as suitable mechanisms for this part of the programme and they will be introduced and discussed in the next section of this paper.

<sup>&</sup>lt;sup>1</sup> Aesthetics of Care Definition from Aesthico project: Aesthetics of Care in technological education is a process. Its aim is ethically responsible action. It is informed/activated by sensory experience and knowledge(s) in a relational world. It entails caring for ourselves, others, and the planet (by attending to sustainable forms of creative practice and attitudes of caring).

### 2.3 Evolving the curriculum

Of critical importance is the reflective part of the TTP where learners are encouraged to consider how principles of the Aesthetics of Care might impact upon their own teaching practice. The relevant learning outcomes specify that the learners will "examine and question teaching material, pedagogical approaches and processes" in a manner appropriate to a "relational, sustainable and dependent world". The learners also will be able to modify their curricula and teaching approach according to individual needs of students across varied disciplines. Within the context of delivery of the TTP this is to be achieved by a significant number of reflective exercises following the experimentation with game-based learning. This would include group discussion, feedback and other approaches deemed suitable by the tutor.

## **3 CASE STUDIES**

Three distinct games were presented during an Intensive Study Programme (ISP) of a duration of 3 days in total. The games were part of a large set of workshops and events that were set to inspire teachers and learners to test the pedagogical methods resulting from the Aesthico project. A set of keynote talks was performed before playing the games. The aim of the chosen games was to foster teamwork, critical thinking, and exploration of various outcomes related to participants' choice and/or expertise. The games, namely "Atlas of Weak Signals", "In the Loop", and "Revolt", served as educational tools that prompt questioning of decisions, actions, and attitudes concerning ecological ethics, sustainability, design practices, and aesthetics of care.

### 3.1 Atlas of Weak Signals

The Atlas of the Weak Signals is a toolkit designed by Mariana Quintero and the Fab Lab Barcelona. Its objective is to search of indicators to identify changes in the future with little or no impact on the present, but with the potential to lead to the identification of major impact events. Those indicators are called "weak signals", and they can set trends and indicate certain directions and by that draw up future scenarios. The game provides an opportunity to seek opportunities, threats, challenges and shared visions for innovation, policymaking, intervention, research, and business opportunities in the future. It sets a collaborative approach to the exploration of indicators or "weak signals" that have been detected across our strategic areas of action research over the past decade.

Atlas of Weak Signals affords variations of all sorts and is open-ended in terms of structure and execution. The particular manner it was performed at the ISP involved – the cards aside – big pieces of paperboard that allowed (and rather motivated) the participants to make impromptu notes and sketches as the game proceeds so as both to keep a 'roadmap' of the tenets discussed and to provide a conclusion in a tangible form. The game serves as a useful tool for understanding how speculative and future scenarios can be incorporated into teaching methodologies. It presented an intriguing methodology for questioning and challenging existing systems, using simple techniques and key topics to stimulate critical thinking and group discussions.

### 3.2 In The Loop

In The Loop is a 2016 board game designed and produced by Katherine Whalen. The motivation for the design and production of the game is to create an educational experience that would introduce players to circular economy concepts such as systems thinking, remanufacturing and critical materials, and make the circular economy "fun and understandable".

The focus of the game is set on the material conditions of manufacturing objects simulating the current economic global trends. Each player represents a business that is encouraged to accumulate raw materials to facilitate the production of specific products, sell them in the global market, and make profit out of it. Different sorts of strategies can be adopted by the players/businesses stimulating the reflection on the ethical and environmental consequences of its actions (positive or negative). Gradually, as the raw materials are being depleted, the game pushes the players to change their business-as-usual strategies (mostly based on economic incentives) to more ethical and sustainable ones.

## 3.3 REVOLT

REVOLT is a card game designed and produced by Clément Chabot in 2020. The purpose of the game is to provide players with insight into the energy consumption involved in our regular day-to-day activities. The motivation for this is the challenge of transitioning to lower energy consumption habits and the game's proposition is that we can only do this if we have a better understanding of how much energy is involved
in the things that we do every day. Rather than presenting this information using "complex scientific units", REVOLT employs the clever device of what it calls the "pedalpunk universe", where all energy consumption is related to how much time it would take to generate a certain amount of energy by pedalling on a bicycle hooked up to an electricity generator.

The dynamic of the game involves players being asked to guess how much pedal-power would be involved in various activities that they would typically do every day, and consequently encourage them to reflect upon energy consumption habits and the challenge of the transition to lower energy and more sustainable ways of living. The purpose of the game is to stimulate discussion and encourage reflection on how consumptive and energy intensive many simple activities that we might take for granted are.

# 4 RESULTS

A recurring comment highlighted the advantages of transdisciplinary methodologies, collaborative approaches, and the exchange of ideas regarding theory, ecology, and practice. However, a common concern was the need for more targeted material specifically addressing the AoC. The idea of designing a custom-made toolkit, borrowing the structures of the presented games and adapting the content to reflect the project's work, was expressed multiple times by different partners. Additionally, the group recognised an overall weakness in the current material, which lacked practical-based approaches and their relationship to the theoretical aspects of the project.

In The Loop, while it is an involving and engaging experience, it does not function as an appropriate or effective way of communicating the principles of the Aesthetics of Care (AoC). Among the problems identified were (a) it abstracts the players too much from the underlying issues that it seeks to raise concerns about (b) it is too long and too complicated and (c) there is no space for discussion/reflection during the gameplay.

The REVOLT game lacks, therefore, a systemic perspective on the overall ecological impact of the objects in the cards. While focusing on the energy consumption it leaves aside all other aspects that can be explored as part of the materiality of the objects. Still, such tenets could easily surface REVOLT sessions and be discussed accordingly. The game is under a CC BY-NC-SA licence, which makes it possible to adapt it accordingly to the objectives of the activities of the TTP.

## **5 DISCUSSIONS**

Notwithstanding the relationship of the game-based review and its relationship to an AoC, the TTP found in all games, this approach did foster teamwork, critical thinking and exploration of participants positions, choices, and opinions in their everyday life. "Atlas of Weak Signals" offered an engaging approach to examining and contesting current structures, employing basic methods and essential subjects to foster analytical thinking and collective dialogues. It enables relational discursive critical activity among the participants involved. A 'mapping' evolves and becomes visible and tangible for each group as statements, challenges and opportunities are negotiated. Cards are placed down on a large paper space where participants write down words and statements. Relational lines are drawn between ideas and propositions. The 'In the Loop' game highlighted, through playing, many of the experiences, knowledges and perspectives that persist in our world economic perspectives presently. In the feedback presented in this report, themes of – 'abstractness', competitiveness'; extractive processes; and even 'concealing intentions and strategies' are highlighted as coming to the forefront in playing 'In the Loop'. This aligns to economic values of wealth, ownership, growth, development and individual, that dominate present thinking and activity. This overly highlights these attributes at the expense of emphasising the AoC perspective of care; ecology; relationality and sustainment.

Then "Revolt" demonstrated a more focused approach, using pedal-powered energy concepts to promote understanding of energy consumption, but it was criticized for its narrow perspective and lack of a systemic view. The participants came to the conclusion that while the game provides a useful toolbox that may need to be modified to suit AoC issues and requirements, it does have use in the context of teacher training. In conclusion, the feedback and analysis of these games provided valuable insights for the development of a custom-made toolkit for teacher training that will incorporate the principles of the Aesthetics of Care, taking into account the need for adaptability, ecological thinking, and a comprehensive understanding of AoC in the context of technological education. The ISP highlighted the importance of developing a toolkit that encourages relational thinking, ecological consciousness, and a holistic approach to technology education. While these games engaged participants and encouraged reflection, some limitations emerged. "In The Loop" was considered abstract, complicated, and lacking space for discussion during gameplay, which

hindered its effectiveness in communicating the principles of AoC. On the other hand, "Revolt" demonstrated a more focused approach, using pedal-powered energy concepts to promote understanding of energy consumption, but it was criticized for its narrow perspective and lack of a systemic view. "Atlas of Weak Signals" offered an engaging approach to examining and contesting current structures, employing basic methods and essential subjects to foster analytical thinking and collective dialogues. The participants came to the conclusion that while the game provides a useful toolbox that may need to be modified to suit AoC issues and requirements, it does have use in the context of teacher training.

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# **6** CONCLUSIONS

The discussion, actions, workshops and gameplay try-outs undertaken by participants, students and other interested partners was a multidisciplinary approach, Intensive Study Programme (ISP). This was a set of processes devised to question interventions to technological education in order to address an Aesthetics of Care (AoC). The evaluation of existing toolkits examined here, will of course not have a clear connection to the theoretical aspects for this project concerning an Aesthetics of Care. This will need to be to the forefront in developing the toolkit. The findings from this ISP is that, in developing strategies for a teacher training programmeme, we need a tool kit that is relational in how it augments existing activity, knowledge, and ideas of technology, in order to build new approaches that re-think, speculate, re-evaluate, re-imagine approach to thinking as a relational AoC. The most pertinent question being – what is a toolkit of support to enable teachers to have confidence in developing ecological thinking, knowledge, language with processual activities that incorporates an Aesthetics of Care for Technological education. This ISP has allowed the participants to gather in-depth opinions, insights and feedback into the material collected and interrogated in order to develop, in the next phase, a robust custom-made toolkit for a teacher training programme, connecting AoC to technological education.

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# ANALYSIS OF CIRCULAR DESIGN METHODS IN PRODUCT DEVELOPMENT FOR A CIRCULAR DESIGN TOOLKIT FOR SMALL AND MEDIUM-SIZED ENTERPRISES

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# ABSTRACT

This contribution deals with circular design methods, which were identified and pre-selected with the help of a systematic literature research on the scientific database Scopus based on the requirements developed in a previous contribution for small and medium-sized enterprises and small development teams. Both design methods and design tools were identified, which are summarized in this contribution under the term circular design methods (CDM). The CDM are analysed, categorized, and elaborated upon with respect to these requirements to support product development in increasing the circularity of a product. The analysis provides insights on the status of CDM and which activities in the product development process are supported by them. The contribution follows the overarching process for method selection according to Ernzer and Birkhofer [1], whereby existing CDM are first identified and then analysed. Afterwards they are organized in the context of a strategic level, resulting in an initial draft of a catalogue of methods, which forms the foundation for the creation of the Circular Design Toolkit, with 21 CDM. The aim of this contribution is to provide product developers with a preselection of methods suitable for circular product development by analysing the existing CDM from circular design to support their work and activities in the direction of circular economy and circular design. This contribution derives an application-oriented multi-mode catalogue based on the needs of small and medium-sized enterprises using previously developed criteria. The paper also helps with the further development of methods for the circular economy.

Keywords: Circular design, design methods, product development, circular economy, circular design toolkit, SMEs

# **1** INTRODUCTION

Due to political and economic interests, the circular economy (CE) is gradually becoming more relevant for companies and their product development projects. small and medium-sized enterprises (SMEs) in particular are facing adaptation challenges due to limited resources and capacities, as can be seen from studies on current transformation processes of SMEs towards a CE orientation. Students are confronted with similar challenges in their studies and practical projects, such as limited time and resources, lack of knowledge about the methods and constantly changing requirements. At this level, a comparability can be derived that allows the context of the contribution to be extended to students. The main challenges are changes that require rethinking of product development processes (PDP), new skills and knowledge of new methods and a lack of resources (cf. [2], [3] [4] [5]). The development of circular products is a complex task that the use of new methods is necessary [6]. However, such methods are particularly advantageous for SMEs and small development groups like student projects as they are simple and easy to apply compared to complex LCAs which are therefore increasingly used by large companies. However, the acceptance of such methods in practice appears to be low [7]. It is primarily the consideration and inclusion of the complete product life cycle that makes a product development (PD) with a focus on the circularity of the product comprehensively complex, whereby several usage cycles may have to be included in the consideration. In addition, an understanding of the topic of CE is required within some method applications and a broader range of skills is necessary in PD [5].

For this purpose, design methods with a focus on the circularity of PD are useful and can support the accomplishment of complex tasks [8]. However, the growing number of CDM developed in recent years

represents a further challenge for users, as there is a lack of knowledge about design methods, their application and intercompatibility [9].

The contribution therefore addresses the question of which existing design methods from circular design support circular PD in the context of SMEs. It also provides an overview of existing design methods with a focus on circularity and thus a preselection of suitable CDM. In addition, the detailed examination of the content of the design methods from Circular Design provides further information on the spectrum of CDM and helps developers of new design methods to identify and address existing gaps. This will serve to help select such CDM and thus be integrated at first into the teaching of integrated design engineering (IDE) and furthermore become thus disseminated as a teaching aid.

# 2 RESEARCH APPROACH

In order to obtain an overview of existing product development methods that can be assigned to circular design, a systematic literature search will be carried out on February 18, 2023, using the scientific database *Scopus*. Search queries are formed from search terms that relate to topics of circular design, product development methods and product development. The search terms are specifically "circular design", "design for circularity", "Kreislaufdesign", "tool\*", "method\*", "Methode\*", "Werkzeug\*, "circular\*", "zirkulär\*", "Zirkularität", "product\*", "produkt\*", "tool\*", "method\*", "Methode\*", "Wethode\*", "Werkzeug\*", "design", "product development", "Produktentwicklung". A two-stage narrowing down and screening of the content of the 178 hits identified six design methods, six tools and two method catalogues that are relevant to the research field shown in Table 1.

Title	Туре	Year	Reference	<b>Cross-reference</b>
Circular Product Readiness Method	Т	2022	[10]	
Use2Use-Toolkit	MC	2021	[11]	
Circular Economy Assessment Tool (CCET)	Т	2013	[12]	[13]
Multi-Criteria Evaluation Method of Product-Level Circularity Strategies	М	2020	[14]	
Circular Business Model Planning Tool	Т	2018	[15]	
Consumer Intervention Mapping	М	2018	[16]	
Circular Composites Design Method	М	2022	[17]	
Circular Design Guide	MC	2017	[18]	[19]
Spider Map	Т	2015	[20]	[19]
Disassembly Map	М	2021	[21]	
Concept Circularity Evaluation Tool	Т	2020	[22]	
Emotional Durability Design Nine	М	2018	[23]	
Time-based Disassembly Method	М	2018	[24]	
Circularity Potential Indicator	Т	2017	[13]	

Table 1. Overview of the identified methods, tools and method catalogues

M = Method, T = Tool, MC = Method catalogue

A total of 45 relevant CDM are thus identified, including the design methods from the method catalogues. Furthermore, the identified CDM are evaluated and assessed using a qualitative utility analysis [25] of evaluation criteria from the areas of circularity, integrability and applicability [9] and grouped into content-related categories.

# **3 METHOD ANALYSIS OF CIRCULAR DESIGN METHODS**

The CDM identified from the literature review are analysed using a three-stage method selection process according to Ernzer and Birkhofer [1]. According to Figure 1, first, the identified CDM are evaluated

using a utility analysis. This creates a pool of relevant methods that can be embedded in the context of the PDP. Accordingly, a preselection of categorized CDM is created at the strategic level, from which SMEs can make a project-related selection.

To carry out the utility analysis, this contribution is based on a set of evaluation criteria that are subordinate to the requirements for CDM - circularity, applicability and integrability [9]. The design methods which meet the requirements are then assigned to activity-related categories of the PDP. At this point, the activities of the IDE approach according to Vajna [26] provide the basis for the content-related categories.



Figure 1. Three steps to select methods (according to [1], S. 1306)

The 45 CDM are evaluated according to the three requirements of circularity, applicability and integrability, and their subordinate evaluation criteria, which have been explicitly formed for the evaluation of CDM [9]. The evaluation of the assessment criteria results in both partial utility values and total utility values, which provide an indication of the suitability of the CDM for SMEs. In order to only consider CDM that are fitting the requirements, a minimum value is set at 2.5, which is the arithmetic mean of the highest possible score of 5. Table 2 shows results from the evaluation. By exclusion, 24 design methods that do not meet the requirements can be identified. This leaves 21 CDM that are considered relevant for the creation of an application concept. The examination of the methods shows that the reasons for exclusion are in most cases due to insufficient focus on the CE, lack of information and material for implementation or prototype status.

# 4 SETTING UP THE CIRCULAR DESIGN TOOLKIT

The evaluation of the CDM provides information on which CDM can be integrated into the PDP. In order to create a generally applicable catalogue of methods, the methods need to be assigned at an operational level. The IDE approach is used here due to its interdisciplinary nature and versatility [26]. The aim of the categorization is to group CDM with similar goals and application purposes in order to support developers in selecting the most suitable CDM for their project. For this purpose, the CDM are classified into categories that show which tasks and activities are supported in the PDP. This provides an overview of the tasks or activities for which a CDM can be used effectively. To create content-related categories, the activities in the IDE approach are used as a guide [27]. The classification of CDM into categories derived from the activities that occur during a product development results in six categories shown in Figure 2.



Figure 2. Method categories classified in the context of the phases of the IDE approach

The identified CDM are used conclusively at different stages in the product development process and support different goals and activities during the PDP.

	Circularity	Applic- ability	Integrat- ability	Utility value
Circular Opportunities	4,17	4,14	3,86	4,06
Circular Designs Ideation Pack	4	4	4,14	4,05
Concept circularity evaluation tool	4	4,29	3,86	4,05
Circular Brainstorming	3,17	4,43	4,43	4,01
Circular Flows	4	4	3,71	3,9
Spider Map	3,5	3,71	4,29	3,83
Use2Use Thinking Activation Pack	3,67	3,86	3,71	3,75
Insides Out	3,5	3,86	3,86	3,74
Service Flip	3	4	4,14	3,71
Disassembly Map	3,5	3,29	4,29	3,69
Circular Designs Evaluation Pack	3,17	3,86	3,86	3,63
Materials Journey Mapping	4	3	3,86	3,62
Safe & Circular Product Redesign Workshop	3,33	3,71	3,57	3,54
Circular Product Readiness Method (CPR)	4	3	3,57	3,52
Circular Journeys Exploration Pack	3	3,29	4,14	3,48
Smart Material Choices	3,5	3,57	3,29	3,45
Circularity Potential Indicator (CPI)	3,17	3,86	3,29	3,44
Multiple Use-Cycles Exploration Pack	2,83	3,57	3,71	3,37
Product Journey Mapping	3,67	3,14	3	3,27
Circular Business Model Planning Tool	3,17	3,43	3,14	3,25
Material Selection	4	2,86	2,86	3,24
Multi-Criteria CE evaluation method	3,33	3,14	2,43	
Regenerative Thinking	2,83	2,86	2,43	
Moving Forward with Materials	3	2,29		
The Circular Economy Assessment Tool (CET)	3,5	2,28		
Consumer Intervention Mapping Tool	3	2,43		
Circular composites design method	3,17	2		
Emotional Durability Design Nine	3,33	1,57		
Learn from Nature	2,33			
Time-based disassembly method	2,17			
Digital Systems	1,83			
Imagine New Partnerships	1,83			
Align your organization	1,83			
Continuous Learning Loops	1,67			
Circular Buy In	1,5			
Circular Business Model	1,5			
Concept Selection	1,5			
Launch to Learn	1,5			
Create your Narrative	1,5			
Building Teams	1,33			
Create Brand Promise	1.33			
Define your Challenge	1,17			
User centred Research	1			
Embed Feedback Mechanism	1			
Rapid Prototyping	1			

# Table 2. Results of the utility analysis of circular design methods

The architecture of the Circular Design Toolkit (CDTK) is created by developing the categories and assigning the CDM to them. Figure 3 shows the classification of the relevant CDM into six categories based on their content. Assigning the 21 circular CDM to the six categories results in a method catalogue that offers product developers a preselection of relevant CDM to develop products holistically for a CE and allows them to select CDM on a project-specific basis at an operational level.



Figure 3. Categories and design methods of the Circular Design Toolkit

# **5 DISCUSSION AND OUTLOOK**

This contribution identifies similar application hurdles which, as shown at the beginning (section 1), are lamented in the industry. Some CDM only exist in a prototype state and are not readily applicable for product developers. Furthermore, some CDM do not focus sufficiently on the principles of circular design and therefore cannot be used for the intended purpose. It should be noted that the utility value analysis is a subjective assessment. Accordingly, a further evaluation of the CDM by experts and users makes sense to counteract the subjective nature of the evaluation. Nevertheless, the analysis shows that CDM exist in order to be able to focus on a development towards the CE and support the work of product developers throughout the entire PDP. The contribution thus provides a selection of relevant CDM, as well as their content-related categorization for product developers in SMEs. However, methodological gaps were identified in the analysis of the CDM. For example, the methods for generating ideas largely relate to the concept of brainstorming and the CDM for strategy alignment are mainly aimed at technical cycles. There is a lack of methods that focus on the development of biological cycles. In addition, there are no methods that focus primarily the social dimension of sustainability. This raises the question of the balance between the dimensions of sustainability in the discussion about circular design and which methodological means can be used to enable a more targeted consideration of the social dimension in PD. In view of the results, the analysis serves as a prerequisite for the creation of a mature method catalogue, in which the categories and the CDM contained therein are visually prepared so that they quickly and easily convey the essential information that is relevant for product developers when selecting methods. In the following contributions, the CDTK will be finalized to create a basis for a continuous expansion of methodological knowledge and will be provided to the master course of the IDE to disseminate CDM-knowledge.

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# SYSTEMS THINKING IN DESIGN EDUCATION – THE CASE STUDY OF MOBILITY AS A SERVICE

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# ABSTRACT

Designers are faced with more complex, environmental and societal challenges than ever before. Those challenges require the ability to see how things are interrelated in the bigger picture and to analyse multiple causes and effects, rather than working from a siloed point of view. Systems thinking is a strong tool to enable designers and engineers to understand how an entire system works and how elements in the system are interconnected.

This paper demonstrates an approach to systems thinking and an analytical tool that could be applied to teaching future designers and engineers. This approach was used in the final year Advanced Design Management module during the 2023/2024 academic year at Aston University. This paper introduces a real-world Mobility as a Service (MaaS) trial that is implemented in the UK as a case study. It involves highly complex socio-technical systems whose investigation requires systems thinking. Cognitive Work Analysis (CWA), a systems level approaches, has been applied as part of the User-Centred Ecological Interface Design (UCEID) process.

Guidance will be provided to facilitate students' learning of an analytical tool for comprehensive system analysis and modelling. The benefits of applying systems thinking in the design and development processes of products and services based on a holistic understanding of the systems in which they are incorporated will also be explained.

The knowledge generated in this work is expected to inform design educators to recognise the importance of systems thinking. Ultimately, this will help them consider and apply systems thinking successfully in their teaching of relevant subjects with the enhanced knowledge of a systems level approach. This will facilitate future designers' problem solving of complex issues.

Keywords: Systems thinking, User-Centred Design, Mobility as a Service (MaaS)

# **1** INTRODUCTION

Contemporary societies are facing increasingly complex challenges and often they could have a ripple effect globally. Such challenges are "engineering system problems" that require cross-disciplinary effort and input [1]. They are often viewed as wicked problems as it is almost impossible to identify a specific cause or solution because the system components are highly interconnected. Systems thinking enables the complexity to be more fully recognised and embraced when addressing such problems [2].

Modern engineered systems tend to be combinations of social and technical elements [3]. Those systems are created to serve the users, rather than the technology itself, the users being one of the most important factors that constitute the system [4, 5]. Therefore, this study focuses on an approach to investigating complex sociotechnical systems as part of user-centred design whose primary aim is to maximise usability of the designed elements. Despite the well-known benefits of systems thinking, it is challenging to teach systems thinking and how to apply it in students' learning activities due to increasing complexity inherent in systems.

This study demonstrates an approach to facilitate students' understanding about systems thinking and their competency to use suitable approaches to their own learning. A real-world example of Mobility as a Service (MaaS) has been used as a case study for which a trial is currently being conducted in the Solent region of the UK.

The results of the study can produce benefits in the following manner. Teaching the systematic approach and relevant analytical methods could boost students' competence and confidence in applying systems

thinking in their studies and solving of problems that are often required in the context of highly complex sociocultural demands [6].

# **2 LITERATURE REVIEW**

#### 2.1 Systems thinking

Systems thinking has recently gained a significant attention in education research. A greater emphasis has been placed on systems thinking since the publication of the Benchmarks for Scientific Literacy [7], [8]. Understandably, it has also been incorporated in many curriculums globally [8].

Systems thinking is the cognitive ability to perceive wholeness rather than parts and pieces and to recognise the interconnections between elements in the system. It is suggested as being the ability to see how and why the system is organised and for whom [9]. Similarly, it is defined as the ability to comprehend "how an entire system works, how an action, change, or malfunction in one part of the system affects the rest of the system". It involves "judgement and decision-making; system analysis; and systems evaluation as well as abstract reasoning about how the different elements of work process interact" [10, 8].

Teaching systems thinking is important because complex systems have ambiguous boundaries that need to be judged from an appropriate understanding about how systems interact with their surroundings. Furthermore, once learners have a sufficient understanding about systemness, they are more likely to experience a distinct change in their ways of thinking about the world as well as their lives [9].

Modern engineered systems such as smart cities, automated vehicles and emerging systems enabled by artificial intelligence involve highly complex interactions among social and technical factors [3]. Those socio-technical systems involve complex interactions between humans, machines and the environmental elements of the work system. All those aspects should be considered when designing such systems [11]. Amongst those requirements, users' needs should be prioritised in the design of the systems to ensure usability of the systems. It is because the ultimate purpose of those systems is to serve the user, not to use the technology itself [4, 5].

Relevant principles have been suggested with the purpose to help inform the development of sociotechnical systems in which user-centred design is incorporated as a key part. The focus is on the understanding of users, their tasks, the environments and specification of the context in which the system will be utilised [11, 5].

#### 2.2 User-Centred Design

User-centred design processes suggest all the stages involved in a design and development life cycle. Each stage requires a deep understanding of the user who will be utilising the product [12]. It analyses potential users' preferences and needs in the initial stage in order to maximise usability of the product or service. It involves users to specify problems, to identify potential solutions and to generate inputs to refine the design outcome through iterative processes [13, 14]. However, how user-centred design is accomplished is left fairly open [5].

User Centred Ecological Interface Design (UCEID) suggests a novel method combined between usercentred and systems level approaches. It enables comprehensive analysis of a complex system with a focus on users' needs, capabilities and limitations. One of the human factors' methods that, is incorporated in the UCEID process is Cognitive Work Analysis [15, 16].

#### 2.3 Cognitive Work Analysis (CWA)

Cognitive work analysis (CWA) is a methodology for the analysis, design and assessment of complex socio-technical systems. It has been used for various purposes, such as designing interfaces, decision support systems and analysing training needs [17, 15, 18]. CWA consists of five phases of analysis, but Work Domain Analysis (WDA), the first phase has been most commonly used [17]. The results are presented in the form of an Abstraction Hierarchy (AH). It helps examine system constraints such as physical objects, their functions and values related to the overall purpose of the system [15]. AH consists of five levels of abstraction from the most abstract level, 1) 'functional purpose' to 2) 'values and priority measures', 3) 'purpose-related functions', 4) 'object-related processes', to the most concrete level, 5) 'physical objects'. Each level includes elements (nodes) correspond to the characteristics of the levels. Nodes at different levels are linked by means-end links that presents the relationships between them [15]. Nodes linked at the adjacent level immediately above explain why the functions are needed. Nodes connected at the adjacent level immediately below show how the functions can be accomplished [19].

# **3 CASE STUDY**

#### 3.1 Mobility as a Service (MaaS)

MaaS is a relatively new mobility solution that aims to provide seamless transport that incorporates a range of transport modes and associated services that aims to meet users' travel needs through a single digital interface [20]. Its core elements include real-time information for all modes available in the area, technological integration to plan, book and pay to suit mobility needs [21]. It encourages people to use more sustainable travel methods and reorganises transport to respond to sustainability challenges by offering alternative to private car usage [22]. More societal benefits are expected as a result of wider acceptance.

However, there are various challenges in designing MaaS in order to ensure the potential benefits are fully realised. Although there have been successful MaaS trials, it is not easy to define an optimal version of MaaS for a specific region. One of the main reasons is MaaS is significantly dependent upon the characteristics of the existing transport systems [23]. In addition, a high level of integration of those systems makes it even harder to determine the scope of design tasks and areas to focus on than when designing a single system. This indicates that the successful design and implementation of MaaS need holistic understandings of the current transport systems that could generate more practical design considerations. This can be achieved through a systems level approach, rather than investigations that concentrate on isolated elements of the systems or independent observations of social and technical systems [19].

# 3.2 Implementation of Cognitive Work Analysis (CWA) – Work Domain Analysis (WDA)

WDA was implemented to describe constraints in the MaaS system as part of the UCEID process. Relevant constraints were identified from a user's viewpoint and positioned at five different levels in AH. For example, the system boundaries were defined with respect to the system as experienced by users. For the development of the AH, information from various secondary and primary data were used. They were sourced from government literature [24], academic literature [25], design workshop studies [26, 27], participant observation studies and the Solent MaaS app usability testing studies [28] performed for the project.

Nodes at each level were identified based on prompts as follows in the order of top to bottom levels. They include: what are the fundamental goals of MaaS and why it exists (level 1); how well does the system perform to accomplish the fundamental goals (level 2); what are the effects of affordances and roles of physical objects in the system, and how do they have an impact on the user or how do they benefit them (level 3); what are roles and functions of physical objects in the system (level 4); what are roles and functions of physical objects in the system (level 4); what are any artificial, natural or physical components in the system that matter to the fundamental goals of MaaS (level 5). An excerpt from the full AH developed for the project is given in Figure 1.

Insights are generated based on the interpretation of the AH as follows. The fundamental goals of MaaS includes accessibility, sustainability, convenience and efficiency of transport (level 1). There are multiple ways to achieve those goals, such as maximising financial and physical inclusivity, maximising time efficiency of travel and increasing micromobility use as shown at level 2. However, due to space constraint, this analysis will only focus on increase of public transport (PT) use as it is one of the most sustainable methods of transport. PT use could be facilitated by all the nodes defined at level 3, that include optimization of PT journey planning, ticketing and booking as well as travel cost. It could also be encouraged by motivating people to help protect the environment and by recognizing the health benefits of using PT. Nodes at level 4 and 5 represent how those purpose related functions identified at level 3 could be attained. As shown in the AH, there are various physical objects that include payment systems, mapping systems, traffic statistics and user analytics that enable those functions described at the higher levels.

This analysis could be particularly useful for learners to understand the entire system that is under analysis and to see how system elements are interconnected. It could also help them understand what other elements that are linked directly or indirectly in the AH should be considered in their design in order to maximise the desired impact of the products or services they are designing.



Figure 1. Excerpt from Abstraction Hierarchy for MaaS for the Solent Mobility as a Service

*Note*: Means-end links connecting nodes at level 2 and 3 have been removed excluding those connecting 'Increase of PT use' marked in the red box and those at level 3 due to space constraint.

# 4 **DISCUSSIONS**

This section provides practical guidance on how to implement the systems level approach in teaching that could support students' learning about systems thinking. It also discusses how the application of CWA techniques could facilitate students' ability to practice systems thinking in their activities. This method was applied in a small classroom environment for the final year Advanced Design Management module during the 2023/2024 academic year. The students provided highly positive feedback. They mentioned that the method helped them think about functions of the service elements being designed in relation to the wider system. They also said that using the techniques enabled them to organise their thoughts which can be beneficial to further develop their design ideas. They were surprised to see direct and indirect relationships between elements discovered in the AH which they had not recognised before. When applying the method, it is recommended to encourage students to apply a systems level approach in their own projects by adopting the following steps. They were modified based on the Revell et al.'s UCEID process [16]. These steps can be performed in one session or multiple session depending on how familiarized students are with their own topic. First, once students have an initial idea on what products or services they want to design (areas to focus), the context of design and aims of analysis need to be defined. Second, a literature review on the topic can be conducted, including industry reports, government reports, statistics and academic literature, depending on what is currently available in the domain. Third, data collection can be performed through various methods that include technology benchmarking, subject matter expert and user interviews as well as focus groups. Fourth, a systemslevel approach can be implemented, such as CWA-AH based on the secondary and primary data. Explanations of the characteristics of each level in AH should be provided. It is recommended to encourage students to generate prompts for each level that suit the context of their own topic. It is because those prompts can inspire them to find relevant elements (such as physical elements, functions, values) appropriate for each level more effectively from the collected data. It is easy to start from the

top level that explains the fundamental goals of the system, then to go to the bottom level that presents physical objects in the system. Once the bottom level is completed, roles and affordances of those physical objects can be identified and positioned at the adjacent level immediately above. Nodes at the middle level could be established considering the impact of those roles and affordances on the user. The second top level contains nodes that can explain how the ultimate goals of the system can be attained. **Fifth**, once, elements (nodes) are appropriately positioned at each level, means-end links need to be created between nodes at the adjacent level immediately above and below. It is important to guide students to think about the interrelations of the elements they pay attention to (such as the product being designed) with the elements that are directly or indirectly linked in the AH that can be done by reviewing the nodes connected by means-end links. For instance, this activity could assist students to consider alternative solutions, ripple effects or trade-offs between potential solutions. It is also advised to help students identify how functions of the products and services being designed could be achieved by reviewing nodes connected at the lower levels in the AH, and why those functions are needed to accomplish the fundamental purpose of the system by analysing nodes connected at higher levels in the AH.

These steps can be adopted in any stages of the design process, however it would be more beneficial to apply in initial stages of design processes, such as the concept development stage. Holistic understandings about the systems in which their product or services would operate will enable students to consider a variety of possibilities in subsequent stages. In line with the principles of user-centred design, this systematic approach can involve multiple iterations for optimisation of the design.

# **5 CONCLUSIONS**

This study offers guidance in systems thinking and specific analytical techniques that could be applied in design related learning activities. Such techniques are a systems level approach within the broader context of user-centred design. A real-world case of MaaS was used as an example in which those techniques (CWA–WDA in UCEID) were applied. The processes could minimise ambiguity related to the identification of the system boundary and elements as well as their interconnections. Step-by-step instructions have been provided that could be applied in teaching systems thinking and practical skills. It is expected to facilitate students' understanding the functions of the product or service they are developing in relation to the entire systems.

Further work would involve teaching the approach detailed in this paper to an automotive specific module. For this, the Multiphysics System Design module on the Future Vehicle Technologies MSc at Aston University will be used during the 2024/2025 academic year. The teaching on the Multiphysics System Design module currently involves the development of control algorithms for autonomous vehicle operation, using the Roboworks Rosbot Plus TX robotic platform. Including the approach detailed above will give the students a chance to design the Roboworks Rosbot Plus TX robotic platform for a 'real life' operation/application.

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# BEYOND-HUMAN PERSONAE: VISUALISING ECOSYSTEM PERSPECTIVES FOR SUSTAINABLE INNOVATION

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# ABSTRACT

The evolving field of design and engineering education is increasingly focusing on ethical, social, and environmental issues, demanding innovative approaches that integrate ecosystem services and social entities into the design process. This contribution introduces the concept of 'Beyond-Human Persona' - a novel approach - that seeks to embody the needs and roles of non-human entities within ecosystems, thereby fostering a more inclusive and holistic approach to design. By focusing on examples such as field larks, bats, and wild bees, this contribution demonstrates how applications and tools can encourage biodiversity measures and adhere to animal-aided design principles. The utilisation of AI-assisted visualisation tools is explored to simplify complex ecological and social challenges, providing a clearer understanding of the interconnectedness of life, and facilitating the creation of more effective, sustainable and biodiversity-conscious designs.

Keywords: Non-human persona, more than human design, planet centred design

# **1** INTRODUCTION

The realm of human-centred design has long acknowledged the user as its core subject. Yet, the present environmental shifts echo the imperative to expand the focus to a broader perspective. Recognising that ecosystems are active participants in design processes, this paper seeks to integrate non-human entities into the design lexicon. This shift aligns with recent findings on species decline, highlighting the urgency for 'Beyond-Human Design Personae'. Such integration is not merely innovative; it is a necessary evolution of our design ethos to preserve the interdependent web of life. Within product development approaches Personae are fictitious, specific and archetypal characters that are used as prototypical representatives of certain user and target groups. They help companies to further develop their products by enabling them to better reflect the needs, goals and expectations of their customers. Personae<sup>1</sup> are therefore used to ensure that the company's products are aligned with the needs and expectations of customers [1].

By developing a persona, a company can better analyse what its target group needs and where possible opportunities and weaknesses lie in the user orientation and the product itself. By identifying with the target group, the development becomes more tangible for the project team [2].

The method has become established due to its low complexity and adaptability [3]. The usefulness for target group reflection, also in product development, was the top priority [4]. In the product development context, the method is mainly used to ensure that the results are aligned with the needs and expectations of the target group [5].

# **2 OBSERVATIONSOF A SHIFT TO RECOGNITION OF NON-HUMANS**

A review of human-centred design literature extends methods to non-human contexts. Trends toward non-human personae in design are evident, with an emphasis on including these perspectives in areas like smart city planning and sustainable systems. Tomitsch et al.'s work [6] highlights a move toward more inclusive practices, recognising non-human stakeholders. Social science perspectives suggest

<sup>&</sup>lt;sup>1</sup> In this contribution, personae represent the plural of persona, which is used as a mouthpiece for certain types of users. The understanding of the term is based on that of Kooschko et al. [7].

simplifying design choices may promote sustainable behaviour, highlighting the crucial interplay between humans and ecosystems.

In social sciences and product development, the concept of 'non-users' provides insights for extending human-centred design to include specific needs [8]. The exclusion parallels seen in user groups are akin to the neglect of non-human stakeholders in design narratives.

This contribution proposes a framework that considers the full spectrum of stakeholders, both human and beyond-human. Through mapping, empathising, narrative creation, and impact analysis, it advocates for an integrated approach that enriches design with ecological empathy and cooperative coexistence. These strategies not only enhance the design process but also aim to foster sustainable practices that respect the symbiotic relationships inherent in our ecosystems.

This contribution sets the stage for the presentation of the authors own methodology, which is informed by the latest in interdisciplinary research and grounded in practical design challenges.

# 3 PROPOSALS FOR THE IMPLEMENTATION OF BEYOND HUMAN ASPECTS

The following sections outline and highlight the relevant steps in the development process, including the AI alternatives. The proposal is based on the identification of elementary human needs and transposed to categories that are also found in the life cycle assessment. This is followed by a reflection and decision between human persona and non-human persona, which leads to a discussion of possible visualisation techniques. Possible tools for their realisation are then considered.

#### 3.1 Integrating basic human psychological needs

The aim is to succinctly integrate Hassenzahl's basic human needs [9]; autonomy, competence, relatedness, popularity, stimulation, and security - as motivational drivers in environmentally conscious design, extending these principles to beyond-human personae. For instance, leveraging the need for popularity can encourage adoption of sustainable behaviours, promoting environmental care as a pathway to enhanced social status [9]. Incorporating Desmet's 'design for virtue' encourages ethical behaviours benefiting the environment, aligning with needs like relatedness and competence, while 'design for pleasure' focuses on creating enjoyable experiences, linked to stimulation and pleasure, fostering positive environmental relationships [10]. This integration helps design products and experiences that meet human needs and promote ecological empathy, leading to sustainable, fulfilling design practices that bridge human and environmental well-being.

## 3.2 Personae generation based on well reflected categories

In this approach of creating Beyond-Human Personae, the authors propose to utilise typical Life Cycle Assessment (LCA) impact categories such as Climate Change, Land Use, Eutrophication Potential, Biodiversity, Pollutant Release, Acidification of Ecosystems, and Water Use as the foundation for developing individual personae. Each category forms a unique persona tailored to the specific product or project, reflecting its distinct environmental impacts and needs. Categories not relevant to the product are omitted, while key aspects like Biodiversity can be further subdivided and detailed if deemed highly relevant. This methodology ensures a profound integration of ecological considerations into the design process, promoting a comprehensive approach to sustainability.

The integration of LCA impact categories alongside the Sustainable Development Goals (SDGs) [13] forms a crucial foundation in our design process. This approach acknowledges that no individual designer possesses complete insight into the complex interplay of environmental, social, and economic entities. However, by grounding our personae in these established frameworks, we aim to capture a more holistic view of sustainability concerns. The LCA impact categories offer detailed insights into environmental implications, while the SDGs provide a broader perspective on sustainable development, encompassing social and economic dimensions. Together, they enable our personae to represent a more complete picture, reflecting the vast array of interdependencies within our ecosystem and encouraging designs that are mindful of their multifaceted impacts on both human and non-human entities.

#### 3.3 Beyond Human vs. Non-Human

The distinction between non-human and beyond-human personae is crucial for a reflexive and immersive discussion of the aspects in impact onto a persona.

In comparison, non-human personae focus solely on entities without human attributes, exploring perspectives distinct from the human experience. However, when considering beyond-human personae, the vision is extended to include entities that not only exist independently of humans but also those that are intertwined with human activities and decisions. By doing so, we acknowledge the integral role of interconnectivity in driving meaningful changes in behaviour and design practices, ensuring that our efforts contribute positively to the broader ecosystem.

Conversely, every human persona is developed with an explicit consideration of how it interacts with and impacts beyond-human entities. In each beyond-human persona that detail its impact on human needs, human health, and well-being, illustrating the shared existences of everything and its profound interconnectedness. This reciprocal consideration forms the bedrock of our strategy, aiming to cultivate empathy and responsibility across our design practices.

Integrating Hassenzahl's basic human needs provides insights into how design can harness these needs to foster sustainable behaviours and attitudes. Moreover, applying Desmet's 'design for virtue' and 'design for pleasure' aligns our design intentions with ethical standards and enjoyment, enriching the user experience while promoting environmental mindfulness.

#### 3.4 Possible Visualisation Strategies for the Personae

When it comes to visualising the complex relationships within ecosystems, the choice between AIassisted tools and images from the impact research phase is context-dependent, influenced by entities such as resources, time, licensing, and environmental impact considerations. AI tools can generate innovative, clear visualisations of interactions and impacts, offering flexibility and creativity in depicting ecosystems. Conversely, images from research provide grounded, authentic insights directly linked to specific environmental studies, potentially offering a more nuanced understanding. Furthermore, the classic visualisation through a sketch artist is a creative and very engaging option. All three options have their strengths which are shown in *Table 1*. The decision on which method to use should be tailored to the project's specific needs, available resources, and the desired level of engagement with the audience, ensuring the most effective and responsible conveyance of complex ecological relationships and sustainability issues.

Feature	AI-Assisted Tools	Photos	Manual Drawing
Strengths	Flexible visualisations; high variety in depicting ecosystems.	Grounded, authentic insights; directly linked to environmental studies.	Emphasises critical, impactful aspects through human interpretation and creativity; provides clarity and engagement.
Flexibility	High - can generate a wide range of visuals on demand.	Medium - dependent on available research imagery.	High - artist can adapt and focus on key elements as needed.
Authenticity	Medium - may lack specific real-world details.	High - based on actual data and observations.	High - captures human perspective and prioritises relevance.
Resource Intensity	Medium to high - depends on computational resources and software.	Low to medium - depends on access to and processing of research images.	Low to high - depends on the artist's skill and time investment.
Engagement	High - innovative visuals can attract attention.	Medium - authenticity resonates with informed audiences.	High - human touch can enhance relatability and emotional connection.
Best for	Exploring complex interactions and futuristic concepts.	Providing evidence-based insights and grounding discussions.	Highlighting key concepts and engaging audiences with a human- centric approach.

Table 1. Visualisation methods and their strengths and weaknesses

The choice between AI tools and photos and manual drawing is more than a matter of convenience; it reflects our commitment to matching the visualisation technique to the unique ecological and social context of each design problem.

# 3.5 Tools

To support the creation of Beyond-Human Personae, several tools can be utilised. The Idemat-app is instrumental for classifying environmental damages and relevant categories based on the materials used [11]. The Sustainable Strategy wheel [12] aids in identifying central problems of products throughout their life cycle. Digital whiteboard tools like Miro or FigJam facilitate the creation of personae by allowing for collaborative and visual mapping of persona characteristics and impacts. Looking forward, the development of a specialised tool to generate persona texts and images could significantly streamline the process, offering customised outputs that directly reflect the environmental considerations and sustainability strategies pertinent to each product.

# 4 **METHODOLOGIES**

The methodology for integrating beyond-human personae into the design process involves several key steps:

- 1. **Mapping Out Affected Entities**: Identifying the broad range of entities affected by design decisions, from individual organisms to entire ecosystems inspired by LCA categories, planetary and social boundaries or the Sustainable Development Goals of the UN [13]
- 2. **Research**: Investigating the behavior of ecosystems and the specific needs of the entities within them.
- 3. **Identifying Needs and Impacts**: Describing the needs of non-human entities and assessing the positive and negative impacts of design decisions on them.
- 4. **Empathising with Non-Human Entities**: Engaging in imaginative empathy to understand the experiences and needs of non-human entities and their connection to human needs.
- 5. **Story Creation (optionally beneficial)**: Developing narratives that encapsulate the roles and perspectives of these entities within their ecosystems and create stories affecting humans.
- 6. **AI-Assisted Visualisation**: Utilising AI tools to visualise the entities and their interactions within ecosystems, refining these visualisations based on iterative feedback.
- 7. **Inclusion in Decision-Making**: Conceptualising non-human entities as stakeholders in the design process, ensuring their needs and perspectives are considered in decision-making.

This methodology enables us to operationalise the beyond-human persona concept, making it a tangible asset in sustainable design endeavours.

# **5 DISCUSSIONS**

The integration of beyond-human personae into design education and practice offers a pathway towards more sustainable and innovative solutions to environmental challenges. By broadening the scope of design considerations to include the complex web of life, future designers and engineers can develop projects that are not only innovative but also ethically and environmentally responsible.

# **6** CONCLUSIONS

The 'Beyond-Human Personae' approach represents a significant paradigm shift in design and engineering, advocating for a more inclusive, sustainable, and biodiversity-conscious an approach. By leveraging AI-assisted visualisation tools, engineers and designers can easier and faster understand and incorporate the needs and perspectives of a broad range of non-human entities, leading to innovations that respect and sustain the intricate web of life that supports us all. This contribution contributes to the discourse on ethical, social, and environmental issues in design and engineering education, offering practical insights and methodologies for integrating more-than-human perspectives into the design process. By doing so, it not only addresses pressing environmental challenges but also paves the way for a future where design is truly inclusive and sustainable. In conclusion, this paper not only contributes to the discourse but also calls for a sustained commitment to expanding the boundaries of inclusive design.

# OUTLOOK

Future work will expand the beyond-human persona framework, testing it in various design contexts and evaluating its effectiveness. It is anticipated that this will lead to more ethical, sustainable, and innovative design practices that contribute positively to both human and non-human entities. As a look into the future, further refinement of the non-human persona framework will involve cross-disciplinary collaborations, underlining the universality and adaptability of the presented approach.

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# USE AND APPLICATION OF GENERATIVE AI IN MULTIDISCIPLINARY PROJECTS: LUNAR HABITACLES, AUTOMOTIVE CONCEPTS AND FUTURE SOUVENIRS

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# ABSTRACT

Artificial Intelligence is currently experiencing a period of "inflated expectations", according to Gartner and its Hype Cycle report on Emerging Technologies, August 2023. As part of this scenario, this article describes and analyses the exploratory approach and implementation of AI in three projects developed in 2023, in three different areas of the Tec 21 Educational Model of the Tecnologico de Monterrey: A five-week challenge with international partners and collaborators; a "Novus" fund for educational innovation, and a transversal subject of creativity and innovation for engineering and business students. In all of them, the use and application of Generative Artificial Intelligence contributed significantly – and in new ways - to the fulfilment of their objectives, as well as with new possibilities and reflections on their implications in the teaching-learning processes and the academic quality of their results. The range of exploration and development processes with Artificial Intelligence used, fed by sketches, 3D models or prompt engineering as a 'stimulus', showed from their use possibilities to detonate the formal genesis of architectural proposals for the exploration of different alternatives, accelerate the iteration phase in the creative process to design a car, and reduce the time and learning curve for the generation of digital representations or "renders". From these results, reflections on new emerging cognitive processes in students using AI, as well as reflections on possible implications and challenges in its approach from Latin America, could be extracted.

*Keywords: Higher education, professional education, educational innovation, artificial intelligence, design* 

# **1** INTRODUCTION

In 1975, in a publication called Edugrafología [1], while reflecting over the inherent qualities of human beings, Víctor Papanek argued that what "healthy" people do is design, in reference to the imaginative and creative capability of making decisions projected into the future, with the intention of influencing it and producing a desired outcome. Although this is true at its fundamental level, as these creative "projectual" processes inherent to designing became more specialized for certain desired outcomes (e.g. designing industrial products, houses, cities, etc.), they also became less accessible to a majority of individuals who did not choose to specialize in these traits, a matter aggravated by the fact that, currently, not even fundamental cognitive traits in design (e.g. project thinking, anticipated planning) are taught in most schools at primary and secondary education, leaving most of the students at this stage with a fairly limited domain of design capabilities in general.

More recently, however, with the arrival and peak of inflated expectations of Generative Artificial Intelligence [2], the creative process for generating new products becomes a much simpler and faster procedure for novice undergraduate students, enhancing their understanding and development of cognitive skills in design, by reducing the learning curve and generating less frustration while obtaining better results in less time. Likewise, for more experienced designers, this expands and accelerates the

iteration and formal exploration phase, generating a virtuous feedback loop for continuous improvement in new product development. As we have seen, the incorporation of AI in education has evolved rapidly in recent years [3], [4], along with several studies carried out on the potential impacts of AI on Education, over the last decade [5]. Hence, it is important to highlight that the growth of AI implementation in education is being accompanied by critical reflections over its ethical implications [6], [7].

This paper thus presents and critically analyses the case of three projects in design education that reflect an interlacement of the phenomena previously described. The projects employ the double diamond as methodological model [8], and specific design-related tools such as sketching, virtual modeling, and 3D printing, plus the incorporation of generative artificial intelligence, with the aim of introducing engineering and design students to a virtual environment which allows for their exploration of the possibilities of AI as a useful tool within their creative process [2], [9].

#### 2 METHODOLOGIES

As mentioned above, the double diamond model is the methodological basis for this descriptive, exploratory, and comparative work, where the use of Generative Artificial Intelligence is a common denominator among the three design projects.

In Figure 1 it can be seen how in the three projects based on the diamond model, AI is used in the divergent phases of both processes, first in the discovery phase, from an extensive ideation where the objective is to explore all possible forms and combinations, only to give way to the definition of the one that brings us closer to the desired objective and, move on to a second phase of iterations on the same idea, with the intention of improving it, detailing it and preparing it for final delivery.



Figure 1. Use of AI through the creative process in three different academic projects

The following sections will describe in detail the three projects and the way in which AI was used as part of their creative process.

#### 2.1 Case 1

The Formal Representation of Space "block" [10], the Tec 21 Model aims for students to design sensory rooms. The objective of the course is to promote, from the design, multidisciplinary critical dialogues that address the understanding of space through sensory perceptions and its material and virtual representation with the purpose of exploring multiple narratives. Concept, design, representation, materialization, and experimentation of a sensory room that inspires storytelling.

The methodology is made up of five stages, divided into five weeks: Experimentation and Analysis, Conceptualization, Synthesis, Enforcement and Delivery. At the start-up, they are introduced to their training partners and collaborators, who, in turn, present them with the brief of the challenge, its requirements and parameters. During the development of each of the stages, the student must have a log where they capture their ideas, concepts, and design process in a graphic way. In this process, students need to iteratively practice drawing techniques that are practiced as procedural content, as well as other experimental techniques.

Phases three and four are where AI is used as a tool for ideation and iteration, as can be seen in Figures 2 and 3, respectively.



Figure 2. and 3. AI applied in the ideation and iteration processes

#### 2.2 Case 2

On the other hand, and with the support of the Novus Fund for Educational Innovation [11], virtual and physical car models are being developed for a virtual car assembler [12], and this project began in February 2023 and will end in May 2024. The ultimate intention of this innovation is the development of skills related to the integration of emerging systems and technologies in Engineering and Design professional students.

The development of the models was based on the Double Diamond Model of the British Design Council [8]. The initial formal exploration of the car proposals (two and four seats) was carried out through photographs and sketches; Later, through several iterations in the process, different alternatives were developed produced by two different Artificial Intelligences: Midjourney and Deep Dream Generator. These proposals were reviewed by the design team to determine the best proposal that contains the required requirements and parameters. Figure 4 summarizes the design process of the two-seater car, with the support of AI and based on the Double Diamond model. Figure 5, for its part, presents the development of the four-seater car, based on the design obtained in the interior process.



Figures 4. and 5. Al assisted double diamond model

In this application of AI, for the development of original automotive models, we believe that it will be well accepted among Industrial Engineering and Product Design students. The above through hybrid learning experiences (digital and physical).

#### 2.3 Case 3

As part of the general education subjects at the professional level, Tecnológico de Monterrey offers a subject of Innovation and Creative Processes in which, one of its problem situations, the development of prototypes for a specific situation, related to physical inactivity as a global health problem, is offered. In the August-December 2022 semester, this project was developed integrating a participatory futures model called Tenkua [13], as a methodology for obtaining these speculative objects. Subsequently, in the August-December 2023 semester, a new group of students was presented with the same project with two new variables: the use of artificial intelligence and the methodological basis of a conceptual exercise called Souvenirs of the Future [14].

The group begin this work based on documentary research on physical inactivity and its various repercussions on people's health, ranging from disorders such as obesity or diabetes, to anxiety or depression. Once this research has been done, the students select a specific situation that may be feasible to solve hypothetically and conceptually, through the souvenir of the future that they design individually. Once they know the context of the problem they want to focus on and know all the variables to consider, they elaborate a 300-word text that helps them generate a prompt, which serves as a bridge between what is desired and what is obtained through different ideas exploration using artificial intelligences such as Leonardo. Adobe Firefly, Bing, Craiyon, Canva, and DreamStudio.

The result is a digital image that is detailed as a render and that manages to explain in a clear and visual way what the students captured in their text. The artificial intelligences used are free, some with a credit limit per day or with paid options to access their premium version, but, without a doubt, all of them, an excellent creative tool for representation and visual communication, which added to other online tools such as Miro or Canva, provide students with an accessible and easy way to generate quality products such as posters, for the presentation of their results and final project deliverables.

# **3 RESULTS**

The results obtained in the implementation of the three cases are presented below.

#### 3.1 Results of case 1

The challenge for the 33 students of Creative Studies ended with their exhibition in one of the largest museums in the city of San Luis Potosí, the Labyrinth Museum of Sciences and Arts. Family, friends, and academic authorities were able to appreciate the result of five weeks of work. In Figure 6 can be seen the final delivery, this consisted of the presentation of the 1:1 scale model, a poster with the explanatory video and the 300-word text previously developed, as well as a QR code with a descriptive audio of the project and elements in Braille, so that blind and partially sighted people could learn about the project, thus closing this collaboration between inclusive design, technology and studies of possible futures.



Figure 6. Poster and 1:1 scale model of Lunar Habitacles

#### 3.2 Results of case 2

Even though the project of this case 2 is in process, results can be observed from the implementation of the DDM, with the support of AI applications such as Midjourney, Leonardo and Vizcom, as well as the Rhinoceros 3D software and 3D printing with Stratasys and Anycubic equipment. As in any product design process, it is important to use 2D/3D drawing and virtual visualization tools, as well as validation prototypes throughout the process. Below, in Figure 7, you can see examples of the visualizations and 3D prints of the car development process.



Figure 7. Examples of the visualizations and 3D prints of the car development process

As mentioned above, the use of artificial intelligence applications was of great help in the development process of the two car models. It is also important to mention that several iterations were carried out with these applications, each time obtaining a more appropriate version that adhered to what was initially planned.

# 3.3 Results of case 3

The project was called "The Third Moment", alluding to the fact that this was the last of the three projects developed by the students in the semester. It is motivating for students to present their projects outside the classroom, as it becomes an important goal and commits the group to ensure that the quality of their work is at the level of an exhibition. In this case, we can see in Figure 8 what they developed, a poster and a model of their souvenir, all presented on a cardboard base with a display. The gallery that provided us with the space was the Central State Library, part of the San Luis Potosí Railroad Museum.



Figure 8. Poster display and prototypes of the Futures Souvenirs

# 4 DISCUSSION AND CONCLUSIONS

Based on the results of the implementation of generative AI in these three cases, we were able to observe that the AI model and the students co-designed their intended products through a series of iterations until the final design was deemed satisfactory. Such a process drastically reduces the technical skills required by students to produce high-fidelity images, while proposing a new emerging cognitive skill that refers to the "curation" of the cues chosen by them in each iteration. Thus, the result is obtained through a combination of hundreds or thousands of "micro design decisions" made by students and AI, the former through words and sentences, the latter through images and representations.

From this, we can affirm that the application of this technology streamlined the processes of exploration and validation of the first ideas, which made generative AI an effective tool in divergent stages of the design process, accompanied by precise and appropriate input from the human counterpart. Thus, creativity is shared between the human and the AI, redefining "what's possible" by combining the AI's database and the human's experiences, memory, and references, assisted by the internet.

In addition, it is key to consider the ethical implications involved in the use of generative AI, with the aim of achieving a balance between innovation and responsibility, where there is a clear ethical framework that encourages the productive use of this technology as a democratizer and enhancer of human design capabilities.

It is important to consider then that AI models are based on databases that contain human knowledge available in digital form, present in disproportionate quantities with respect to different geographies of the world, and that also include their normativity and biases. Therefore, biases in relation to gender issues, anthropocentrism, or modern Western hegemonic worldviews, among others, are also going to be replicated and projected by AI. Therefore, it is particularly relevant that, when using this tool in very diverse multicultural contexts, with coexisting worldviews, behaviours and lifestyles that occupy the same territory, as is the case of Latin American countries and cities, users continue to be critical of the visions projected by AI, since the results could strengthen such biases that position one cultural perspective over others. Consequently, these inherent features and limitations of the tool must be critically addressed, to ensure that the results obtained are truly beneficial to all individuals and populations involved.

In line with the above, the contributions that were developed in the Formal Representation of Space block arose from the dialogues, curatorship and critical reflections that served to interpret the context of

the project and establish proposals that contribute to the promotion of human dignity, having the cocreative imagination as a vehicle for the design of desirable futures.

Although the initial description of the use of AI in the cases mentioned above may seem limited, this first foray into the Latin American context perhaps focuses its lens on emerging cultural issues and sets a precedent for more in-depth research and applications in the future, including exploratory comparative studies between Latin American countries such as Mexico and Peru. We agree that it is essential to recognize that these initial implementations of AI in design in such contexts involve quite particular processes of learning and cultural adaptation, both designers and of the tools themselves. The intention to re-implement AI in future projects, with the aim of conducting comparative studies and expanding the sample, demonstrates a methodological approach of improvement, to avoid falling into an excessive dependence on AI.

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# ASSESSED DEBATES AS A METHOD OF DEVELOPING PROFESSIONAL SKILLS IN PRODUCT DESIGNERS

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#### ABSTRACT

Professional competencies, such as communication, negotiation, and critical thinking, are essential for success in the workplace. However, product design students often do not receive sufficient professional skills training and development during their university studies, resulting in difficulties in getting subsequent employment. For product designers, strong interpersonal communication skills are particularly important to their role amongst multi-disciplinary teams in industry, where designers are often required to liaise with management, engineering, marketing, and sales teams, and well as consult and negotiate with clients. Traditionally, product design education has centred around a studio-based model, where students spend significant time indirectly gaining professional skills through contact with educators and other industry professionals. While modern product design programmes typically include some studio-based classes, larger cohort sizes and the inclusion of more technical content means delivery and assessment methods have been adjusted to suit, with more lecture-based knowledge transfer and less student contact time. Other disciplines with significant technical content, such as the sciences and engineering, have incorporated debating as an assessment strategy. Debating has been shown to improve the professional competencies of students in technical disciplines and therefore may also be effective in product design education.

Keywords: Debates, product design education, professional competencies, skill development

# **1** INTRODUCTION

Professional competencies are essential for success in the workplace, and typically comprise of interpersonal skills such as effective communication, negotiation, critical thinking, and reflective practice. Across disciplines, employers prioritise adaptability, team-working, and the ability to communicate with stakeholders as key skills needed from potential employees [1, 2]. In many instances graduate employers will undertake additional or more bespoke technical training during on-boarding of new hires, and therefore professional competencies are rated as more important than creativity or technical capabilities when it comes to employability [3, 4]. Despite the importance of developing professional competencies for employment, product designers often complete their tertiary education with insufficient levels of professional skills for success in the workplace [5–7]. Students with poorer professional skills may experience greater challenges in gaining employment after graduation, particularly in terms of getting the job they desire, as graduate roles become more competitive [8]. While all jobs require general professional skills, product designers fulfil a particularly varied role which often involves liaising with stakeholders from different backgrounds and is sometimes described as an 'integrator' role within an organisation [6, 9]. In a professional context, product designers may be required to interact with a variety of internal and external clients on a daily basis. Design graduates are sometimes employed in non-design businesses, where their colleagues may have little to no knowledge of design practice [5]. Even those employed in design consultancies or engineering firms must be able to communicate clearly with team members of diverse professional backgrounds, such as management,

sales, marketing, and manufacturing.



Figure 1. Flowchart depicting the client-designer relationship at different stages of the design process in professional settings, from Lewis et al. [2]

Employers perceive that the main purpose of designers is to deliver products that meet client-specified needs [3] and therefore the client-designer relationship is critical in professional settings. This relationship is illustrated in Figure 1, where the designer is expected to engage with the client at almost every stage of the design process and be able to both receive feedback and deliver outputs throughout the design process. Key skills identified by employers include negotiation with clients (e.g., during task definition or when selecting design directions) and interpersonal skills (i.e., the ability to develop a rapport and work constructively with clients and colleagues) [2]. Despite the importance of such skills in industry, product design graduates often lack sufficient professional competencies, in part due to employer's low confidence levels in students' communication and negotiation skills [5, 6]. The demand for graduates with transferable professional skills is high, and the importance of collaborating in cross-disciplinary teams is likely to increase in the future as real-world design problems become more complex [10].

# 2 PEDAGOGICAL APPROACHES TO PRODUCT DESIGN EDUCATION

Product design is both a creative and technical discipline, meaning a mixture of educational approaches are used by higher education institutions to teach a variety of design skills. Traditionally, design education has been centred around a 'master-apprentice' model, where students gain first-hand experience of the skills needed in design through studio-based classes [11]. In studio classes, instructors model appropriate professional behaviours and cultural practices which students can observe and adopt. Students are thereby inherently developing professional skills throughout their educational experience [12, 13].

However, product design education is beginning to incorporate more technical content and skills; some universities now house their product design schools under engineering faculties and offer majors such as 'Industrial Product Design' [12, 14, 15]. Product design can comprise of specialisations including industrial design, digital (UX/UI) design, game development, and chemical formulation; these subjects require a significant amount of technical knowledge similar to engineering and science degrees, as well as the development of creative design practice [15]. As such, contemporary product design education often encompasses a combination of approaches, with technical content conveyed through lectures and workshops, while design studios and group project work provide active, experiential learning methods. Due to the added technical content, these degree programmes have a broader focus and wider appeal, leading to higher student numbers. Therefore, there is limited time and staff availability for studio-based classes, meaning students receive less contact time and pick up fewer professional skills during these classes. Product design now faces the so-called 'competence dilemma' which has been well documented in engineering disciplines [5, 6, 16, 17].

# **3 DEVELOPING PROFESSIONAL SKILLS THROUGH DEBATE**

The contemporary approach to product design education as a combination of engineering and design teaching methods means students are exposed to a wide range of assessment methods including portfolios, posters, written reports and exams, and verbal presentations. Verbal presentations, critiques, and 'flipped' lectures are typically considered valuable for developing professional skills, as students

gain experience with public speaking and communicating effectively [19–21]. However, these strategies are typically only 'one way' activities where opportunities for back-and-forth discussion are limited, and therefore do not always address professional competencies such as negotiation, adaptability, and critical thinking [22].

Debate is an educational tool involving contradictory discussion by students on a particular topic. Students are required to formulate and present persuasive arguments and defend their stance on the spot in response to rebuttals and questions. Debates have been strongly linked to professional skills such as negotiation, discussion, and interpersonal communication [23], all of which have been identified as key elements of a designer's professional identity and skill set [3]. Debating has been shown to increase understanding of the subject at hand, improve student confidence, and enhance reflective practices [17, 24]. Other benefits of using debate as an assessment strategy include the development of teamworking and cooperative approaches [25] and improved critical thinking and effective communication under time pressure [26, 27]. Students perceive debating to be a valuable and effective assessment method, with the majority finding that enjoyment of the challenge outweighed any experiences of nerves or anxiety [28– 30]. Additionally, students tend to conduct a greater depth of research and obtain a better understanding of complex topics within their discipline [31]. Debating has been implemented in fields such as medicine and nursing [32-36], language [37], culture [38], education [23, 39], political science [40], geography [27], and business studies [41, 42]; development of students' professional skills has proven successful in these areas. More recently, debating has also been incorporated into undergraduate and postgraduate courses in civil, chemical, and mechanical engineering [24, 29, 30, 43]. As yet, there has been limited exposure to debating in product design education.

# **4** IMPLEMENTING DEBATES IN PRODUCT DESIGN EDUCATION

Beginning in 2021, debating has been incorporated into a Masters' level 'Design Ethics' course as part of the postgraduate product design programme at the University of Canterbury in New Zealand. An excerpt from the course outline described the course:

"...develop an understanding of the concepts of ethics in design in a practical sense... it will introduce students to the many aspects of ethical and moral debate within the contemporary product design industry... through the nature of the course and its assessment it will develop student's research competencies, communication and debating skills, all core skillsets in the contemporary designer's tool kit."

The assessment activities scaffold multiple debate sessions on an (educator provided) topic, followed by the debate of a self-selected topic and the creation of a journal-style paper discussing the final topic of debate. The inclusion of debates has served as both an assessment methodology and scaffolding upon which to build learning, and a trial to determine the impact of regular debating on the development of design students' professional skills. The methodology introduced has remained largely consistent year on year, comprising three group debates and one individual debate over the duration of the course. The debates were structured to require:

- An opening statement (approx. 3-5 mins per team)
- A period of debate between the two teams (approx. 15-20 mins total)
- A closing statement to conclude (approx. 3-5 mins per team)

This debate structure was based on typical formats described in literature [29, 43]. Students were informed about the debate format and requirements prior to the assessment through lecture presentations, in line with recommendations from Bradshaw et al. [44]. Teams were given in-class time to bond and form group working strategies, and lectures on the debate topics were provided as a starting point for their arguments. Teams were informed of their debate topic and stance one week prior to the debate; preparation time in the literature varied from as little as 10 minutes before the debate up to multiple weeks [29, 30, 43, 44]. However, the intention in the course was to allow students to conduct in-depth research and gain a deeper understanding of complex ethical issues [29, 30, 43, 44], and one week was considered sufficient.

Anonymous course evaluations demonstrated that students found the debating experience valuable, with one student stating: "The interaction of the assignments was a fun way to learn knowledge and literature. To then form a perspective to present back. This was engaging and made learning easier to do on topics. The debate format was also something that has not been covered before in this course and was a refreshing change of pace that felt more appropriate for a postgraduate course, over a standard

presentation." The course team required students to debate for and against a number of core topics, including:

- Product Design is an Ethical Discipline
- Design for Good Can be Profitable
- Successful Design Relies on Successful Manipulation

The choice of (somewhat) controversial topics relating to design ethics was described as "engaging, interesting and topical" and supports the findings in literature that debating ethical issues has been shown to be popular amongst students. Across disciplines, controversial topics were highlighted for their ability to create an interesting debate with different perspectives as well as to deepen students' understanding of complex issues [27, 30, 43, 45]. Debates which discuss ethical issues allow students to reflect on the current state of their discipline; in a design context this may help students develop more reflective and critical thinking as part of their design practice. Within this course, educators observed a developing capacity for debate as a practice, as well as student exhibiting greater self-reflection throughout the semester. This reflection helped to cement learning and indicated an improved ability for students to critically analyse their own performance within the course, without the need for formative or summative feedback as seen through traditional assessment practices. In literature we see that the opportunity to reflect and improve on past performances is linked to improved professional competence, particularly lifelong learning [17, 26]. This suggests that a series of multiple debates within a course is likely to have a greater impact on students' professional skill development. Another important factor is the assessment criteria chosen - the literature suggests that students' performance should not depend on 'winning' the debate and should instead be based on fair criteria such as research quality, presentation clarity, strength of arguments, and effective responses to rebuttals [30, 32].

#### **5 CONCLUSIONS**

Educators need to provide more support for the development of product design students' professional identities and skill sets in preparation for entering the workforce. Debate has been an effective assessment method for improving the professional skills of students in other technical disciplines. Additionally, early trials of debating in a postgraduate product design course at the [ANONYMOUS] show promise, with high student engagement and positive feedback regarding the debates in the course. Further research is needed to more definitively understand whether debating is an effective assessment method for developing the professional skills of product design students. Gaining an understanding of students' and educators' experiences of debate in the product design context, as well as analysis of student performance across the duration of the course, may provide insight into the efficacy of debating in product design education. Further research is likely to include a thematic analysis based qualitative study to gather student perspectives for greater confidence in results.

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# SPECULATIVE DESIGN THROUGH THE LENS OF AI

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## ABSTRACT

This review paper explores the evolving relationship between artificial intelligence (AI) and speculative design. Through a literature review analysing ten case studies, this paper highlights the nuances of using AI-driven tools in envisioning speculative futures. The paper investigates how AI influences speculative design approaches to identify the benefits, limitations, and potential challenges when combining the two. The results are presented according to the three most prominent themes identified across the ten articles: using AI for image generation, perceived accessibility of AI, and using AI to envision future scenarios. While using AI to automate parts of the design process is perceived as a significant benefit, some also regard the results produced by AI as uninspiring and needing more contextual factors. This is addressed in the discussion section, focusing on the challenges of AI-generated images. Lastly, this paper discusses the ambiguous terminology used about speculative design and what implications this could have for future research.

Keywords: AI tools, generative AI speculative design, design fiction, critical design

# **1** INTRODUCTION

Technology is becoming increasingly advanced and more accessible than ever. This is reinforced by the emergence of artificial intelligence (AI), which has developed even further over the past few years, bringing countless new opportunities. As AI continues to become more mainstream, riding off the success of the language model ChatGPT and the vast possibilities of text-to-image programs such as Dall-E and Midjourney, there are many unanswered questions about adopting these tools. Exploring these new possibilities with a sense of urgency and criticality will be necessary, as many disciplines, including design, are entering uncharted territory. We have moved beyond debating whether AI will have a role in design to discussing exactly what role it will play. Recognizing the impact and utility of different AI tools and differentiating helpful tools from potential distractions seems increasingly vital to understanding how AI can be useful within various areas of design. Focusing specifically on speculative design approaches, this literature review maps out ten different use cases to identify the benefits and challenges of using AI in design. The structure of this paper is organized as follows: the first part is a general introduction to AI, speculative design, and the terminology this article entails. The second part involves the methodology conducted throughout this review and presents the case studies that serve as the base point for this paper. The third part introduces the findings, highlighting how AI is used in speculative design and pinpointing advantages and disadvantages. Based on these findings, the article then culminates a discussion about using AI-generated images in speculative design and the challenge of unclear terminology when researching this topic.

# **2 THEORETICAL BACKGROUNDS**

# 2.1 The emergence of generative AI

AI covers many opportunities, from general abilities like learning and understanding to more specific tasks like playing chess, creating poetry, and diagnosing diseases [1]. One of the emerging parts of AI is generative AI, an artificial intelligence model that analyses existing data and creates new content like images, text, and music from that data [2]. Ray [2] states that models like *ChatGPT* are versatile applications that can be utilized across various domains. This is further emphasized by Latif et al. [3], who highlight the capacity of generative AI models like *ChatGPT* to summarize text, do problem-solving and creative writing, and answer complex questions. As these models keep evolving, it is predicted to affect the jobs of coders, writers, marketers, and designers [4]. Latif et al. [3] do, however,

state that it is difficult to assess the model's capabilities and is, therefore, more uncertain about the immediate impact on the creative industry.

# 2.2 What is Speculative Design?

For the past two decades, speculative design has played an important role in challenging the status quo of design practice and raising discussion about technological development [5]. Many have embraced this critical design domain, and there are currently numerous definitions and interpretations of what speculative design entails.

Mitrović et al. [5] explain speculative design as a discipline that asks critical questions about the future while highlighting and presenting how the future might look and offering some essential alternatives for today and tomorrow. Auger focuses more on the utility of speculative design, describing speculative design proposals as "tools for questioning" [16, p.29]. He argues that speculative design aims to showcase how technology affects or may affect our lives to create a discussion about the subject. Lukens and DiSalvo [8] emphasize speculation as a design practice encompassing practices from across various disciplines. They highlight the importance of technological fluency in speculative design moving forward, as the discipline keeps blending multiple design approaches. The need to understand technology and how to use it is becoming even more prevalent as speculative design is getting more recognition as a design practice. Dunne and Raby [6] discuss other design disciplines closely related to speculative design. They point out that several disciplines, such as design fiction, overlap interchangeably. When Lukens and DiSalvo [8] explain the term design fiction, they use speculative design to differentiate design fiction as a more recent manifestation of speculative design.

# **3 METHODOLOGIES**

#### 3.1 Identifying articles

Google Scholar was used to find and identify articles about the use of AI and speculative design. The publication search range was set to post-2018 to focus on research from the past five years and obtain the most up-to-date research. When locating articles predominantly about speculative design as a design practice, the search range was set to post-2000 to get a broader perspective. The search words used to identify articles about the use of AI in speculative design were a combination of: "speculative design" AND "artificial intelligence," OR "AI" OR "generative AI" OR "AI tools." This resulted in 2620 results on Google Scholar. However, most of these articles were found not to be articles about the use of AI in speculative design but rather a combination of words like "AI" and "speculative" without a clear connection to the design discipline. As mentioned in the introduction, several design approaches and terminologies are closely related to speculative design and without clear differentiations. Thus, articles mentioning "design fiction" and "discursive design" were deemed closely enough related to speculative design to be included in this review and increased the dataset to 11,000 results. A process of locating and selecting articles that addressed the use of AI in speculative design projects was done by identifying abstracts, conclusions, keywords, and introductions that described use cases of AI in speculative design. This preliminary screening resulted in ten articles offering a comprehensive overview and highlighting AI's most important use cases in speculative design. The ten articles are shown in Table 1, with title, author, publish year, and a brief description of the use cases.

# 3.2 Analysis

The ten articles were analysed based on the following parameters: use case of AI in speculative design, advantages, and disadvantages. Afterward, the data findings were contextualized and compared to books and articles discussing the general benefits and problems with speculative design. This was done to identify if similar issues occur with or without the use of AI, if new problems arise, and if some specific areas are better suited for using AI.

Name	Author(s)	Year	Use case
AICA: Artificial Intelligence Conversation Assistant [18]	Bhatia et al.	2020	Future scenario,
			Prototype
			Testing concept
Poetics of Future Work: Blending Speculative Design with	Yams and	2019	Co-creation
Artistic Methodology [13]	Muñoz		Future scenario

Table 1. Articles with publishing year and use-case

			Ideation
Generative AI Futures: A Speculative Design Exploration [9]	Lin and	2023	Visualize artifacts
	Long		Ideation
			Image generation
Exploring the Reflective Space of AI Narratives Through	Hohendanner	2023	Future scenarios
Speculative Design in Japan and Germany [16]	et al.		Create artifacts
Contestable Camera Cars: A Speculative Design Exploration of	Alfrink et al.	2023	Future scenarios
Public AI That Is Open and Responsive to Dispute [12]			Concept video
Pushing divergence and promoting convergence in a speculative	Simeone et	2022	Co-creation
design process: Considerations on the role of AI as a co-creation	al.		Ideation
partner [14]			
Work of Fiction: Using Speculative Design to Deliberate on the	Kaur et al.	2022	Future scenarios
Future of Hiring [19]			
Introducing Speculative Design, Gender, and AI in Lean UX for	Gonzalez	2023	Future scenarios
HCI Education [10]			Ideation
			Image generation
Artificial Design Fiction: Using AI as a Material for Pastiche	Blythe	2023	Image generation
Scenarios [11]			Future scenarios
Co-Design Futures for AI and Space: A Workbook Sprint [15]	Mucha et al.	2020	Future scenarios
			Co-creation

# 4 **RESULTS**

This section breaks down the three most prevalent themes identified across the ten articles: Using AI for image generation, the experienced accessibility of AI, and the use of AI in creating future scenarios.

# 4.1 Image generation

The emergence of generative AI tools that create images, such as *Dall-E, Midjourney*, and *Stable Diffusion*, has opened new opportunities within speculative design. Three of the ten analysed articles write about using AI to generate images or artifacts. Lin and Long [9] used generative AI tools to create speculative designs and visualize artifacts that have yet to exist, bringing new, realistic manifestations of ideas to life. González [10] also utilized image generation in her workshop, where students created personas, wireframes, and images of the future. She states that AI can produce realistic images, which can be used in a design process. Blythe [11] expands on this concept, highlighting the use of image generation in provocative design fiction to stimulate debate and raise awareness about the climate. He emphasizes the ease of producing these fictional images and sees them as a good tool for discussing different topics. On the contrary, he also mentions that AI-generated images make it seem like a more simplistic narrative and fail to consider the complex social, political, and environmental problems surrounding it.

While González [10] focused on creating realistic images, those were still directed toward a speculative design context. The focus was creating user personas and prototypes to allow designers to explore different designs quickly. In Blythe's [11] case, the images created were not realistic, as he classified the images as nothing more than helpful to be used in a mood board or as a think piece in developing a concept further. One of the problems with speculative design today is the over-eagerness to make speculations seem real [6], exemplified in González [10] workshop. Dunne and Raby [6] argue that doing so results in a lack of inspiration and becomes a target of practical thinking. Thus, Blythe's case seems closer to the use of AI that Dunne and Raby envision for speculative design, as the images are created to strike a balance of not being too realistic while still being relatable enough to be a piece for discussion.

# 4.2 Accessibility

Despite their boost in popularity, speculative design and AI are two disciplines shrouded with unfamiliarity and a general lack of understanding among many. Speculative design might overlap with other design approaches, and AI is complex and constantly changing. It is challenging to grasp either well, let alone both in combination. Alfrink et al. [12] highlight the need for sufficient experience and understanding to constructively debate the implications of implementing AI. Yams and Muñoz [13] experience that using speculative design in future scenarios made it easier for non-programmers to explore different futures. These futures were produced using AI, and through their case study, they also

observed that the more the participants used and learned about AI, the more positive they became towards the technology. They started exploring and ideating more positive futures as they gained more knowledge of what they previously experienced as a complex and challenging technology. Yams and Muñoz, therefore, stress the importance of giving the participants sufficient time to learn and enable them to adapt the use of these tools to fit the needs of their organization. Giving them time to adapt it to their organization also strengthens their understanding as they relate more to their work. Through the same study, it also became clear that the results generated from AI depend on the participants' creative mindset and skills. The students in Simeone et al. [14] highlight the lack of proficiency as a challenge when working with AI as a co-creative partner. The students needed time to understand how to use AI and even expressed their desire to understand some of its fundamental aspects. Later in the process, when they were more familiar and experienced with using AI, they felt that the AI functioned as a cocreative partner. Mucha et al. [15] also mention that AI is perceived as abstract and not well understood by outsiders. They stress the importance of making AI understandable and accessible to more people and propose that design could mediate this gap between people and technology. Throughout their study, they also observed that people became more positive towards AI as they became more familiar with using its tools, which resembles the opinion of the students in Simone et al.'s study [14].

#### 4.3 Future scenarios

Eight of the ten reviewed articles mention the use of AI in speculative design concerning speculations about the future. The use case for these scenarios ranges from creating future scenarios to increase creativity and engagement [13] to envisioning futures where technology-driven digital public spheres are a reality [12]. Throughout the eight articles that use some future speculations, the terminology used when mentioning the future differentiates and ranges between using *future scenarios* [16,15,13], *plausible futures* [9], *possible futures* [13,17], *desirable futures* [15], and *pastiche futures* [11]. Some articles, like Blythe [11], use multiple words, like pastiche, future, and speculative scenarios. The common determinator between the articles is that they all use scenarios to speculate about the future, even though the terminology differs.

In Yams and Muñoz's [13] study, using AI allowed the participants to create products and services for future scenarios. The scenarios made it easier for the participants to understand the negative and positive implications of the products they were creating. Combining AI and scenarios made the participants more creative as they explored more possibilities. Lin and Long [9] saw similar results in their case study, where they experienced that creating scenarios through AI made it easier to develop different concepts. It also helped them to envision what a particular future might look like. Simeone et al. [14] had a different way of utilizing future scenarios, as they asked their participants to create possible future worlds with AI. The scenarios created enabled the participants to engage in the task and think creatively with a specific goal in mind. Yet another way of utilizing scenarios in speculative design is illustrated by Blythe [11], as he introduces AI to make pastiche scenarios. Pastiche scenarios differ slightly from future scenarios. The introduction of AI, especially language models, makes producing text in various styles and creating pastiche scenarios easier. However, Blythe critically points out that despite its flexibility and potential, currently, AI does not create sufficiently compelling pastiches.

# **5 DISCUSSIONS**

The analysis of the ten articles has located the advantages and disadvantages of using AI in speculative design. For the next part, the paper will focus on image generation, its challenges, and its potential use in speculative design in the future. The discussion will then delve into speculative design's imprecise terminology and implications for future research.

# 5.1 Challenges with image generation

Imagery and storytelling are essential parts of speculative design, as this is one of the primary methods, besides prototypes, to convey a design and create meaningful discussions. Utilizing AI, designers can make quick iterations with an immediate visual response. Quick iterations open the possibility to further experiment with diverse and creative visuals, and creating AI-generated images might also inspire designers to discover and experiment with different directions [14].

Understanding the current challenges of speculative design can help contextualize and point out other benefits and limitations of using AI. Dunne and Raby [6] draw attention to the challenge of realism and

how too realistic images can limit the imagination of the people observing them. They highlight the usefulness of cartoon-like images, inspiring people to daydream and think more freely. AI can be prompted to create cartoon-like or unrealistic images, producing many variations in a short time, giving it a significant advantage over traditional approaches. Programs like *Dall-E* and *Adobe Firefly* allow the user to easily alter the image style and compare different images. Thus, the challenge of using AI-generated images is not in creating these images but rather in the designer's knowledge and capability to prompt these programs to achieve the desired results.

Similarly, Blythe [11] expresses disappointment in AI's ability to produce novel and exciting ideas. Even though he highlights automation as beneficial when creating scenarios with AI, he also experienced that most of the images he created were unusable or merely good enough to inspire a final concept. This may be why there is still not an abundance of research illustrating the use of AI-generated images in speculative design. As for now, it is still demanding to use AI to achieve desirable results. It requires the knowledge and time to prompt the programs properly. How long this will be is uncertain, as technology keeps improving. *Dall-E* just released its third iteration, improving the program's understanding of contextual factors and making it more accessible to achieve better results [17].

#### 5.2 Ambiguous terminology

A significant part of this review has been dedicated to identifying articles discussing the use of AI in speculative design. The terminologies used within speculative design overlap, and terms like design fiction, critical design, speculative design, and design future are used interchangeably. A lack of a standardized vocabulary about speculative design can risk confusion or misconceptions. Taking a closer look at how Blythe [11] utilizes terminology, one can exemplify the difficulty in differentiating various design approaches. The beginning of this article gathers critical and speculative design in the same explanation, stating that they often aim to stimulate debate or raise awareness. Auger [7] reflects upon this ambiguous terminology and states that the difference between design fiction and speculative design is subtle, making it difficult for people outside the design community to differentiate speculative design from other related disciplines. Similar tendencies can also be spotted with Dunne and Raby [6] when they point out that design fiction is a narrower genre than speculative design and focus more on using fiction as a workshop tool to explore the implications of technology. By this definition, the study conducted by Lin and Long [9] might seem closely related to design fiction, as it revolves around the future of technology and has a workshop format. The article still refers to speculative design, not design fiction, indicating a discontinuity in how these terms are differentiated among scholars and practitioners. This interchangeable use of terms is further exemplified by how the ten articles use different words to describe future scenarios (see Section 4.3). Additionally, Lukens and DiSalvo [8] explain speculative design as an umbrella term, encompassing practices from different design disciplines. This emphasizes how difficult it can be to distinguish the scope of speculative design from other disciplines, making it harder to use the correct terms. Consequently, locating research connected to AI and speculative design becomes challenging, as only nuances separate speculative design from domains such as critical design. This ambiguous terminology may affect research efforts as highly relevant articles can become challenging to identify due to unclear or inconspicuous search terms. The further AI is being improved, the more research conducted, the more prominent the need for precise terminology might become.

#### **6** CONCLUSIONS

This review has highlighted how AI is utilized in speculative design by analysing ten papers. The case studies illustrate the current use of AI tools in speculative design and pinpoint their advantages and disadvantages. Utilizing AI to generate future scenarios appears to be the most common use case in these papers, as the current AI tools are accessible to designers and can produce adequate results. A benefit of using AI is that it gives people easy access to envision and reflect upon the implications of specific scenarios, functioning as a tool to encourage discussion. For designers, such use of AI can also help to improve creativity, allowing them to challenge themselves to delve into future problems with a more critical mindset. Combining future scenarios with images to either present a potential future or visualize future concepts is identified as one of the primary uses of AI in speculative design. AI enables the rapid creation of images and the possibility to iterate at a moment's notice, testing various image styles ranging from realistic to cartoon-like. Although such image generation can potentially be an important asset in speculative design moving forward, the analysis of the articles also illustrates that AI-generated images currently are perceived as a bit lacklustre, without a solid conceptual framing, or at
best suited as preliminary inspiration. At the rate AI is developing, it might not be far into the future before speculative design can utilize the full potential of AI in more parts of its practice. However, more experience and research need to be added, and a better distinction between different terms used in speculative design could increase awareness about AI's potential and further research on the topic.

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# THE BOUNDARIES OF INDUSTRY-ACADEMIA INTERACTIONS: FIRST STEPS TO PREPARE IA-DESIGN EDUCATION FOR SOCIETY 5.0

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# ABSTRACT

This article explores the integration of digital and physical assets in Society 5.0, emphasising the role of design and AI education in addressing societal challenges through technological innovation. It advocates for an agile action research approach in design education to equip students with practical skills for realworld challenges, aligning with global trends in human-centric design. The research methodology involves a collaborative effort among 20 academics, industry professionals, and students, and in this paper, we are analysing data from two workshops. The workshops focused on understanding integration models between industry and academia. This study used qualitative analysis and tools like Python's Matplotlib and NetworkX libraries to examine the workshop deliverables. It is predicated on the idea that transformative industry-academia collaborations will be essential in Society 5.0, requiring a synergy of theoretical research and practical applications. It underscores overcoming bureaucratic and trust barriers to create sustainable, impactful collaborations. Our outcome so far is that the success of industry-academia partnerships depends on the following key factors: alignment of values, effective translation of academic research into practical applications, empathy in the context of multidisciplinary collaboration, clear communication and expectation management, and a focus on broader societal impacts. Future research focuses on integrating technologies with Society 5.0 objectives, enhancing cooperation, and reducing discrepancies between academic theory and industrial practice.

Keywords: AI Integration, educational innovation, Society 5.0

# **1** INTRODUCTION

As we move towards smart societies driven by technology and innovation, we face significant knowledge gaps and challenges. This transition aligns with Society 5.0 principles, a concept conceived in Japan where digital and physical realms are integrated to drive economic progress while solving societal issues concomitantly [1]. Simply put, it recognises that we can no longer develop things just because we can (for profit only). Embracing digitalisation in design means incorporating design accountability in addressing societal challenges. Enacting such a framework requires close collaboration between industry and academia, as these entities represent the foundational pillars for fostering innovation and addressing the complex challenges of realising smart societies. Despite the immense potential for mutual benefit, an inadequacy exists in how these two sectors collaborate, often leading to missed opportunities and groundbreaking innovation. Such inadequacy is exacerbated by the emergence of artificial intelligence (AI) technologies and their disruptive impact on new product development.

The gap in novel collaboration approaches reveals a broader issue: the unclear path forward in collaboratively developing and implementing novel technologies to mitigate current and future societal challenges. Society 5.0 promotes the harmonious integration of technological advancements with everyday life, emphasising the role of design and engineering education in preparing a new generation

skilled in AI and capable of contributing to these societal goals. Thus, a novel path in design education and research is needed to facilitate quick, adaptable learning and effectively equip people to tackle world challenges. This collaborative paradigm shift towards innovative, human-centric design is essential for navigating the complexities of smart societies and achieving the aspirations of Society 5.0.

However, the path to realising these goals is fraught with obstacles, particularly in industry-academia collaboration. University bureaucracy often stands in the way of swift project implementation, contrasting sharply with the industry's need for quick adaptation to market demands (and profit, no matter what). This disparity between academia's focus on long-term, theoretical solutions and the industry's emphasis on immediate, practical innovation creates a disconnect between research, practice, and education, hindering effective collaboration and opportunities for teaching informed by applied research. The disconnect is twofold: a collaborative model for developing knowledge and a lack of formal integration between applied research and education. Therefore, integration between industry and academia can lead to better integration of research into teaching, creating a dynamic educational paradigm driven by inquiry and evidence-based practices. This article explores these dynamics, advocating for a more integrated and agile approach to bridge the theoretical and practical gap.

#### 2 THEORETICAL ASSUMPTIONS

Despite efficacy uncertainties, theoretical evidence suggests that agile methodologies can enhance productivity and quality in industry-academia collaborations. [2]. As shown in Figure 1, a 2006-2024 search within Scopus using the term "industry-academia collaboration" suggests an upward trend in line with the findings of [2].



Figure 1. Documents per year and country

It must be acknowledged that much research uses Case-Study Research as a research strategy, indicating that such an approach still needs to be explored. Publication and selection bias exist as most published results are positive, and most identified scholars are from Electronic and Electrical Engineering and Software Development (Figure 2). So, readers must be mindful that lessons cannot be generalised.



Figure 2. Predominance within Computer Science and Engineering

Nonetheless, evidence indicates an emphasis on the importance of mutual engagement and goal alignment, with agile principles playing a crucial role in success [3], a need for legal frameworks for establishing commitment and conflict resolution approaches [4], enhancement of productivity and satisfaction and reduction of bureaucratic challenges [5]. Employability has a level of dependency on Artificial Intelligence (AI) in some recent research [6][7][8]. If the industry uses Artificial Intelligence (AI), academia must include AI in education and research to meet industry needs. Considering the above, this research supports the notion that using agile action research and AI represents a plausible way to strengthen the collaboration between industry and academia to solve the complexities of smart societies.

#### **3 OUTLINE RESEARCH METHOD**

These are the initial results of developing an agile action research framework to streamline industryacademia collaborations for Society 5.0 solutions involving 20 contributors from various countries (Brazil, Chile, Colombia, Netherlands, UK and USA), including students, academics and industrialists. Data was collected through two online workshops to a) understand the contextual implications of collaborating and to leverage participants' perspectives regarding factors that enable the convergence or divergence of collaboration between industry and academia and b) to identify factors that facilitate and hinder interaction between industry and academia. Workshops were recorded, transcribed and subject to inductive qualitative analysis to identify factors contributing to (convergence) or hindering (divergence) collaboration. From the excerpts, a Table of Dispersion of Divergences and Convergences was developed using the Matplotlib library [9] in Python to facilitate comparison and visualisation of the factors. The analysis to understand the connections between characteristic keywords and to identify underlying meanings and implicit messages was based on a keyword network map created using the NetworkX library [10] in Python to facilitate the graphical representation of the interconnections between different themes and concepts discussed by participants. These approaches were known to the research team and considered appropriate for this level of investigation.

#### 4 INDUSTRY AND ACADEMIA DYNAMICS IN SOCIETY 5.0

Data from Workshop 2 revealed patterns in participants' discussions, allowing us to identify successful and unsuccessful interactions. Recurring themes included difficulties converting academic projects into real-world applications, institutional (legal) barriers, and student engagement. Concerning unsuccessful interactions, the challenge of translating academic projects into practical applications was prominent. Participants expressed deep frustration, noting, "Creating projects with academia is complicated because the translation process is difficult." others echoed this, e.g. "very difficult to collaborate with people from academia and then work or study for a long time on it and then come to a corporate scenario." Regarding institutional barriers as significant impediments, various remarks such as "The university would not allow us to share that kind of information with all the different departments and faculties" and "aborted collaboration" that "did not even start because right after the project, the top manager, now vice president of the company, asked me to run a new project" highlight the bureaucratic hurdles hindering collaboration and emphasise the unpredictability and provisional nature of these partnerships. Positive examples of fruitful industry-academia collaborations were less evident within the data. However, examples included a participant recalling a small-firm-academia collaboration, which "was a very successful collaboration," indicating that successful partnerships are possible and potentially rewarding. The emphasis on student professionalisation through practical engagement in real-world projects is "An example of a collaboration where companies come... and invite the students to participate, bringing problems or projects for the students to work on during the semester." The role of student-led initiatives in fostering these relationships was highlighted by some "30 students in our university who were volunteers dedicated their time trying to unite the industry with academia basically," and "I participated in a project called junior companies which students entirely make." These instances suggest that student involvement can help bridge industry-academia collaborations. Figure 3 below shows a simplistic network graph constructed after analysing key terms from Workshop 2.



Figure 3. Network map of key themes and concepts

The above map illustrates the interconnectivity of key themes and concepts. The 'Collaboration' node is at the centre to highlight its pivotal role in connecting industry and academia. It directly links to 'Academia' and 'Industry', stressing the collaborative nature of these interactions. The 'Academia' and

'Industry' nodes are connected and linked to 'Innovation' and 'Success'. This sequence suggests that while innovation is a key focus in academia, practical outcomes and market success are primary concerns for industry. The link between 'Innovation' and 'Flexibility' suggests that innovation in academic research often requires flexibility, be it in approach, methodology, or application. Similarly, the connection between 'Challenge' and 'Communication' suggests that effective communication is crucial in overcoming collaboration challenges. Furthermore, the 'Success' and 'Learning' nodes are connected, indicating that successful collaborations often lead to valuable learning opportunities, benefiting both sectors. The linkage between 'Learning' and 'Diversity' implies that learning encompasses understanding and embracing diversity in ideas, approaches, and cultural backgrounds. The connection between 'Flexibility' and 'Diversity' indicates the importance of adaptable approaches in diverse environments, which is crucial for successful collaborations. Additionally, the link between 'Communication' and 'Collaboration' so flaboration is foundational to effective collaboration.

The subsequent analysis considered the convergence and divergence within the interactions. The study shows instances with a higher divergence score than their convergence score, indicating scenarios where industry and academia face significant challenges in aligning their objectives and methodologies (Figure 4). The higher divergence score reflects a predominant presence of conflicting interests, differing operational cultures, or distinct end goals that overshadow the combined strengths of the partnership. Such instances often involve scenarios where the theoretical and research-focused approach of academia clashes with the practical, results-oriented focus of industry, leading to challenges in effective collaboration. These scenarios highlight the need for earlier and improved communication, mutual understanding, and establishing common goals. The elevated divergence score is a critical indicator of areas within industry-academia collaborations that require strategic attention and resolution.



Figure 4. Divergence and Convergence Diagram

The instance "Translation Process Difficult" signifies the challenges in translating academic theories into practical industry applications. This reflects a high divergence score due to the stark contrast in objectives and methodologies between these sectors. "Successful Small Firm Collaboration" demonstrates a lower divergence and a higher convergence, indicating that effective alignment of goals and mutual understanding might be easier between universities and smaller organisations. Instances like "Difficulty with Corporate Scenario" and "University Sharing Restrictions" represent barriers to effective collaboration, with high divergence scores due to differing operational cultures and bureaucratic hurdles. "Difficulty with Corporate Scenario" again indicates situations where the theoretical, research-focused approach of academia may clash with the practical, results-oriented focus of the corporate world. In university innovation ecosystems and industry alike, a range of restrictions are imposed by both partners to safeguard intellectual property and ensure adherence to confidentiality agreements. These include confidentiality policies, which limit the disclosure of sensitive research data to protect intellectual property; publication restrictions, that control the dissemination of research findings, particularly relevant for patents or commercial applications; and regulations on external collaborations, governing the scope of partnerships between industry and academia, encompassing shared resources, funding, and student involvement. While essential for protecting the interests of both sectors, these restrictions can sometimes challenge the fluidity of industry-academia collaborations, highlighting the need for a balanced approach to managing these partnerships for mutual benefit. As participants were from various countries, it became clear that some universities are more profitgeneration-led, whereas others are knowledge-generation-led (another disparity in the global scenario).

Conversely, "Prototype with Potential" and "Project Involving Students" are marked by lower divergence and higher convergence, showcasing scenarios where industry-academia collaborations have led to tangible outcomes and valuable learning experiences. "Prototype with Potential" suggests that the collaborative effort resulted in a tangible and promising outcome, in this case, a prototype that embodies innovative ideas from academic research and is viable for practical industry use.

Aborted Collaboration" is another instance illustrating high divergence, where the collaboration did not commence or was terminated prematurely due to misaligned goals or expectations. "Frustration with Practical Application" highlights the often-experienced frustration in academia when industry-focused projects do not yield research results, again indicating a higher divergence.

The diagram provides a nuanced understanding of the varying dynamics in industry-academia collaborations, ranging from highly successful integrations to challenging divergences. It is difficult not to overstate the importance of harmonising the activities and objectives of both sectors to cultivate fruitful research partnerships [2]. Although with some variation, industry is principally concerned with identifying critical business issues and devising solutions, while academia aims to uncover and fill knowledge gaps, contributing to the wider body of scholarly knowledge. In considering the goals of Society 5.0, additional complexity is added to the design of products and services directly or indirectly intended to benefit society.

Figure 5 presents a conceptual framework for addressing societal challenges developed based on precedent existing agile approaches used in research [3, 11] and focused discussions with workshop members. The framework highlights four primary societal problems or opportunities: hunger, poverty, natural disasters, and immigration. These issues catalyse industry and academia to collaborate, fostering an environment where knowledge and resources can be shared to innovate and solve pressing problems. Ultimately, the objective is to contribute positively to Society 5.0, a vision for a human-centric society that balances economic advancement with resolving social issues through integrating cyberspace and physical space. Within the model, AI is restricted to prototyping and data analysis.



Figure 5. Agile Action Research Model for Society 5.0

The confluence of agile methodologies and AI within educational paradigms marks a significant evolution. This integration is a pedagogical shift and a strategic realignment towards responsive and adaptive forms of education, addressing the complexities of Society 5.0. Agile action research in this context transcends traditional boundaries, enabling a fluid interchange and rapid prototyping of ideas. which is key to keeping pace with rapid technological advancements. Incorporating AI in this framework magnifies its potential, allowing nuanced analysis and understanding of technical and societal variables. AI's role in design education includes its use as a powerful tool for simulating complex systems and societal scenarios, enabling students and researchers to experiment and iterate solutions in a controlled yet grounded environment. This experiential learning, underpinned by AI, cultivates a deeper understanding of the intricate interplay between the researcher's need to generate new expert knowledge, the industry's drive for technological solutions, and societal needs. Moreover, the agile approach within this educational model ensures that learning is not static but dynamically evolves with real-world challenges and technological advancements. The outcome will be a generation of engineers and designers who will be technically proficient and acutely aware of their role in shaping a society that is increasingly digital, interconnected, and reliant on harmonious human-technology interactions. This educational approach is also promising for addressing the complex societal challenges of Society 5.0, many of which may benefit from an agile approach managed within university-industry partnerships.

#### **5 FINAL REMARKS**

The new paradigm proposed for Society 5.0 necessitates a transformative approach to academicindustrial collaborations. Industry and academia must align their endeavours, fostering synergies that drive technological innovation and address this era's quintessential societal needs. There are many justifications for such collaborations.

Firstly, Society 5.0 accentuates the role of advanced technology in resolving societal challenges. Academia, with its research prowess, and industry, with its implementation capabilities, are pivotal in translating technological advancements into societal benefits. Secondly, this collaboration ensures that academic research can be translated into real-world applications, thus enhancing its relevance and impact. Thirdly, it provides a framework for academia to contribute actively to economic growth and societal well-being, aligning with the ethos of Society 5.0. Hence, the necessity for academic and industrial interactions becomes a pursuit of technological advancement and a commitment to societal advancement. This alignment with the Society 5.0 agenda ensures that such collaborations are purposedriven, focusing on creating a sustainable, human-centric future.

It is imperative to address and remove existing bureaucratic and trust-related obstacles within industry and academia to facilitate the development of such impactful projects. This change requires conducting thorough research to understand the current context of interactions and proposing more agile forms of integration. Such an approach becomes increasingly vital considering the rapid advancement of technology and the exacerbation of social problems over time. Bridging the gap between industry and academia in alignment with the agenda of Society 5.0 is not just about fostering technological innovation but creating a sustainable and equitable future. We can ensure these collaborations are productive and responsive to urgent social issues by overcoming bureaucratic and trust barriers.

The convergence and divergence factors identified in this article will form the foundation for the next steps of our research. In this regard, we will aim to identify elements integrated with technologies oriented towards Society 5.0 that enhance the convergences and minimise the divergences by developing rapid prototypes that can be evaluated throughout 2024. This approach seeks to align the theoretical and practical aspects of industry-academia collaborations more closely, fostering a mutually beneficial relationship that is in tune with the evolving dynamics of Society 5.0.

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# DEVELOPING AN OPEN-SOURCE LEARNING ANALYTICS TOOL FOR PROVIDING INSIGHTS TO SUPPORT STUDENTS AND IMPROVE TEACHING PRACTICE

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#### ABSTRACT

Learning analytics and data-driven approaches have gained real traction in higher education institutions, enabling insights into student attendance, engagement, and performance trends. This paper introduces the development of an open-source course-level data analytics tool, 'the student record,' designed to complement the conventional institutional approach with a responsive, context-specific, and user-centred method for gathering, analysing, and presenting student attendance data. In developing the tool, our team experimented with Microsoft Excel's natural language interface and artificial intelligence capabilities and currently the tool uses predefined python scripts in a Jupyter Notebook to generate visual dashboards, flags, and recommendations based on statistical process control (SPC) principles and machine learning models. This approach aims to facilitate a dynamic student engagement dialogue between staff and students, fostering a rolling academic health check to support students and provide contextual insights for module teams and course leaders. The tool's ethical considerations prioritise transparency, data privacy, and student accessibility to their own data, aligning with personal academic tutoring systems. The paper outlines the tool's development, capabilities, and a critical discussion of key aspects, including AI integration, data security, and ethical implications.

*Keywords: student attendance and engagement, machine learning, ethics, information system, contextual insights.* 

#### **1 INTRODUCTION AND BACKGROUND**

Data analytics has been employed extensively in the higher education sector in recent years. It has enabled powerful insights into trends such as the growing gap between male and female applicants in England [1], attainment gaps between ethnicity groups [2, 3], the rise in the number of students reporting mental health issues [4], and predictions of the rise and fall in the populations of 18-year-olds [5] as shown in Figure 1.



Figure 1. a) English and Welsh 18-year-old population predictions to 2036 [1]
b) Proportion of students reporting a mental health condition in English Universities [2], c) Male and female accepted applicants in UK Universities [3], d) Percentage first degree qualifiers achieving top degrees by ethnicity [4]

A more student-centred approach to data analytics is learning analytics, which can be a valuable tool for gaining insights into general trends to help course teams develop, but also a means to provide more targeted support to students at course, module, and individual levels. At our institution, we have a generic web-based register tool for reporting data into a central visualisation tool (QlikView), but these are not designed for reporting and have real limitations for extracting useful insights. Our web-register tool also only provides data for the most recent two-week window, and so it fails to give a complete picture over a semester or academic year. In addition, there is a system (StudentView) which gives completed module results, however this only provides a single final result for modules. Overall, these systems do not work together in an integrated way and leaving little room for transparency or student ownership of engagement or attendance data. While results and feedback are contained within the virtual learning environment alongside teaching content, personal tutors and staff who do not teach on those modules do not have access to student outcomes, and so there is no integrated solution that can inform personal tutor conversations with students. Furthermore, it seems design and other studio-based courses do not seem well serviced by typical attendance monitoring systems. As a result, we were keen to develop a tool that would service the needs for our studio-based product design and design engineering courses in order to be better informed in our support for students.

In terms of monitoring attendance in a university setting, Newman-Ford et al. [6] have provided compelling evidence of a significant relationship between attendance and attainment in a large-scale study involving 22 undergraduate modules (Figure 2). They also showed that self-developed tools can be a powerful way to gain high-level and detailed insights that can cater to specific institutional or departmental needs. While there is a current trend for more streamlined, technological means to gather data (e.g., face recognition, video, fingerprint, RFID), there seems to be less focus on using technology to generate useful insights to directly support students or inform and improve teaching practices.



Figure 2. Attendance across two terms by assessment result (left) and attendance by performance (right) [6]

Statistical process control (SPC) is a long-standing total quality management approach that provides a framework for identifying patterns and interpreting data, enabling statistical inference and assessment, and generating insights and this has also been applied successfully to an education setting to improve outcomes [7]. Total quality management (TQM) processes emphasise continuous improvement by minimising failures, and it is common practice for institutions to present visual information through staff or student-facing dashboards to report on attendance, engagement and attainment. By extension, one study has even experimented with using a 'risk of failure' as part of visualisation dashboard integrated into a student counselling system to inform academic staff when advising students as shown in Figure 3 [8].

Código	Materia		Riesgo de Fallar	2			5
FIEC00075	ELECTRÓNICA						Potencia Modelo
FIEC01800	LABORATORIO DE REDES ELÉCTRICAS	×		68%			+++ Excelente
FIEC00745	SISTEMAS DIGITALES II	×	Similaridad Estudiantes	Promedio		•	# de Casos
FIEC02097	SISTEMAS OPERATIVOS	×					
			Similaridad Semestre	Nivel 2 - Di	ficultad	3 🗖	169 casos
Intervale	o de Tiempo y Cambios en Ca	nrrera 1096	1000 1004 1009	2002 2006	2010	2014	6
1	4 A	1900	(C)	2002 2006 D	E	2014	
	<	-		ed E		2	

Figure 3. Example of visualisations integrated into a student counselling system: 1) Course selector, 2) Predicted academic risk value visualisation, 3) Model selector, 4) Time period selector and consistency visualisation, 5) Model predictive power visualisation and 6) Case completeness visualisation [7]

# 2 DEVELOPMENTS OF A COURSE LEVEL LEARNING ANALYTICS SYSTEM

#### 2.1 System requirements

Based on our identified needs and objectives, a set of user requirements and corresponding specifications were outlined for the development of the course-level learning analytics system as shown in Table 1.

Requirements	Specification
Provide a visual dashboard to display student attendance, engagement, and assessment data.	The system should generate configurable dashboards with graphical representations of student data, including attendance percentages, formative and summative assessment results, and feedback.
Foster transparency and student ownership of their data.	The system should allow students to access and view their own data, aligning with personal academic tutoring systems.
Generate insights for students, staff, module leaders, course leaders, and the institution.	The system should provide targeted recommendations and actionable insights tailored to different stakeholder groups. User Requirement: Facilitate targeted action to support students.
Facilitate targeted action to support students.	The system should identify students at risk or in need of support based on their attendance, engagement, and performance data, enabling timely interventions and personalised support.
Ensure data security and ethical considerations.	The system should prioritise data privacy and adhere to ethical guidelines, including transparency in data handling and secure storage.

	Table 1.	System	requirements	and	specifications
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# 2.2 Data collection for student attendance, engagement and assessment

Data collection for student attendance, engagement, and assessment was aligned with the existing workflow of the institution's Web Register tool to simplify the process for staff when inputting data. A password-protected Excel file including tabs for each module and for summary dashboards was located on the course team's secure SharePoint site. In this file included information with the following separate columns 1) course, 2) year, 3) student number, 4) Surname, 5) Firstname, 6) formative assessment mark, 7) formative feedback comments, 8) summative assessment mark/s, 9) summative assessment mark/s, 10+) attendance for each session (separate columns for each) 11) module attendance, 12) notes relating to module as shown in Figure 4 which shows an excel template with filters and conditional formatting.



Figure 4. An example student record dataset for a module (fictitious)

# 2.3 A student record: Central to the ongoing 'personal tutoring' dialogue

The 'student record' could then serve as the main record for conversations between students and their personal tutors, module tutors, course leaders, and student support and guidance tutors. The key aspect is to present information visually and engage students in analysing their data. For each module, the student record includes attendance data (cumulative percentage), formative assessment results and feedback, and summative assessment results and feedback. Attendance data is able to be presented in multiple formats, including self-comparison (e.g. comparing attendance in multiple modules, or comparison between morning and afternoon sessions), comparison to others on the module (anonymous collective data), and comparison to the entire course cohort. Metrics and trend analyses are conducted, such as fluctuations, upward/downward trends, percentage above a threshold in a rolling period (e.g. every two weeks) in line with SPC run charts which can help to flag statistically significant scenarios that deviate from the ordinary flow of events for modules or individual students. The Filter tool in Excel enables the presentation of data for individual students during personal tutorial meetings, and also the display of groups of students with low attendance or attainment in formative or summative assessments for module or course level analysis. Conditional formatting is employed to colour-code attendance and

attainment data, aiding visualisation and Macros were used to improve the usability of the system by including programmed buttons for searching, sorting and filtering data for students, modules and courses.

A more sophisticated system was then developed as a Jupyter notebook which processes a series of Python scripts to compare attendance patterns (e.g. across different days, or between morning and afternoon sessions) are shown as box plots and are analysed to highlight potential issues with sleep patterns, commuting difficulties, employment, or caring responsibilities. In response to some requests from colleagues in other departments, an open-source repository of the student record system was made available on Github at https://github.com/derekcovill/student-record/).

Figure 5 (left) below shows an example plot showing attendance for a module for an individual student. The analysis of module and course-level data allows for a comparison of attendance and attainment data across modules and courses presented as quartile data (upper, median, lower as shown in Figure 4 - right). This goes beyond the formal data reported centrally at exam boards, offering a more comprehensive view of student performance and engagement for module and course teams. The work is currently being extended to exploit the natural language AI insights tool (*Analyse Data*) and GPT plug-ins for Excel. For students, this tool can potentially be used to generate insights into their individual behaviour, while module leaders can examine students' collective behaviour, and course leaders can compare data across modules. The AI tools within Excel should also allow us to extract trends and further support to students. This can be done within a module, across modules, across years for modules, and for individual students to synthesise comments across modules and identify key areas for improvement.



Figure 5. Example plot showing attendance for a module for a student (thick blue line), with dashed grey lines showing the upper and lower quartiles and the solid grey line the median student percentage (left) and example box plot showing percentage results for various grade bands (right)

# 2.4 Course and module dashboard: Analysis of collective student behaviour and course oversight

The course and module dashboard provides a comparison of attendance and attainment data across modules and courses presented as quartile data (upper, median, lower as shown in Figure 4 - right). This goes beyond the formal data reporting that occurs centrally at exam boards, offering a more comprehensive view of student performance and engagement.

Currently some testing is being done to further exploit the natural language AI insights tool (*Analyse Data*) and using machine learning tools in our Jupyter notebook using regression and classification models for predicting outcomes and identifying at-risk groups based on their engagement and attainment profiles. For students, the tool can be used to generate insights into their individual behaviour, while module leaders can examine students' collective behaviour, and course leaders can compare data across modules. The more sophisticated tools seem capable of extracting trends and common traits in feedback, packaging these for staff to provide guidance and further support to students. This can be done within a module, across modules, across years for modules, and for individual students to synthesise comments across modules and identify key areas for improvement.

#### **3 FINAL REMARKS**

Our course-level data analytics tool, 'the student record,' has started to provide some data-driven insights using various technologies to support student success in design-related courses. By integrating attendance, engagement, and assessment data in a way that is accessible to the course team, the system provides a useful view of student performance and enables targeted interventions and support. The system's key strengths lie in its visual dashboards, trend analyses, and the integration of data across the course into a robust system that is easy to use for the course team. These features facilitate a dynamic 'student engagement' dialogue, allowing staff to identify potential issues and provide tailored guidance to students. Ethical considerations, such as transparency, data privacy, and student accessibility to their own data, have been prioritised in a relatively simple system design, aligning with personal academic tutoring systems and fostering a reflective learning process for staff and students. While the system has been developed to some extent through experimentation and exploration in the past 12 months to meet our own needs, further exploration of other machine learning tools and the scalability across different departments or even institutions could enhance its capabilities and impact.

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# IT'S ABOUT TIME: WHAT CAN WE LEARN BY HAVING UNIVERSITY DESIGN STUDENTS TRACK TIME?

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# ABSTRACT

Ninety-one undergraduate students tracked time spent throughout the semester in entry-level design courses. The correlation between time and student performance was low, but data validity may be an issue due to the self-reporting nature of time tracking. In one course, students averaged the expected amount of time (given the course credit hours). Students fell below 75% of the time expectations in another course. The exercise of tracking time teaches students about themselves, helping them recognise opportunities for improvement. Most students do not like tracking time, but many admit it is beneficial. Time tracking empowers them to be personally accountable. Many conversations with students have shifted from "Tell me how to get a better grade." to "Help me improve time management so I can learn more and do better." Time-tracking data also provides additional context for professors to interpret student performance. When students are not performing well, time-tracking data can help clarify how to help: Do students need help recognising the discrepancy between time invested and expected results? Do they need guidance on learning strategies to help them be more effective and efficient with their time utilisation? Or do they need additional help understanding and applying course content?

Keywords: Time management, student performance, personal responsibility, design education

# **1** INTRODUCTION

How does time management affect a college student's performance? Students often must determine how to manage academic, work, social, familial, and other responsibilities and interests. Students coming straight out of the public education system usually have to learn how to juggle all these things for the first time when beginning university studies. Time management skills may be one of the main determining factors of student success. The two primary purposes of this study are as follows.

- Better understand to what degree the amount of time a student invests in a course correlates with their overall performance in a course. (In other words, is doing well in a course mainly a function of the time a student invests?)
- Observe if time tracking has any other effects on student learning and development.

# 2 THE STRUGGLE TO MANAGE TIME

Irrespective of the field of study, students grapple with unique challenges in time management. Majors differ in workloads, assignment types, and demands. For example, students studying design and its emphases encounter many project-based learning activities. Project-based learning is "an active student-centred form of instruction characterised by students' autonomy, constructive investigations, goal setting, collaboration, communication and reflection within real-world practices" [1]. This pedagogical approach provides students with the opportunity to work on authentic projects and the development of products [2]. Project-based learning is distinct from problem-based learning, which shares similarities but focuses on the learning process, whereas project-based learning emphasises the culmination of an end product [3]. Project-based learning stretches students by requiring them to actively engage in an assignment over an extensive period [4]. In the context of a Design class, a Project-based learning assignment requires a heavy workload as students spend time researching, ideating, prototyping, revising, and polishing an elegant final product to submit for a grade.

Participating in this real-world process provides Design students with experience for their future careers. It often requires students to use more soft skills (e.g., communication, collaboration, and time management) than traditional pedagogy. In project-based learning, self-regulated learning readiness

(i.e., the ability to learn independently) and self-management skills are paramount to a student's success and result in increased learning outcomes [5]. Conversely, this same learning method leaves room for students who need more self-regulated learning skills and motivation to fall behind in a particular project. Fortunately, research shows that these skills aren't personal traits that students have or don't have but are character traits that can be taught and developed. Zimmerman explains that a student's level of learning varies based on their ability to personally adapt the following self-regulated learning skills to each learning task.

- setting specific proximal goals for oneself,
- adopting powerful strategies for attaining the goals,
- monitoring one's performance selectively for signs of progress,
- restructuring one's physical and social context to make it compatible with one's goals,
- managing one's time use efficiently,
- self-evaluating one's methods,
- attributing causation to results, and
- adapting future methods [6].

This study focuses on the component skill of managing one's time use. Good time management is the ability to "[schedule] sufficient time, spread consistently throughout the designated learning duration, to complete the learning tasks that are tied to the learning goals set" [7]. Multiple studies indicate a positive correlation between effective time management and academic performance [8] [9] [10].

One aspect of time management is "perceived control of time." A 1990 study by Macan et al. found that out of four relatively independent factors of time management:

- 1. setting goals and priorities
- 2. planning and scheduling
- 3. perceived control of time
- 4. and preference for disorganisation,

the most predictive was perceived control of time—the extent to which an individual believes they can affect time spent. The study found that "students who perceived control of their time reported significantly greater evaluations of their performance, greater work and life satisfaction, less role ambiguity, less role overload, and fewer job-induced and somatic tensions" [11]. A 2019 study by Adams and Blair added confirmatory evidence to the research done by Macan et al. They found that student perceptions (regardless of gender, age, and semesters in the degree program) of their time positively correlate with academic performance [12].

# **3 TIME TRACKING AS A WAY TO HELP TIME MANAGEMENT**

Time tracking is a method that might help students improve their time management abilities and increase their perceived control of time. Time tracking is the term used to describe the process of logging time spent completing a particular task. In the digital age, this can be accomplished using a variety of dedicated time-tracking applications such as Toggl Track, Clockify, Harvest, Timely, and more. Using one of these digital tools to track time spent on project-based learning activities could help students improve the self-regulated learning skills necessary to be successful in project-based learning activities. However, there is limited research regarding the effect of time-tracking tools on student performance.

While standard learning management software systems, such as Instructure's Canvas, have metrics on how often and how long students are logged into and interacting with a page in the system, they are devoid of time-tracking functionality for students and instructors to gauge the length of time spent on an assignment or a project. There are some plugins that students can use to track time, but they are not well integrated into the learning management systems. The plugins only act as a shortcut to start and stop time and report it back into the third-party system. They do not automatically pull or associate assignment and project data with the logged time.

Of the few studies available regarding student time-tracking, the leading research, conducted in 2015, suggests that "using mobile devices to log and track the time devoted to study across contexts might lead to an improvement on time management skills" [13]. A 2020 study by Sorokina et al. also found that the implementation of time tracking increased project scores among a small sample size of higher education students [14]. In addition to these findings, one of time-tracking's benefits is its ability to measure time-on-task learning. With students' access to technology today, learning is "plagued by high levels of distraction and multitasking, which leads to negative effects on students' learning" [15].

Logging time spent on learning may help students avoid these distractions, introducing an aspect of selfawareness and accountability. Bowman et al. state that having students log time while they work "can help them to become more aware of what they are doing so they can make conscious choices about what they want to do" [16]. Prior research also demonstrates that students respond positively to time-on-task data visualisations [17], and migrant language learners became more motivated using a time-tracking app [18]. Given the findings of these studies, students may be open to tracking time spent on courses.

While the potential of time tracking to enhance student learning and performance is promising, more research is needed. The initial findings of Tabuenca et al. [19] and Sorokina et al. [20] provide a starting point. Still, additional, discipline-focused research might further establish the impact of time tracking on student performance across disciplines. This gap is particularly pronounced in the case of university-level design students. This study explores this research gap by analysing the effects of time tracking when implemented in two introductory design courses: 1) Design Thinking and 2) Product & User Experience Design.

#### 4 METHODS

Undergraduate students in two introductory design courses were taught how to use the free version of the Toggl Track time tracking app and were instructed to use it to track their time spent on the course (including in-class and studio time). Students were reminded that the university expected them to invest at least three hours (including class and studio time) per credit hour into the course each week. The introductory courses, credit hours, expected hours per week, and number of student participants were as follows:

Course	Credit Hrs.	Expected Hrs./Week	# of Students
Design Thinking (DT)	1.5	4.5	43
Product & User Experience Design (P&UXD) - Section 1	3.0	9.0	21
Product & User Experience Design (P&UXD) - Section 2	3.0	9.0	27
		Total	91

Table 1. Courses & Number of Student Participants

Students submitted reports generated in the "reports" section of the Toggl Track application. It is important to note that when the lead author of this study began having students track their time, he did not intend to conduct a formal research study on the matter. Thus, there are some differences in how reporting occurred between the two courses. In the DT course, students submitted a weekly time report from the Toggl Track system, and the time reports were reviewed weekly. In the P&UXD course, students started tracking their time when we were one-third (i.e., five weeks) through the semester, and they only submitted two-time reports (each accounting for five weeks) for the remainder of the semester. In both courses, students were awarded points for tracking their time and submitting the report, not for how much time they spent. We did not award students points based on the amount of time spent so as not to incentivise dishonest, inaccurate, or inflated reporting of time. Students were reminded at the beginning of both courses and a couple of times throughout the semester that if they hoped to perform well in the course, they should anticipate investing at least three hours of work (including in-class time) per credit hour.

After the semester ended, we aggregated all time reports for each student and compared time spent to their final grade. We calculated the average time students spent on the course each week and the correlation strength (measured by the correlation coefficient r) between time spent and the student's final grade. The authors of this study reviewed time reports only after the semester was completed and grades were awarded to ensure that no grades were affected by knowing how much time a student spent on the course.

Due to slight differences in instructions given in both courses regarding time reporting, we could also calculate the average time explicitly spent in the DT class and studio sessions, where students could receive instruction and help from the instructor. With this additional data, we also explored if there was any relationship between in-class and studio time and students' final grades in the DT course.

# **5 STATISTICAL RESULTS**

Karl Pearson's Coefficient of Correlation formula was used to determine the correlation between students' total time spent in a course and their final grades.

In the (DT) course (which students should have expected to spend at least 4.5 hours per week), students reported an average of 4.87 hours per week. The correlation between total time spent on the course and the final grade was low (r=0.33). However, the correlation between time spent in class and studio (where students could receive feedback and help from the instructor), and their final grade was moderate (r=0.50).

In the two sections of the (P&UXD) course, students spent an average of 6.81 hours per week in section 1 and 6.17 hours per week in section 2 (which is significantly below the minimum of 9 hours per week that they should have been spending on the course). The correlation between time spent on the course and the final grade was low for section 1 (r=.41) and very low for section 2 (r=.02).

# **6** LIMITATIONS

Students self-reported their time. Though they were reminded and encouraged to track their time in realtime using the Toggl Track application, it was apparent in some time reports that students went back and manually entered times after the fact right before submitting their report. Students guessing how much time they spent on the course could significantly affect the reliability of the results.

Students received no course points for the time they spent on the course. However, some might have overestimated their time for various reasons, including being concerned about being judged. As mentioned earlier in this paper, the principal author explored the effect of time tracking on student performance after gathering time reports as part of the course's requirements. In the future, with the intent to more systematically and accurately capture the effect that time invested in learning and doing has on student performance, the authors aim to reduce the number of limitations of results and findings in subsequent studies.

# 7 DISCUSSIONS

Before aggregating and running a statistical analysis on the time reporting data, we suspected we might find a strong correlation between the time spent on the course and the student's final grade. However, this was not the case. So, either the amount of time a student puts in has less effect on student performance (as measured by the final grade) than we anticipated, or the data is not reliable enough (due to the self-tracking and self-reporting nature of time tracking) to draw a firm conclusion at this time. We intend to do additional studies where we take measures to increase the reliability of the data, such as

- 1. utilising a time management software platform built for teams that allows the authors to more easily distinguish between real-time tracking and tracking that occurs after the fact.
- 2. make sure to gather reports and award students points for tracking their time weekly (at a minimum), as frequency helps students not to procrastinate manually logging time, thus reducing guestimates and increasing the accuracy of time reported.

Though the macro relationship between time invested in a course and the final grade was not what we thought it would be, having students track their time yielded some interesting insights, results, and ideas. When students come to the instructor and are concerned about their grades, the instructor can review assignment scores to evaluate the quality of their work AND review the time and effort the student is investing. When students are not performing well, time-tracking data can help clarify how to help: Do students need help recognising the discrepancy between time invested and expected results? Do they need guidance on learning strategies to help them be more effective and efficient with their time utilisation? Or do they need additional help understanding and applying course content?

This data changed many conversations the instructor had with individual students from "Why am I getting a bad grade?" to something often more pertinent and at the root of the problem, like "How might I establish more time for myself to work on this course?" Most students don't like tracking their time. However, like eating vegetables, many realise it is healthy and helpful by the end of the semester or soon after. Several students have reported using Toggl Track or other time-tracking software to measure how much time they spend on something else. The most common application of time tracking that students report after my classes is for freelance work.

When beginning the experiment of having students track their time, I wanted to help students learn how to better account for and manage their time. However, the data provided some interesting insights about

the actual course load of these two courses. In the DT course, many students complained in their student ratings that the time required by the course far exceeded the one-and-a-half credit hours of the course. However, the 4.86 hours average time spent per week per student is right on the money for how much time students should have expected to put in the course. Similarly, some students in the P&UXD course complained that there was too much work. However, on average, students put in much less time per week (e.g., 6.81 hours in section one and 6.17 hours in section two) than they should have given that it was a three-credit course that expects at least nine hours of work per week.

When time reports were required weekly, students better spread their time across several weeks for large projects. When time reports were required every five weeks, most students put in much less time during the first couple of weeks and increasingly more time during the final three weeks.

Interestingly, the correlation between time spent in class and studio (where students could receive feedback and help from the instructor), and their final grade was moderate and much higher than any other correlating factor measured by this study. We want to explore that further.

One thing lacking in these time-tracking experiments was self-reflection. The original intent of having students track their time was to become more self-aware about how they use and manage their time. However, we need to implement regular reflections for students to move away from the view that this is just some tedious exercise required of them by the course towards the view that this is an opportunity to learn about themselves. Collecting data about themselves and reflecting on that data regularly through thoughtful prompts may help students become more independent, accountable, and self-aware learners.

# 8 CONCLUSIONS

Soft skills, like time management, are often not explicitly taught in primary, secondary, or university education. Most students understand the concept that practice makes perfect. However, when stressed and juggling multiple responsibilities, they often try to cut corners in their learning processes. This study does not establish a strong correlation between the final grade and the time spent in these two courses; however, it has had some unintended results. Some students have actively sought help from the instructor when realising they were struggling to balance the demands on their time, which suggests that Time tracking has been a way to help students hold themselves accountable, reflect, and troubleshoot time management issues affecting their learning and performance This study has also yielded valuable insights regarding actual course load, course cadence, and student project progress cadence, which suggests that time tracking (as pedagogical practice) might help other instructors looking to hone their courses and improve student learning experiences.

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# THE INTERSECTION OF AI AND BLOOM'S TAXONOMY IN DESIGN EDUCATION: A ROBOTIC DESIGN CASE STUDY

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# ABSTRACT

Generative Artificial Intelligence (GAI) tools are getting involved in the learning process of new generations, and these tools can make a change in product design education, which can be used in different design phases. This study examines their integration through a student project at Linköping University, focusing on the creation of an autonomous robot. From its observation and reports, it is analysed how these tools influence the different design phases and their application, and how students with different skill levels adapt to AI integration. This case study presents not only the practical use of GAI in design but also its impact on educational paradigms, particularly in how it gets involved and reshapes the traditional learning hierarchy outlined by Bloom's Taxonomy. Our findings indicate that GAI tools not only improve efficiency in the design iteration but also introduce a possible shift in learning approaches when it comes to new skills, which may make students skip the learning of base knowledge. GAI has the potential to promote an inverse learning sequence in which students participate in practical application and creation before fully understanding theoretical foundations. This shift implies a re-evaluation of educational frameworks to ensure that while embracing the benefits of GAI, critical thinking and foundational knowledge are not excluded. A balanced approach to teaching that incorporates GAI tools while preserving fundamental engineering and design concepts might be a desirable future.

*Keywords: Designing with artificial intelligence, GAI processes, design and product development, CDIO 3.0, design engineering education* 

# **1** INTRODUCTION

Education in design and product development is facing immediate change as a result of the text-tocreation revolution or the more popular name Generative Artificial Intelligence (GAI). GAI refers to using prompts to create a creative output by entering sentences or words, for example, "classic car, Etype, Bugatti Chiron" and a photorealistic image is generated nearly instantly. This revolution started in late 2021 and has evolved exponentially. Another type of GAI is Large Language Models (LLM). LLM has a longer history stemming from the middle of the 1960ies when Joseph Weizenbaum developed the first chatbot ELIZA at MIT and became known to the public when OpenAI introduced ChatGPT in 2022 [1]. Today, GAI tools can generate executable code, create layouts for designs, perfect design renderings of simple sketches, and 3D printable models directly from graphic images. In design and product development, this means that the step from idea to concept, which previously required extensive experience with various computer programs and several hours to do, can be carried out in a few seconds. Nowadays, engineering students in design and product development can rapidly explore a large number of possible ideas, create new concepts, and explore the design space by generating and developing variations. Repetitive design tasks can also be automated. This means that the time spent in the early product development phases such as the Planning Phase 0 and Concept Development Phase 1, [2] can be used more efficiently. Design judgement and decision-making processes [3] may also be affected using GAI tools. It may place higher demands on design engineers and product developers due to more choices and more opportunities and increase the number of bad proposals. Pedagogic discussions on how to educate students in GAI for design and engineering and what to teach will be ever more paramount in the near future. Curriculums will need to change; courses need to be updated and new ones created.

This paper explores how students' learning outcomes are influenced by the use of GAI tools in the course Advanced Product Development given by Linköping University in the fall of 2023. Bloom's taxonomy [4] is utilised as a framework to analyse and discuss the findings.

# **2 THEORETICAL FRAMEWORKS**

Bloom's Taxonomy, created by Benjamin Bloom in 1956, is a foundational educational framework that classifies cognitive skills required for learning into a hierarchy from basic to complex [4]. t progresses from lower-order thinking skills (LOTS), which include "Remembering" and "Understanding," to higher-order thinking skills (HOTS) such as "Applying," "Analysing," "Evaluating," and "Creating" [5]. This framework is essential for designing curricula and assessments that meet diverse cognitive demands.

At the "Remembering" level, students recall facts and basic concepts. "Understanding" involves explaining ideas or concepts by organizing and summarizing information. "Applying" sees learners using knowledge in new situations. In "Analysing," students break down information into components to examine and understand its structure. "Evaluating" involves judging based on criteria to critique ideas or materials. The highest level, "Creating," requires synthesising information to form new patterns or structures, representing the most complex cognitive tasks [6].



Figure 1. Bloom's Taxonomy [5]

The integration of Generative AI (GAI) adds complexity to Bloom's Taxonomy, suggesting that traditional educational models and the application of the taxonomy might need re-evaluation[7].GAI tools enhance learning by providing access to extensive information, personalized pathways, instant feedback, and expanded creative options. This challenges the traditional progression of cognitive skill development and calls for a revision of learning experiences to leverage GAI's dynamic capabilities.

# **3 COURSE DESCRIPTION OF ADVANCED PRODUCT DEVELOPMENT**

The advanced product development course is a mandatory twelve ECTS (European Credit Transfer and Accumulation System) credits master's student project course at Linköping University, Sweden, that runs during the autumn semester and ends before Christmas with an exhibition. The course projects must have both industry and scientific relevance, several of which stem from ongoing research projects. Each project team receive their project brief from either a company, a research group, or a governmental organisation. Pedagogically, the course follows the CDIO 3.0 [8] framework which stands for Conceiving–Designing–Implementing–Operating. The core principle of the pedagogic framework is that engineering education is more than technical knowledge and skills, it is part of a larger context that encompasses "product, process, system, and service lifecycle development and deployment" [8].

The course mandates that students work in teams to solve an open-ended brief. They are expected to take responsibility for the progression of the project and learning outcome. The project teams are mixed from three different engineering educations to create multidisciplinary teams [9, 10]. Students apply for the projects making the teams highly motivated and increasing the rate of success in the projects.

The intended learning outcomes for the course include mastering the identification, selection, and application of theory and knowledge areas tailored to specific problems. Students will plan, implement, and research an industry-related product development project, and systematically integrate knowledge acquired during their studies to solve real product development challenges. Additionally, they will apply

methods and knowledge from design and product development, create, analyse, and evaluate technical solutions, and utilize relevant literature to the project.

This article examines one of the student projects in the course Advanced Product Development and analyses how the new technology of GAI influences their design and learning process.

# 4 CASE STUDY: STUDENT PROJECT FUTURE OF AUTOMATION SKETCH TO-3D PRINTED ROBOTICS

The research methodology in this article follows Miles et al. [11] process of qualitative data analysis. As in line with Yin's [12] recommendations when doing exploratory research where the goal is to understand 'why' and 'how' things have happened and explore contextual phenomena.

*Case description*: A global material handling company tasked students with a project to explore automation, robotics, GAI, design, 3D printing, and computational linguistics. This initiative aims to transform product design and development, emphasizing the application of emerging technologies for future uses. The project's goal is to leverage various AI tools and processes to design new functions, components, and modules for an autonomous robot, culminating in a proof-of-concept model.

*Participants*: The student team consisted of five students from two different educations, all students identified themselves as male and were 24 years of age. They study their ninth semester in a five-year civil engineering program (master level). All had selected the project as their primary choice.

*Data collection*: The authors monitored the student's progress through weekly meetings, collecting their project reports, reflections, and final presentations. Notes were taken during a mandatory seminar where students discussed their methods and processes. The students' exhibition materials, proof-of-concept robots, and posters were also photographed.

*Data analysis and Conclusion drawing*: The collected material was analysed in two ways; first through a grounded theory [13] approach where cues and themes were coded, and analysed and new conclusions were drawn on how the students described their design process and how it was influenced by their application of new GAI tools. The second approach was to analyse the student's learning outcomes utilising Bloom's Taxonomy [6], understanding learning patterns in the design steps.

# 5 STUDENTS DESIGN PROCESS APPLYING GAI

In the process of designing a robotic as an educational design challenge, the integration of Generative Artificial Intelligence tools has modified the way students approach the development of new design challenges in this context. This section outlines the design steps and GAI tools employed by students to design a robot, emphasizing an iterative process. From an initial idea to the final stages of optimization, GAI tools have been instrumental in guiding students or supporting them through the phases of the design process. In the next figure, the steps supported by GAI in this case study are shown.



Figure 2. Depicts the students' overall design process in the project

The utilization of Generative AI (GAI) technologies in different phases of the design process significantly enhanced creativity, visual representation, depth, modelling, prototyping, and optimization. In the brainstorming phase, OpenAI's GPT and Bing's DALL-E generated numerous initial concepts, fostering an environment for creative exploration and idea refinement. During the visual representation stage, Vizcom aided in sketching and refining designs, with additional support from Adobe Firefly and Photoshop to enhance image details. ZoeDepth contributed by adding depth and enhancing the realism of visual representations. In modelling, tools like Blender and Fusion 360 allowed for precise 3D modelling, while Common Sense Machines (CSM) streamlined the transition from 2D sketches to 3D models. The prototyping phase involved using 3D printing and Arduino components, with guidance from ChatGPT to create functional prototypes and understand electronic functionalities through iterative trials. Lastly, in the optimization phase, Fusion 360's GAI capabilities were utilized to optimize the robot's design for better structural integrity and efficiency. The degree of AI reliance varied among students based on their prior knowledge, affecting their ability to critically evaluate and refine the GAI outputs.

# 6 ANALYSIS OF BLOOM TAXONOMY IN THIS CASE STUDY

When bringing GAI into classrooms, especially for projects like building robots, it can change the way students get involved in the learning process. Bloom's Taxonomy [6] is a way to think about learning, starting with basic remembering and moving up to creating new things. But when students use GAI, in this case study we observed that the order of those steps might change.

During the semester, two different themes were observed in the student design process. The first is when students use GAI as a helper for tasks, they're already good at. The second is when GAI helps them dive into areas they don't know much about yet. As we look at these situations, we show how GAI might make us think differently about the steps of learning it has always been used. It was observed that sometimes, students jump right into applying and creating with AI's help, even before they fully understand or remember everything about what they're working on. This indicates that educators need to ensure that theories, foundational principles and best practices are not overlooked when GAI tools are involved.



# Figure 3. GAI integration themes

**AI Integration in Familiar Domains** When students applied GAI tools to tasks within their skill set, they adhered to the conventional order of Bloom's Taxonomy (Figure 1). GAI served as a booster, enabling fast prototyping and iteration but did not fundamentally alter the cognitive process. Students began with the remembering stage, recalling prior knowledge. They proceeded to understand the task as sketching, applying their skills using GAI, analysing the outcomes, evaluating the results being able to put into context issues with the perspective of the dimensions thanks to their prior knowledge, and finally creating solutions.

# Theme 1: Al Integration in Familiar Domains

- 1. **Remember**: Students recall their existing knowledge of sketching, CAD, and prototyping. This is the stage where they bring to mind what they already know before engaging with GAI tools.
- 2. Understand: They understand the principles behind the design tasks. For example, they understand that certain design requirements need to be applied to the robot and what makes for a functional and aesthetic prototype.
- 3. **Apply:** GAI tools come into play here. Students apply their knowledge, using GAI to support and improve the modelling and sketching tasks they are already familiar with. The GAI ease rapid prototyping and iteration, allowing for quick visualization and modification of designs.
- 4. **Analyse:** With GAI-generated models, students analyse a broader number of alternatives as outcomes to ensure they meet design requirements and specifications. They use their knowledge to analyse the GAI's work, understanding how the design choices affect functionality and user experience.
- 5. **Evaluate:** Students evaluate the efficacy of using GAI in the process. They can critically assess the quality and efficiency of what was created by GAI integration, comparing it to traditional methods they are used to.
- 6. **Create:** Lastly students use their knowledge and the GAI's capabilities to create an advanced result. The creative process is interfered with by their understanding of the subject, in combination with the GAI's ability to generate and modify quickly.

**GAI Integration in Unfamiliar Domains** A shift takes place when students engage with unfamiliar tasks, such as Arduino prototyping. Here, the cognitive process begins with the Apply stage, as they make use of GAI to perform tasks beyond their current understanding, trusting the tool. Following this, they entered the Create phase, using GAI to generate functional code and circuit design suggestions that they put into practice. They might not be able to generate the code by themselves, and they don't understand what it is in the code, but they make use of it. This inversion highlights a learning process that is exploratory and application-driven, leading to an understanding of how basic concepts work by trying out the AI indications and leading us to a remembering face. As they Analysed and Evaluated the

functionality of their creations, they gained a deeper understanding of the underlying concepts by comparing what they promoted for, and what they got as a result. In this case, we would see a mix of lower-order thinking skills (LOTS), and higher-order thinking abilities (HOTS). This becomes an iterative process where knowledge is gained through applying unknown knowledge and trusting a GAI tool.

# Theme 2: AI Integration in Unfamiliar Domains

- 1. **Apply**: Students begin by applying GAI tools to generate code and instructions for building an initial part of the robot with Arduino, with which they are not familiar with. They trust GAI to guide them through the coding process leading to a creation step which might or might not result in their initial objective.
- 2. **Create**: Based on the GAI-generated instructions and code, they create a functioning piece of the robot. The creation here is more exploratory, as they are heading into an area where they have less or no experience.
- 3. **Remember:** Positioned after the hands-on experience of creating, the act of remembering is now framed by a context of practical engagement. At this stage, students are more likely to internalize the concepts and procedures of Arduino coding, as their thoughts are based on tangible experiences, errors, and achievements. They remember the way of connecting the different components thanks to the GAI guidelines and creation as a result.
- 4. **Analyse**: Once a part of the robot is created, the student analyses its functionality. They examine the result and see if it aligns with the expected outcome.
- 5. **Evaluate**: The evaluation phase involves assessing the performance of the robot and the accuracy of the GAI-provided instructions. They consider the efficacy of the solution and identify any gaps in functionality for later on going back to the application phase.
- 6. **Understand**: Through trial and error and the iterative process of analysing and evaluating, students begin to understand how the Arduino works. The GAI's guidance, combined with practical application, leads to a conceptual understanding of the coding and electronics involved.

# 7 DISCUSSION AND CONCLUSION

The implementation of GAI tools into the educational design process, particularly in this context of robotic design problems, represents a transformative approach to learning and creativity. The use of GAI tools changed students' approaches to the design challenge given by the case company. These tools did not only aid the creative process, but also functioned as co-creators allowing for a larger exploration of ideas, rapid prototyping, and optimization. The GAI-enhanced iterative design approach enabled the students to efficiently refine their ideas from abstract notions to a proof-of-concept prototype. However, a GAI-driven design learning method raises various considerations. Firstly, we identified that the case students' learning process, as defined by Bloom's Taxonomy [6], got disrupted when GAI tools were introduced. From the comparison of both scenarios previously presented, the students' learning approach in this exploratory project, in some phases, began by directly applying GAI tools and techniques to find knowledge, skipping the basic stages of remembering and learning.

Second, the implementation of GAI requires critical thinking in both learning and design. Although GAI tools aid in various design tasks, they demand a critical analysis of their proposals, acknowledging that these solutions might not always be the most effective or efficient. Rapid results from GAI can be misleading without a solid understanding of the underlying concepts, underscoring the importance of critical thinking and problem-solving skills beyond mere tool usage. This case study highlighted how students applied critical thinking to familiar tasks like sketching, modelling, and optimization when using GAI.

Using GAI requires trust in the technology, especially when applied to unfamiliar areas. However, this trust needs to be balanced with critical analysis. Students should not only use GAI technologies but also critically evaluate and question their outcomes, exploring alternative applications. Educators should offer guidelines to help students assess the relevance, accuracy, and reliability of GAI results, recognizing that while these tools enhance learning and creativity, they are not infallible.

Lastly, this new setting can bring issues about what it means to teach and learn. The problem is not just in finding the right way to implement these technologies, but in understanding the teacher's position in a GAI-enhanced learning setting when it becomes easier to avoid early steps in Bloom's taxonomy (Figure 1), i.e. building a knowledge foundation in a subject. Teachers may need to emphasise more on teaching 'basic principles' in subjects to encourage critical thinking and creativity beyond what GAI can provide in building a strong knowledge foundation. At the same time, in some scenarios the teacher's role might change to facilitator and help through reflections, once the basic concepts are settled, being able to create more personalised and independent learning processes for the students letting them become more self-directed.

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# REFLECTIONS ON A COMMUNITY OF INQUIRY APPROACH TO DESIGN STUDIO EDUCATION: A CASE STUDY

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# ABSTRACT

Design studio pedagogy is the principal teaching method used in design education. The studio environment promotes learning through engagement with real-life projects that are typically ill-defined and supported by a design tutor. While learning is rooted in an experiential modality (learn-by-doing), the *why* of the designing (purpose, methods and tools) mostly remains implicit. The differing nature of design projects means that systematic approaches are seldom used, therefore students must understand the fundamentals of the discipline to succeed.

This research paper presents a pilot case-study on the integration of a Community of Inquiry (COI) approach into the design studio aimed at subverting the implicit nature of design education. The COI framework is taken from Lipman and Sharp's 1970s reimagining of philosophy for children, in which inquiry through communal dialogue is used to explore the philosophy of a discipline. In the adapted version presented here, the *discourse* revolves around the principles of design and emerging artefacts (sketches or prototypes), the design tutor becomes the *facilitator* who labels design moves and models design skills, and the *stimuli* are democratically selected design projects.

Survey results provide insights into students' experiences along with their challenges with this approach. Observations of students' design tendencies along with their design outcomes are also presented. In addition, the rationale for integrating COI, along with how it was adapted for use in a first-year product design module will be outlined, along with challenges, benefits, and learnings for future implementation.

Keywords: Community of inquiry, design studio education

# **1** INTRODUCTION

# 1.1 Design studio pedagogy

Design studio pedagogy is the principal teaching method used in design education [1]. The studio environment is rooted in an experiential learn-by-doing modality that promotes learning through engagement with real-life projects [2]. Here, product designers typically tackle ill-defined problems that go beyond mere form giving [3], requiring synthesis of specialist subjects as diverse as ergonomics, sustainability, and design for manufacture [4], and use of a multitude of possible design tools [5]. The differing nature of design projects means that systematic approaches are seldom used [6], adding to the challenge of design education. Furthermore, the why of the designing (purpose, methods and tools) mostly remains implicit in design education [3, 7-9], meaning process knowledge is only gained through experience. This research paper presents a pilot case-study on the integration of a Community of Inquiry (COI) approach into a design studio module, aimed at making the implicit explicit.

The design programme in which this case-study takes place, has had much success in graduate employment and at both national and international design awards. However, recurring observations across several years of final year students' capstone projects hinted at graduates that may not fully understand the rationale of designing, the methods, or tools. This pilot study was undertaken to investigate if this knowledge gap could be lessened.

# **1.2 On Community of Inquiry (COI)**

Community of Inquiry (COI) was chosen for integration into this study as it is an educational approach that explores the philosophy of a discipline, with the goal of making the 'why' explicit. It was deemed a good fit for design studio environment as it facilitates active and collaborative participation in a student

led learning forum. The COI framework used in this pilot study is taken from Lipman and Sharp's 1970s reimagining of philosophy for children. This differs from Garrison's [10] version typified in online usage which espouses social, cognitive, and teaching presence.

In COI, deep learning and understanding is achieved through participants collaboratively exploring ideas while asking rich and meaningful questions of each other on topics of interest. Through COI participants learn to guide themselves, think independently, and make informed choices [11]. Important factors in achieving this include discourse, community, facilitation and stimulus. Discourse involves inquiry into the fundamentals of a discipline, collaborative experiences are increased through a community of participants, the teacher becomes a facilitator [12], and the stimulus is material, such as a video, that prompts discussion from which a democratically chosen subject emerges. The role of the facilitator (sometimes called a moderator) is to act from the Socratic "position of ignorance", working at the same level as the participants, labelling moves and challenging assumptions, uncertain where the inquiry will lead.

#### 1.3 On design

Design projects typically start with a design brief given by either a design tutor or industry partner. Set out in this design brief is the contextual background, project aims, expected deliverables, design phases, deadlines, learning outcomes, and assessment criteria. Students then engage in a series of scheduled phases working towards a design solution that fits the predetermined design constraints of the brief. Design programmes typically take a scaffolded pedagogical approach starting with simple design projects and introduction to fundamental design tools in the formative (initial) years of education [13]. Each design phase typically spans one or two weeks, with each student attempting a variant of the same design brief. Projects can be individual or in teams and range in duration from several hours to several months. Design slams are short intensive projects which can start and finish in a matter of hours, while many cap-stone projects run over an entire year of study.

The design studio acts as a community of practice with students of all years working on projects in a shared space [14]. Discourse is central to this design studio community taking place in many forums such as tutor mentoring and teaching, informal peer discussions, and design reviews [15]. The design review, or crit, is a designated time during a project when students present their work and have experts and fellow students review and offer feedback [16]. However, the emphasis in these forums tends towards the designed object and advancement of solutions rather that of the why of the designing (purpose, methods, and tools).

The product design process model introduced in this module matches Kruger and Cross's [17] 7 stage expertise model. Due to the introductory nature of this first semester module, only phases 4-7 were engaged in to simplify the process. Phases 4-7 include: 4) define problems and possibilities; 5) generate partial solutions; 6) evaluate solutions; and 7) assemble a coherent solution. From a vast array of design tools such as sketching, CAD, prototyping, cultural probes, roleplaying, immersion, and mind-mapping, only sketching and prototyping were introduced.

# 2 METHOD

The following section outlines how Lipman and Sharpes COI framework was adapted for a first-year design studio module along with how data was gathered from the pilot study.

#### 2.1 Context of study

The design studio module in which the case-study takes place is the first design module students will take in their four-year degree programme at the University of Limerick. The aim of this module is to introduce the fundamental skills and cognitive processes of product design and to lay the foundations for subsequent design studio modules. Participants comprised 43 Product Design and Technology students (20 female, 23 male) and ran over eight weeks, with one three-hour studio session per group each week. In this time students engaged in four projects, three of which were group projects (3-5 students per group), with the final project undertaken individually. The class was split into two groups of 21 and 22 students. The researcher was also the design tutor (facilitator). Each project ran for two weeks, a total of two three-hour sessions per project.

# 2.2 How COI was adapted

Elements of Lipman and Sharpe's COI framework that were deemed appropriate (workable?) in a design studio context were selected (see Table 1). In the adapted version presented here, the discourse revolves around the principles of design and emerging artefacts (sketches or prototypes), the design tutor becomes the facilitator who labels design moves and models design skills, and the stimuli are democratically selected design projects.

COI elements	COI focus	Adaption for design studio pedagogy
Discourse	Inquiry and discussion to improve	Inquiry into the 'why' of design and
	concept formation through	designing (principles, methods, and tools).
	equipping students with such tools	Shift in focus from discussions around the
	as criteria, reasons, arguments and	designed object, to discourse on the
	definitions [18].	principles, methods or tools of design.
Community	Increase in collaborative	Increase in team projects: (from 25% – 75%).
	experiences for learning where peer	
	engagement is essential [19].	
Facilitation	The teacher as a facilitator or guide	From tutor defined projects and schedules to
	<ul> <li>acting as a bridge between</li> </ul>	student led. From role of tutor to moderator,
	concepts and arguments [12].	facilitating critical discourse on the rationale
		of designing.
Stimulus	A democratically chosen subject	From tutor defined project topics to
	from which discussion emerges	democratically self-selected design projects.
	[20].	

Table 1. Comparison of COI and design studio

# 2.3 Survey & Observations

A survey was used to gather participant feedback on their experiences of the integration of COI into design studio education. The aims of the survey were to find out:

- 1. how students found learning to design through the integration of COI and design studio.
- 2. if the group work prepared students enough for their individual project.
- 3. the main challenges for students.
- 4. the students' overall impression of the module.

Students were asked 15 questions, 13 of which were 5-point Likert scale questions and two open ended questions. Questions were structured to avoid social desirability bias and primacy bias. The data was collected using paper surveys distributed to 43 student participants, 38 students participated. Observations were noted in weekly diary entries about session organisation, student engagement, discussions topics, student assumptions, novice tendencies, and work produced. Ethics approval was granted by the University and all participants consented to involvement in surveys and observation studies.

# **3 FINDINGS**

# 3.1 Survey

Survey results present an overall positive experience for participants. Overall student satisfaction rating for the module was high with 47% satisfied and 34% very satisfied on a 5-point Likert scale (not satisfied – very satisfied). Learning through group projects was also deemed positive with 58% rating as enjoyable, and 23% on the very enjoyable rating. Students were also asked how prepared they felt for taking on an individual project following three rounds of group projects. In response, 74% stated yes somewhat, and 18% yes, a lot. Free text answers offer some rationale for this positive feedback: "I felt that the previous stage gave a trial run on how to work on the project, also got insight into how others think"; and "Yes, because I could learn from my mistakes in the group project."

39% of participants found engagement in group projects easy, while 26% found it very easy. The majority of the class enjoyed having the autonomy of self-directed projects with 39% satisfied and 50% very satisfied on the Likert scale with only 8% stating they would prefer given projects. Motivation in group work was stated as high for 45% and very high for 21% of participants. Results were similar for the individual project with 47% stating motivation as high and 29% as very high. Free text answers support an increase in very high motivation for individual projects: "I think that working in the group

projects prepared me well for the individual project and it made me excited to explore some of my own ideas and skills".

The survey also captured students self-rating on six elements from the design projects including project selection, ideation, prototyping, sketching, understanding the process, and time management. Here, project selection, time management and ideation were rated most difficult of the six, with sketching and prototyping as the easiest. The following free text answer presents an example of why ideation can be difficult for novices: "I felt the initial stage of creating an idea hard as I was not thinking about a problem. I was trying to think of a product". Free text from a question on how you could have been better prepared for the individual project supports the ratings that project selection was the biggest challenge (10 references), followed by time management (7 references).

#### 3.2 Observations

Excellent participant engagement in group work together with good quality discussions were observed and recorded in weekly diary entries. In addition, students seemed to enjoy the format. These behaviours are evident in photos of group whiteboard discussions and group prototyping.

Students' design outcomes were of high quality relative to time spent on projects with a remarkable diversity of self-directed projects undertaken. Group projects ranged from orthopaedic corsets to personal electric transportation devices, personal substance tracker, and a student backpack.

Student's difficulty with ideation, as found in the self-rated survey question, was also observed in weekly diary entries. In general, students tended to generate single or limited number of ideas, despite discussions around the divergent nature of this creative design phase. A second noteworthy novice tendency was also observed throughout the pilot study – the absence of iterative practice across ideation and prototyping activities.

Diary entries also highlight the two main challenges for facilitation of a COI approach in design studio education. The first was balancing discourse with the 'learn by doing' activities in projects. While energetic discourse was obvious at times, the 'doing' nature of design resulted often dominated the sessions. Secondly, the uncertainty of facilitating student-led rather than tutor-led sessions was daunting. Not knowing where the self-selected design projects will take different groups was challenging, as it takes much tutoring experience, an understanding of the rationale of design, and knowledge of novice tendencies.

# **4 DISCUSSIONS**

#### 4.1 Engagement, motivation, and self-directed work

Student survey results and researcher observations during this pilot study present an overall positive learning experience for students. Student engagement, an important factor in effective learning [21], was excellent. Dewey's [22] notion that academic achievement is positively influenced by the amount of active and collaborative participation in the learning process highlights the benefit of the collaborative learning experience central to Lipman and Sharpe's COI.

Research has also shown that the more educators give their students autonomy of choice and control, the more their motivation and engagement are likely to rise [23]. As this is the first study, it is unfortunately not possible to compare to past experiences. However, observations of design outputs were refreshingly diverse and demonstrated good thinking in bringing ideas through phases 4&5 of Kruger and Cross's [17] expertise model (4. define problems and possibilities & 5. generating partial solutions). This may be partially due to Pintrick and Schunk's [24] idea that students learn subjects that they are interested in and have autonomy in making choices, they tend to perform better. This also hints that to date we may also have been underestimating students by providing overly structured briefs and perhaps being too prescriptive. In addition, by making the implicit (the why of design) explicit through discourse, the autonomy afforded to students is more worthwhile.

#### 4.2 Novice tendencies

Four novice tendencies were highlighted by the survey results and weekly diary entries. These included difficulties with, idea generation, project selection, time management, and iterative practice, each a tendency that would be expected from novice designers with little process experience. Limited idea generation is common in the work of novices due to tendencies such as design fixation [25] while good time management would rely on experience of design methods and tools. Despite being discussed in class; it was obvious that iterative practice is not a natural tendency and is something that will be

explored in future implementations. Interestingly, results from the survey and observations were at variance for project selection. Despite students' selection of appropriate and interesting design projects resulting in good outputs, these survey findings highlight students' desire for certainty & achievability in design projects [26].

#### 4.3 Facilitation

Two major challenges with facilitation were highlighted in the Findings. Firstly, encouraging discourse on the 'why of design to develop a shared understanding of the rationale of process and tools was challenging. As Golding [11] notes, the moderator has to be skilled in facilitating group inquiry. The challenge in this forum is that design is an action, and maintaining the balance between dialogue and action was problematic as often students just wanted to "get on with it". Secondly, the experience of facilitation can be nerve racking, due to the radical uncertainty of this approach [12]. No longer is the teacher the 'sage on the stage', therefore setting one's ego aside and accepting you may not know the answer is crucial. Facilitation also requires patience and practice not to give 'the right answer', therefore competency as a tutor and an understanding of novice designer tendencies is critical. The loss of educational control can be uncomfortable for some [27] but the benefit of this is that the burden of learning is transferred to the student, freeing the facilitator to be fully immersed in facilitation.

#### 4.4 Learnings for future implementation

The positive results from this pilot study are encouraging for future iterations. Managing and maintaining discourse should be a considered in future implementations, as the 'doing' can take over from the discourse. In addition, consideration of how this mode of delivery is extended across a variety of subjects and years should be made.

#### 4.5 Limitations

There are several limitations to this pilot study worth considering for analysis of the study findings and for future research. As this was the first design studio module undertaken by participants and similar data had not been collected on previous cohorts, a comparison of approaches or learning experiences could not be undertaken. Due to the scope of the study, only surveys and research observations were used. In future studies, additional methods and independent observers may reveal deeper and less biased insights into the student learning experience. Furthermore, a follow up study would be required to establish whether or not there is a long-term positive effect on subverting the implicit nature of design education through COI.

# **5 CONCLUSIONS**

This research paper presents a pilot case-study on the integration of a Community of Inquiry (COI) approach into a design studio module, aimed at subverting the implicit nature of design education. Design education is complex due to the ill-defined nature of design problems, the requirement of specialist subject knowledge, and multitude of design methods and tools. This complexity often creates a dense curriculum that leaves little time for discourse on the why of designing (purpose, methods and tools). However, simply knowing the content will not suffice future graduates that face an uncertain and increasingly complex world. Future design challenges will require students' to be malleable, independent, and have an ability to be self-directed. The findings of this study go some way in establishing a starting point for creating such graduates.

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# EXPERIENCE OF GLOBALLY DISTRIBUTED DESIGN TEAMS IN A CHANGING WORLD

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# ABSTRACT

This study considers and reflects upon the experiences of globally distributed teams of design students, set a particular design challenge and given free choice over the tools that they use to complete that challenge. The study presents a reflective case study undertaken by staff facilitating a class consisting of asynchronous, globally distributed teams. The students were organised into teams across universities from New Zealand, the United Kingdom, Sweden, Finland, India, and Japan. The teams conducted the design challenges over eight weeks, culminating in completed design solutions. The academic staff involved in the delivery of this annual global design challenge reflect upon the changing and evolutionary nature of the class and students working practices since its inception in 2004. Interestingly many "traditional" tools were still employed alongside more contemporary options. The study reflects upon their experiences and how their choices shaped their solutions and learning throughout the design process.

Keywords: Design collaboration, global design, distributed teams, teamworking in design

# **1** INTRODUCTION

The development of modern communication and online collaborative tools has helped to increase the diversity and distribution of product design teams. Remote working and asynchronous design practices are rapidly becoming prevalent and are replacing shared physical spaces of designers. As the world continues to adapt to significant events post COVID-19, there is much debate about whether such working practices may become the norm and the value they render. At the same time, the emergence of digitally driven design and assistive tools offer teams a diverse range of approaches for rapid realisation during design development, with substantial debate regarding the efficacy of using such tools. Modern techniques in computer-aided design, generative design, rapid prototyping, and immersive tools offer new opportunities to accelerate and enhance the design process and, at least in theory, lead to superior design solutions, in comparison to physical model making, which was once the cornerstone of product design. Drawing on the notion that prototyping has been portraved as an excellent activity to share inner thoughts [1], previous research has lacked a deeper connection between knowledge-building, project progression, and the escalation of design processes across distributed teams operating at an asynchronous level. This is further supported using generative AI tools which can support the many other facets of working in a globally distributed design team; tools for language translation, generation of code for mechatronic designs, automated scripting [2]. To facilitate team progression, past studies have looked at how collaborative cloud-based tools can enable efficient sharing, interaction [3].

This paper furthers understanding of how students employ various tools in response to challenges, through students' own experiences. It is important, either from an educational or industrial perspective, to understand the working practices of the next generation of product designers. This awareness not only adds important perspectives to further enhance feedback processes that may enable action points for project management and improve the use of internal team resource competencies [4]. The steps required

to achieve consensus in collaborative practices within design teams vary based on the phase of the design process, emphasizing the importance of cognitive processes and conversation activities [5]. The challenges for distributed team challenges are complex; in a recent study on global innovation teams in an industrial context [6], numerous factors enabling the work were identified. For example, ways to learn from each other, establish collaboration, and choice of technology for communication throughout the project, were seen as essential. Yet by examining critical team dynamics this paper will guide design educators in the support of students during team interactions and for feedback interventions in the act of solving design problems in a distributed setting.

# **2 PROJECT FORMAT & EVOLUTION**

In order to explore these areas a class "Global Design" was created to provide a mechanism for design students to experience a truly international design challenge. The aim was to use digital tools and design methods to facilitate effective global team communication. Students undertaking the class gain a unique educational and design experience operating as part of a distributed global team. The setting aligns well with the ongoing trend of reduced travel for global development teams to lessen environmental impact [7] while also contributing to increased efficiency for the involved team members [8] and work quality [9].

#### 2.1 Participating institutions

The class was initiated at the University of Strathclyde. Initially informed by the research of academic staff and their colleagues at other institutions, where similar programmes in design and engineering were offered and have continued to this day. Over the last 2 decades there have been a number of participating institutions, those involved most recently are shown in Figure 1.



Figure 1. Participating Universities of Global Design 2023

#### 2.2 Project structure and brief

In each iteration of the class, students are organised into global teams of 7 or 8 across at least 3 institutions and set an 8-week design challenge to complete; project timeline is shown in Figure 2. Students are typically from design-related courses but can vary from more technical engineering to business and strategy disciplinary backgrounds. The challenges have varied widely, ranging from designing travel accessories to automated pet feeders. In the most recent iteration, teams were challenged to design a solution to help prevent deep vein thrombosis (DVT) on long haul flights. A series of lectures provided students with the background information on the types of activity expected at each stage. It was up to teams how they organised work, conducted meetings, and allocated tasks for the global team, but there were two main types of design activity (divergent/convergent) and two main modes of working (synchronous/asynchronous). Teams were invited to choose from the tools and methods presented and reflect on their effectiveness with regards to these activities and modes. All teams were required to produce a folio documenting their design process and outcome, culminating in teams presenting their design output in a joint online presentation. The samples of some outputs are shown in Figure 3.



Figure 2. Timeline of the design project undertaken in the global design class

During the project, recurrent reflections by the students were conducted focusing not only on the progress of the project and the collaboration with the international team, but also on the course design. These were collected through field notes and written project reports. However, due to the variant nature of academic calendars around the world, and whether or not the class was included as part of an assessed educational activity or voluntary, each institution could set their own mechanisms of assessment. The academics involved at each of these institutions now reflect on these outcomes over the years and on discussions and observations of student work within the class. This represents a mix of both formally and informally gathered observations drawing from course evaluations, team journals and reflective essays produced as part of the class, each varying by institution.



Figure 3. Samples of output generated by participating teams

# **3 EXAMINATIONS OF PRACTICE & CHANGES OVER TIME**

Much has changed and evolved since the inception of the class. However, it is reflected that many of the principal benefits and challenges of participating have remained consistent. These are best summarised under three principal categories of technological support, organisational matters and cultural aspects. In Table 1 we present a summary of the key observations in each of these areas in the early stages of the class and the later stages of the class.

Table 1	. Summary	of evolving	practices
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	Observations from early iterations of the class (2004 – 2009)	Observations from later itMayerations of the class (2019 – 2024)
Technological support	<ul> <li>Social media quickly becomes the defacto means of communication; students cite the more intuitive means of communication compared to features built into software or email.</li> <li>Different institutions make use of different standard software, this is a perennial challenge still relevant in 2024.</li> <li>Many of the best tools remain prohibitively expensive for student teams, still relevant in 2024.</li> <li>Language and communication software, particularly live systems are limited and inaccurate.</li> <li>While social media is the defacto means of communication video conferencing remains popular and is often cited as the preferred means of synchronous communication as a team.</li> </ul>	<ul> <li>Social media remains the prevalent form of communication. However, as platforms limit cross-platform functionally and require more "buy-in" personal preferences create challenges in arriving at consensus (e.g. "Don't like Facebook", "don't use social media")</li> <li>Language and communication software, particularly live systems, have become increasingly powerful and accurate. However, increased trust presents issues when errors occur and are then propagated by the human users.</li> <li>"Zoom fatigue" has become an issue, a pre-emptive sense of exhaustion prior to large calls.</li> <li>Fewer barriers to equipment post pandemic following the global adoption in both personal and social contexts.</li> <li>AR/VR unfortunately remains of very limited use as it requires such significant buy-in and like-for-like compatibility.</li> <li>Using only e-mails and text messages caused misunderstanding and did not contribute to cohesion</li> </ul>
Organisational matters	<ul> <li>Time difference principal organisational issue for global teams.</li> <li>Variously parts of teams might be in workshop together while counterparts are at home many hours after leaving practical spaces.</li> <li>Access to web conferencing equipment may also be influenced by the space team members are operating in.</li> <li>Cloud based storage influenced by institutional and team member personal preferences.</li> <li>Accommodating different curricula and academic cycles across partners has implications not only in organising the structure and delivery of the class, but for individual team members in co-ordinating meetings and collaboration.</li> </ul>	<ul> <li>Time differences remains significant challenge however equipment access less of a challenge post-pandemic.</li> <li>A challenge still remains with practical work.</li> <li>Increased concern for cyber security has driven greater security steps, notably 2 factor authentication and similar. While these are necessary, they present challenges for shared resources; benefits of particular tools cannot be realised, unless all institutions have the reciprocal tools.</li> <li>Licencing arrangements for each institution, even on the same platforms, present challenges, significantly more so than in previous years.</li> <li>Varying levels of commitment among students can led to low engagement and the formation of subgroups.</li> <li>Differing understandings within the team regarding the problem to be solved resulted in a suboptimal solution. Additionally, the organizer/project owner did not sufficiently clarify the purpose of the expected for a solution and the existing research in the problem area was not optimal for the solution</li> </ul>
Cultural aspects	<ul> <li>Value is really gained in cultural exchange and co-working on a design challenge that is global in nature.</li> <li>There are challenges of integrating the unique cultural natures of teams that have principally been most valuable but potentially problematic challenges in mapping institutional expectations to assessment and outcomes.</li> <li>Attitudes and approaches to design work</li> </ul>	<ul> <li>Use of translation tools to overcome language barriers, which are increasing in accuracy, however these are still literal, and are limited in terms of subtleties, e.g. cannot grasp subjective regional expressions and turns of phrase and can lead to misunderstanding.</li> <li>Differences in communication culture especially in live communication intensity can cause frustrations among participants.</li> <li>Differences in time management culture caused uncomfortableness among teammates. Preferences for a planned schedule versus working intensively when the deadline approached.</li> <li>Differences in decision-making process culture confused teammates. Some were used to adjust the agile approach and others were more used to the waterfall approach.</li> </ul>

#### **4 DISCUSSIONS**

Improvements in the equipment and software available to designers and students has rapidly transformed the pace at which design projects can be completed in a distributed setting. However, challenges of working in a cross-cultural international team remain. Shifting attitudes towards certain software and their parent companies has become a much more prevalent concern particularly among student teams. Regional variance in preferences has also become more noticeable since early iterations of the class. Unfortunately, many of the most advanced and impressive features of particular software and hardware remain prohibitively expensive. For example, many teams have indicated that they would wish to experiment with AR/VR capabilities, and while they have access to particular hardware and software to achieve this, it requires corresponding resources at partner intuitions, which are frequently different or bound by separate licencing agreements, in some cases even where the same suppliers and providers are involved. Those teams which did persevere had some success but it served more as an accompaniment to other design tools rather than a critical tool in itself, and was seldom employed in the convergent design tasks, where critical design decisions are made, it was a general observation by those student teams that if there was greater ubiquity and/or cross-platform options available this would have been a more useful avenue to pursue, perhaps this will be more of a significant shift in the next decade, with costs reducing as time passes.

Time differences remain a significant challenge. Night and day patterns mean team members may be at home rather than the office and do not have access to same equipment as their counterparts and vice versa. Some students also drew attention to having to set very clear boundaries around communication, particularly what types of communication were appropriate and at what times, or indeed what 'out of hours' times should be agreed upon by team members in different regions. Variance in cultural expectations around working patterns and a need to establish trust and confidence early in the project have also been key factors to consider, to facilitate this "ice breaker" activities have been employed. Other studies into distributed student work make similar observations on the influence of team cohesion, identity, trust, and credibility early in the project [10] and the challenges presented by physical separation in design teams [11].

When considering the value of teleconference or telepresence systems, video chatting is frequently highlighted as the preferred option when time allows. When considering why this is the preference teams cite the value of being able to see and read facial cues and to be able to gesture when communicating. The ability to screenshare was also highlighted as a key benefit. Interestingly the advent of another technological assistance, live transcription and translation, has added a compounding layer to this mode of communication. While it has been immensely powerful at assisting communication it has also led to complications with distraction meaning that some facial cues are missed while reading and that regional expressions or idioms which are translated literally lose some of their subjectivity and subtleties. Many teams also highlighted that while such tools are useful, they should not be trusted without question as this can lead to misunderstandings.

Almost all teams reflected on the value of taking the class. Many participants cited the unique experience of being part of a cross-cultural team [12]. Comments frequently arose that it forced team members to consider problems from different perspectives and that this frequently led to potential solutions they would not have considered otherwise. In some cases, this was highlighted even in terms of the different languages involved, where expressions, once understood, provided a different interpretation of a product feature or function.

#### **5 CONCLUSIONS**

Challenges of time difference, choice of communication tools, cultural issues, variance of team member experiences, variance of outcome expectations, language and communication barriers remain a consistent feature of collaborating for students in globally distributed teams. We learnt the methods and tools employed by teams have evolved; in many cases reducing the level of challenge. However, none have been eliminated completely – arguably indicating that the challenges of operating in a global team still exist, and while new tools are positive in minimising these challenges, they are still only effective if used purposefully, with consideration, and with an understanding of their limitations. In reflection the academics involved from the participating universities make a number of recommendations; communication is still the most significant factor in the success of globally distributed projects. Various software and hardware can improve quality but cannot alone replace the fundamentals of good communication. Care should be taken to ensure that such tools do not inadvertently amplify
misunderstandings. This can take many forms, loss of versioning control, cultural misunderstandings and possibly break downs in team moral. It should not be assumed that a team will adopt a suitable default means of communication, preferences and concerns can heavily influence a student team's success, academics and prospective employers should take significant care in establishing appropriate modes of communication: and aspire to create a functioning eco-system where the team can operate. This is best achieved when co-created with student teams themselves.

The longevity of the class is a highlight of the value of collaboration and its success in meeting educational needs in a global society and employability of graduates of the future. There has been a willingness on the part of staff to facilitate the global experience and for students to embrace it as part of their learning journey.

Throughout this study, we have identified further research avenues, such as the development of teaching tools and support for international courses to minimise identified hurdles; exploring how the involvement of global companies can potentially enhance teaching activities and student engagement; and investigating how courses spanning longer durations can potentially cover more activities towards a fully developed solution ready for implementation.

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# A NOVEL ASSESSMENT APPROACH TO ENHANCE MANAGEMENT, TEAM WORKING AND COMMUNICATION SKILLS FOR ENGINEERING STUDENTS THROUGH EMPLOYMENT EXPERIENCE

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# ABSTRACT

The *employment experience module* is an opportunity for mechanical engineering students to get academic acknowledgement of skills and experience gained while working in a variety of companies and industries. The careful design of the learning outcomes for the module has enabled students to develop skills required by accrediting bodies, such as Engineers Ireland, but uniquely does not require that the student be employed in an engineering company. In recent years college attendance has been compromised because many students are in part-time employment, and opportunities were sought to benefit from this reality while encouraging student retention.

The novel assessment approach significantly reduces the costly input of academic/university time, organisation and management as the student's ability to self-manage and use their own initiative is being assessed. The students must source the employment themselves. The employer must give permission for the student to avail of particular opportunities within the company. This highlights the 3-way partnership of responsibilities between the student, university, and the employer.

Inherent in the development of communication, teamworking and self-management skills are the requirements to document evidence in a work journal. Communication of technical information relevant to the company, in the context of safety protocols, operating procedures, quality assurance process and codes of practice, are key to enhancing the technical content and providing a broader context to the employment.

An outline and review of the authentic assessment approach and delivery of the process is presented, along with the participation statistics of students and companies over four years of implementation. The module learning outcomes and the type of evidence provided by students to align with the outcomes are discussed.

*Keywords: Engineering, employment experience, authentic assessment, self-management, communication, organisational, self-directed, reflective, evidence* 

# **1** INTRODUCTION

A novel *employment experience module* is presented that utilises a students' existing employment arrangements to further develop the key skills of communication, self-management, and organisation. *Technological University Dublin* (TU Dublin) strives to encourage early career development by allowing the student to experience these core engineering skills through employment experience and alternatives to traditional engineering placements [1]. There is no requirement for the employment to be in an engineering company, or to involve technical engineering tasks. The students report on the achievement of learning outcomes relating to ethics, health and safety, codes of practice, quality assurance and environmental considerations. Key managerial roles within the companies' structure are also reported on by the student, along with evidence of their self-directed work within teams. The constructive nature of the module delivery process and the authentic assessment approach encourages students to view their job through a wider lens and to review company goals and structures. Permission for the employee to engage in and report on communication and organisational opportunities within the organisation.

The *employment experience module* aims to improve students' learning experience in mechanical engineering by enhancing "non-technical" skills required by accrediting bodies, such as Engineers Ireland, through work-based experience. The process aims to develop key competences of an engineering technician: effective communication and interpersonal skills, self-management, professional responsibility, and creating and applying safe working practices [2]. Behaviours and interactions between people have been shown to be important skills to enhance in engineering education, rather than technical skills alone [3].

Sourcing jobs for the large numbers of mechanical engineering students in a programme is often not a realistic objective for engineering schools due to resourcing issues. However, anecdotal evidence indicates that many students are already in part-time and summer employment to support their cost of living. Although working while studying has been shown to have adverse effects on the amount of time for attending university and completing assignments [4], opportunities were sought by the school of mechanical engineering to encourage student retention. Students present their engineering or non-engineering work experience to an assessment procedure to demonstrate that they have obtained these key competences during their employment. The independent sourcing of employment requires the student to use their own initiative, and the assessment of the self-management of the learning outcomes by the student significantly reduces management input using college resources in contrast to traditional engineering internships, which are costly to run and require significant academic and administration input.

Successful students are awarded a module exemption in a *professional development module* in the next academic semester. Internships in companies support lifelong skills and confidence to choose their preferred career path [5]. This gives students the opportunity to get academic acknowledgement of skills and experience gained while working in a variety of companies and industries that they would not achieve in the classroom. Students are rewarded in this process for presenting the value they add to the company in terms of contributions, valued opinions and personal development, skills that have identified as being essential to industry employers [6].

This paper presents a review of the novel assessment procedure for an employment experience process that has been implemented for four years as an optional module within the Mechanical Engineering Ordinary Degree programme (TU717) at TU Dublin. The module code is MECH2039. A review of the approach to enhance management, team working and communication skills for engineering students is presented. Section 2 gives an outline of the delivery and assessment approach. In Section 3 the participation statistics of students and companies over four years are presented. The module learning outcomes and the type of evidence provided by students to align with the outcomes are discussed in section 4.

# 2 METHODOLOGY AND DELIVERY OF THE EMPLOYMENT EXPERIENCE MODULE

The constructive nature of the delivery of the *Employment Experience Module* is dependent on the successful, authentic, and timely completion of four deliverables:

- 1. Employer's approval questionnaire,
- 2. Students work journal detailing the employment,
- 3. Final written report of the employment experience,
- 4. Oral Presentation to the review panel and accompanying PowerPoint.

The requirement of 200 hours employment is typically completed during the summer after 1<sup>st</sup> year, however part-time employment may extend into the student's 2<sup>nd</sup> year in college. The module delivery process and authentic assessment approach is delivered in three important stages of the early student learning journey.

# 2.1 Stage 1

The optional employment experience module is introduced and explained to the 1<sup>st</sup> year student cohorts. The learning outcomes that must be completed and the reflective nature of the report and presentation are outlined to the students. The deliverables that must be completed, and the relative weightings are explained in detail. As 1<sup>st</sup> year *mechanical engineering* students and the 1<sup>st</sup> year *general engineering* student streams feed into the 2<sup>nd</sup> year *mechanical engineering* cohort, both groups are presented with the opportunity.

Support from the *TU Dublin Careers Development Centre*, in terms of CV writing, employer and alumni connections, is provided. Students are encouraged to attend TU Dublin employment and careers fairs and events. Students are also encouraged to avail of the student membership of Engineers Ireland and the Institute of Mechanical Engineers IMechE.

At this early stage, interested students are given access to the module Virtual Learning Environment (VLE), outlining the module descriptor, submission dates for deliverables, and case studies of previous students' reports and presentations. Students are informed that their employer needs to approve their participation in this process. Examples are given as to how the learning outcomes can be achieved in a "non-engineering" company. This encourages students to keep the learning outcomes of the module in mind when looking for full or part-time employment, or to view their current employment in the context of the module requirements.

# 2.2 Stage 2

Employment is sourced by the student independently of the university. However, the employer's approval questionnaire needs to be sought by the student and signed by the employer during this stage. The objective of this questionnaire is to make the employer aware of the learning outcomes that the student requires and to facilitate these by permission to: i) attend meetings, presentations and to be included in companywide communications, ii) allow access to company information regarding its organisational structure, managerial roles, QA procedures, health and safety, codes of practice and iii) share knowledge of company projects, goals, resources, and marketing of these. Confidentiality is agreed where necessary.

The students are required to complete a descriptive work journal of the activities, training, and projects they are involved with to identify goals and gather evidence. If they deem the nature of their current activities in the employment are not sufficient to meet the learning outcomes self-direction is required by the student to obtain more information on achieving the outcome, or to request more opportunity or information from the employer. The work journal is the main tool used for self-reflection on activities completed and self-management of goals.

# 2.3 Stage 3

The *employment experience* module is processed and assessed in semester 1 of the 2<sup>nd</sup> year of the programme. The students partake in weekly mentoring meetings, where the work journals used to record and reflect on work tasks are reviewed by the students, and evidence of the learning outcomes completed during the placement is gathered and refined for the written report.

The module lecturer approves the participation in the module based on the completed employer questionnaire and the work journal, to confirm if the employment experience has the capability to meet the learning outcomes of the module. The lecturer answers student queries, monitors the timely completion of the deliverables, and gives feedback. Students receive weekly course notes, specific class group meetings and presentations from previous years' students.

The final assessments are an oral presentation on the employment experience and a written structured report giving evidence of the achievement of each learning outcome. Copies are given in advance of a sitting of a panel of TU Dublin lecturers who agreed to award the student a pass grade. Key to the completion of this pass/fail module is i) the ability of the student to complete the reflection activity on the employment experience they have completed and ii) the alignment of this experience against the employment experience module learning outcomes. Consideration is also given to the employer comments.

As this is an optional module, students must be very focused on completing the module deliverables based on their own initiative. Completing the process requires self-management skills and develops responsibility and awareness of lifelong learning. Communication skills are enhanced in preparation for the final presentation. The students are also asked to complete the confidential TU Dublin questionnaire reviewing their experience of the module.

# **3 REVIEW OF RESULTS OF THE ASSESSMENT APPROACH**

In the four years that the *Employment Experience Module* has been taught, 39 students have successfully completed and passed the module. Figure 1 shows the number of students who successfully completed the module from 2020 to 2024. Class participation rates varied from 11% to 21% of the registered students in each of the four years examined.

Students were not required to obtain a job in an engineering company; however, it was observed that significant proportions of students worked in an engineering environment. Figure 2 outlines the number of students who worked in engineering companies as being between 31% and 67% of students participating in the module each year. This cohort also achieved significant additional technical skills specific to engineering, in addition to meeting the learning outcomes of the module. 31% of the students



Figure 1. Employment Experience Participation



who completed the module came through the general engineering 1<sup>st</sup> year programme, indicating that the assessment approach is robust and adaptable and has the flexibility to be applied in a variety of programmes and disciplines.

# 4 DISCUSSION ON THE QUALITY OF EVIDENCE OF ACHIEVING THE LEARNING OUTCOMES

The learning outcomes of the *employment experience module* are outlined in Table 1. They were developed using the key competences of an engineering technician that are expected to be developed after two years of the programme: effective communication and interpersonal skills, self-management, professional responsibility, and creating and applying safe working practices [2]. In addition, consideration was given to the 2<sup>nd</sup> year *professional development module* learning outcomes successful students would receive an exemption from. On completion of the *employment experience module*, the pass/fail is awarded based on the achievement and demonstration of the following module learning outcomes.

1	Communicate technical and other information effectively, both orally and in written form, in a
	professional environment.
2	Work effectively as part of a team and develop self-directed work management skills.
3	Discuss the relevance and application of safe working practices in the workplace, in the context
	of relevant statutory requirements and codes of practice.
4	Describe the company structure, including management roles, HR functions and Quality
	Assurance systems.
5	Outline the project/process/service you are involved with, the key management roles and your
	role in contributing to the achievement of company goals and technological tasks.
6	Summarise and report on learning experiences through preparation and presentation of a
	reflective journal and final report, as per the guidelines given in Employment Experience
	Module Handbook.

Table 1. The specific learning outcomes of the module

# 4.1 Learning Outcome 1

Evidence of communication of information, both technical and non-technical was provided in many forms. Some students had clear customer service and support roles, with others providing training to new staff members in company protocol or sales techniques. Other examples were developing Computer Aided Drawings (CAD) drawings and website designs. One student worked in a car

dealership as a parts advisor managing stock and interacting with customers and mechanics. Where students had little opportunity to communicate at departmental or project meetings, the students were required to demonstrate to the panel the details of the companies' business activities.

An example of this was a student who processed paint cans at a waste processing plant. In his report and presentation, he provided a review of other process provided by the plant about soil cleaning, waste oil, and pesticide management. A student working as a courier manager for a national food delivery service, interacted with courier services in many locations and provided a review of the range of software technologies that facilitated timely delivery of hot food from many providers on the website. The written report and oral presentations are evidence of the student's ability to communicate their experience, and present technical information.

#### 4.2 Learning Outcome 2

An example of teamwork was given by students who were general operatives in a heating and ventilation company working on air handling units for data centres and in furniture manufacturing. They were general operatives who worked in a team of installers who had regular interactions regarding scheduling, coordinating tasks, problem solving and upskilling within the team. Reporting on how problems were resolved in a retail or farming environment highlighted their role in teamwork, and how processes are run by all team members conforming to operating procedures.

A smaller number of students obtained intern field engineer posts, and performed roles in operations management, liaising with contractors, managing schedules and implementing communication and safety protocols while work was being done in relation to water and mast installations and developments within a hospital environment. Self-directed management skills were also developed by completing the process of reflecting on the experience gained. Students described their role within the team in solving company issues and meeting company goals.

#### 4.3 Learning Outcome 3

The application of safe working practice was evident in all employment types, where counter hands in supermarket meat counters were responsible for meat processing equipment and safety and cleanliness protocols. The HACCP management system for food safety in farming, food production and food retail environments was the most prevalent in the evidence. Protocols for selling controlled drugs in a pharmacy environment, and codes of practice specific to construction industries and factory floor assembly were presented. Students demonstrated that they were conscious of their own safety and the safety of others and were trained in using the required Personal Protective Equipment (PPE) requirements correctly. In several instances, the improvements by either corrective actions or operating procedure revisions were recommended by the students to the employers.

#### 4.4 Learning Outcome 4

Students provided graphics of the organisational structure of key departments and managers in larger companies. Examples are leading manufacturing contractors and public supply chain outlets such as Argos, PowerCity, JustEat, Noonan Cleaning, Jones Group, and Intel. The key responsibilities of managers at each level were described, in terms of meeting company goals and managing staff. The roles of Human Resources were presented in varying levels of detail. Details of the quality assurance processes in the particular companies also provided an opportunity to describe some technical detail of requirements they were operating within.

#### 4.5 Learning Outcome 5

Students described the projects, processes, or service they were employed to partake in. They presented an understanding of both the commercial value of what they do and what value they added to the company. Some case studies of interest were selected as good examples of meeting learning outcomes. While some students did work in engineering environments, learning outcomes were achievable in a variety of industries.

Student A worked in a retail franchise and was promoted to a key holder and supervised the maintenance of the fire alarm and sprinkler system. He signed off on new staff inductions and provided training. Student B worked on a vegetable tillage farm and has received manual handling training and gained a forklift and pallet truck license to complete his work. He developed a system that notifies his employer by text of the current vegetable fridge stocks to ensure orders were met.

Student C worked in a family business installing ventilation ducting and insulation. He developed a new project costing system by producing material quantities from CAD drawings and he set up a document control system to ensure the current project drawings only were in use.

Student D gained a summer placement with a heating and ventilation manufacturing company and was trained on the use of the fabrication machines. He was able to work on his own initiative to complete the equipment selection and installation of systems. He has since used this knowledge for his final year project to develop and test a domestic heat recovery unit and is being sponsored by the same company.

#### 4.6 Learning outcome 6

Evidence of the previous five learning outcomes was compiled by all students in the written report and summarised and presented orally in the presentation. This provided evidence of an ability to communicate the required information effectively in written and oral form.

# **5 CONCLUSIONS AND FUTURE PROSPECTS**

The success of the novel authentic assessment approach has encouraged and rewarded employment experience in the mechanical engineering programme. Students have sourced work in farming and food supply, local businesses, services providers, company summer placements and internships. The process has encouraged connections and strengthened links between industry and TU Dublin. The successful implementation of this *employment experience* module has been used as a reference guide to the recent introduction of employment experience in the Mechanical Engineering Honours Degree (TU822) programme.

The approach offers a template to develop work experience modules in other disciplines in engineering or in other disciplines altogether with the careful design of the learning outcomes and the process implementation. The students who completed the *employment experience module* have approved employment experience criteria incorporated into their Ordinary Degree in Mechanical Engineering, which has been approved by TU Dublin and accredited by Engineers Ireland.

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# ENGINEERING DESIGN – DOES AI CHANGE THE PATH OF EVOLUTION IN METHODS & TEACHING?

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# ABSTRACT

Engineering design tools are evolving, where AI can enhance speed and quality. Which of the current and future developments will change the teaching of engineering design? Text-to-image tools appear to be a precursor to text-to-design tools which will offer sensible-looking outputs in areas where many design precedents enable interpolation. However, where novelty is the goal, especially in new design spaces, human understanding of multivariate decisions, including where empathy for welfare and delight are considerations, is hard to express as merit functions for machines to learn. AI is already improving productivity in collating information relevant to discovering and defining performance requirements, and information on design precedents and available supplies. It can also improve the validity of simulation during the creation and refinement of design solutions and automate the application of engineering drawing language to a final design specification. We suggest engineering students' future selves will value their, i) learning to use human interaction to characterise performance requirements, ii) gaining knowledge as to how (well) and why existing engineering designs work, iii) practicing sketching as a means to visually communicate design ideas, iv) using CAD to experiment with state of the art modelling and simulation functionality while creating their own system designs, v) developing proficiency in engineering drawing language, and, vi) learning to make, break and tinker in workshops and to explore the potential & limitations of production. A familiar path, in which to add AI experiments.

Keywords: Engineering design, design methods, AI

# **1** INTRODUCTION

The interface to engineering design methods has evolved from drawing boards and blueprints to use of CAD software on screen and in some cases the 3D manipulation of models viewed in augmented reality. Is engineering design decision making also due to evolve, or is artificial intelligence (AI) unlikely to supplant the disciplines and practices introduced and developed in engineering design teaching? There is certainly ambition for AI to synthesise decision making when manipulating form and material. Generative design already distributes material according to rules for both structural performance and manufacturability. Can distributed computing emulate expertise applied to optimise utility, aesthetic and tactile appeal? If so, what will engineers no longer do while designing; what might not need to be taught?

# 2 WHAT CAN AI DO WHICH CAN BE APPLIED TO ENGINEERING DESIGN

We know AI chatbots, based on large language models, can process languages, applying rules to search, summarise and generate text or computer code, in response to prompts we enter. When trained to relate images to their meaning, AI tools can generate new images and hence video. This appears to imply an understanding of 2D and 3D form. However, there are many design rules and parameters to account for in stepping from a synthesis of elements of a 3D image to an allocation of materials and forms in a 3D design space to meet a combination of requirements.

The probabilistic nature of AI selecting beneficial changes from wherever it starts, introduces uncertainty about its suitability to apply to a creative design process. ChatGPT creators Open AI suggest users should be aware of the tool offering "plausible sounding but incorrect or nonsensical answers" [1], as reinforcement learning must iterate from model proposals - it cannot jump to a trainer's truth.

Improving outputs from chatbots led to 'prompt engineering', helping users structure inputs. The move from using text-to-image tools towards exploring text-to-design, may start offering some sensible-looking outputs. However, as Joseph Flaig asks, "Can a programme that does not understand why a design might work or not work be trusted to consider the potential harm of an issue down the line?" [2].

To limit poor results, AI models can be trained on data which engineers trust to be valid, for example data generated and stored internal to an organisation. Risky extrapolation can be limited by using rules. Engineers may favour deterministic tools, where AI extends optimisation calculations to search for unique solutions to a defined and prioritised combination of parameters in a validated simulation space. Can AI go further to emulate human decision-making during design to prescribe form and material in response to chosen scenarios? Generative design in the sense implemented in current CAD software such as Fusion 360® appears to offer creative assistance though still providing a choice of different solutions with different balances of strength, stiffness, weight and machinability for single components in a defined space between interfaces. The topology optimisation - removal of material until the most efficient part geometry meets intent - may be used to create variants of each design; variants prioritising different optimisation targets. The lightest design would have a different form than that seeking the lowest cost, or with Multiphysics tools engaged, the lowest drag or the most thermally efficient. BlankAI [3] starts earlier in the concept design space. Having been trained on existing 3D designs and their associated meta-data, the algorithm learns from associating design features to specific prompts. BlankAI can generate and edit forms for different types of vehicles and enhance or diminish attributes such as 'modern,' 'sporty' and 'rugged' (Figure 1). Coupled with rendering, preparing concept designs, traditionally the preserve of a skilled sketching process, appears enhanced, or is it just derivation?



Figure 1. Example BlankAI tool offering control of form using semantic inputs for the attributes of AI-derived vehicle concept designs [3]

Figure 2. Example Leo<sup>™</sup> text-to-CAD response to the input "tricycle" [4]

Automated morphing between likely vehicle shapes is based on synthesising the shapes and attributes of existing vehicles. No inputs are sought for other functional performance requirements such as carrying capacity, energy efficiency, durability, safety or environmental impact. Nevertheless, where design precedents can be selected and their form and features coded to some degree in relation to desirable attributes, a number of concept bodies can be created quickly from semantic prompts.

From a starting concept, basic shapes of products in CAD software can be analysed and optimised more conventionally, provided performance parameters can be entered and simulated. The next step is to split a body into a structural assembly of production-friendly parts. Leo<sup>TM</sup>, "the world's first engineering design copilot" [4], is an alpha version tool, offering a text-to-CAD ability to generate an assembly of 3D parts for CAD export. While the ambition is impressive, there is much tricky work to do (Figure 2). Mechanisms comprising several elements are a further interesting case. Permutations in geometry, strength and efficiency for example, all interact also through interfaces between elements which are harder to simulate, such that the number of combinations to explore is much larger. Also, the data needed for AI to interpolate between existing simulations of variants is much less available than say, vehicle body shapes. From a starting mechanism design, depending on the type and complexity, a process of experimentation could begin to both test the suitability of incremental changes in each geometric and material parameter, and confirm dynamic responses to the intended mechanism outputs remain suitable. As with optimisation, local maxima may restrain an algorithm from finding a greater maximum elsewhere. Mapping the whole design space for structures + mechanisms is a computational challenge. Can more powerful computing algorithms further emulate the expertise applied in the engineering design process to 'understand' and simultaneously maximise utility, aesthetic and tactile appeal? Achieving novel engineering solutions remains difficult. As we try to distinguish speculation from predictions as to how AI tools will evolve, and which areas of the engineering design process are likely to change, we should consider the different disciplines and activities in the engineering design process.

# **3 ENGINEERING DESIGN PROCESS – AS TAUGHT TO UG STUDENTS**

The engineering design process we currently teach has been chosen to follow a double diamond. The first stage is discovering and defining requirements to establish a solution-neutral Performance Specification addressing all necessary and desirable requirements, validated from stakeholders' input. The second stage is to create and refine a Specification of the Design solution to meet the Performance Specification. These design stages are illustrated in the example engineering process flow in Figure 3.



Figure 3. Example engineering process flow, featuring the double diamond design process

Considering these two stages we can look at the methods used by engineering designers and how AI tools can now, and may in future, enhance those methods such that our teaching would need to evolve.

#### 3.1 Can AI enhance decision making to discover and define requirements?

Discovering and defining requirements, incorporates two types of knowledge compilation,

a) information sourcing and filtering for conditions and behaviours in a predictable scenario, and,

b) capturing information relevant for a new combination of conditions and stakeholder behaviours. In predictable scenarios information sourcing and filtering is highly suited to enhancement using AI. AI is less suited to exploring conditions and behaviours without direct precedent. Speculating on what

is relevant to new environments requires human judgement to distinguish the plausible from the realistic.

# 3.2 What do we need to teach so students can discover and define requirements?

With or without using AI for enhancing decision making to discover and define requirements, we need to teach students to characterise needs and desires by pursuing a range of human interactions to explore environments and conditions. They may revisit performance scenarios where the set of requirements has seemingly converged to a common understanding, as the data on which an AI model relies may lag real trends. The thresholds for what is necessary and the emphasis between competing priorities may change. Hence students should always be prepared to justify selecting requirements by grounding them in what stakeholders currently believe to be valid. They may pursue unrealised needs with innovation potential. Students who learn to fully explore a performance scenario and its requirements are more likely to question assumptions and jump towards new possibilities, promoting novelty and disruptive potential. In any case, deeper understanding of design requirements is highly likely to ease their role in the process of generating, selecting and refining solutions. The challenge, as always, is to make a performance specification solution neutral. Perhaps AI can be trained to identify solution-partiality as a useful check.

# 3.3 Can AI enhance decision making to create and refine solutions?

The second design stage, to create and refine solutions, can be broken down into various types of decision making, in order to consider what AI can offer to enhance design methods.

# 3.3.1 Solution finding

Solution finding to prepare concepts for evaluation, includes seeking a combination of

- extrapolations from relevant design precedents, to reduce inefficient re-invention. AI tools are adept at searching for design precedents once they recognise and are trained to attribute performance to designs and match the performance with the performance requirements in a scenario.
- 2) **more fundamentally derived solutions** generated from finding matching examples of the generic means of solving a similar type of problem. The ability to derive solutions grows from examining the principles underpinning designs, learned by applying curiosity and training in how they work.

Methods to expand the range of different concepts typically rely on intuitively assembling ideas. We might ask: How does nature solve any similar problems? How would a cartoon character try to achieve the intended performance? Adding AI's 'nonsensical answers,' may complement our brainstorming. Engineers faced with contradicting performance objectives, can find value using TRIZ<sup>1</sup> processes which are more systematic. Enhancing TRIZ with AI is underway. However, a review by Ghane et al. [5] suggests, "most research conducted so far strongly relies on manual intervention by experts... TRIZ fundamentally relies on human cognitive mechanisms..." If AI tools were, in due course, to automate TRIZ processes, its currently limited adoption in engineering industry might spread.

#### 3.3.2 Sourcing information relevant to a Performance Specification such as external supplies

If design engineers spend a third of their time looking for information, including for example external supplies of material and components, then use of AI tools enhancing the finding of such information and judging its suitability, will evolve. Some supplies are not currently described in ways which can be attributed meaning electronically, so publishing will evolve to support supply chain development. No new skills in engineering design appear to be needed, and a normal make or buy analysis should follow.

#### 3.3.3 Solution embodiment

Solution concepts need to be embodied with sufficient detail to evaluate their performance. A design structure, a combination of production-friendly parts, needs to be determined. Given many permutations to explore, the choices are difficult to navigate. AI tools are therefore difficult to train, and they can hardly gain a feel for materials and their manipulation. How easy is the tricycle in Figure 2 to make? Engineering designers who are trained in workshop processes to understand material characteristics as well as how to create manufacturable forms and features have an advantage. Apple's head designer, Jonathan Ive, in 2014 suggested student designers who do not learn how to make things in workshops and rely too much on computers, can create dreadful designs which "look really palatable" [6].

Traditionally the process of embodiment would start with sketching, allocating material to a form to enable visual evaluation. Leonardo Da Vinci would recognise the value of sketching also through computer aided sketch tools to aid manipulation. The Leo<sup>TM</sup> tool accepts a sketch input to help guide it.

#### 3.3.4 Solution evaluation - analysis and choice

Once modelled in CAD with material choices applied, simulation of functional performance and manufacturability, as well as costing and initial environmental impact assessment become possible, to inform changes needed, both within options and choosing between options. Simulated results are not perfect, but sufficient to compare design options.

AI is enhancing the selection of suitable sources of data for software and improving the emulation of performance conditions, the attribution of costs and the veracity of environmental impacts calculated. Provided there is further feedback into simulation software through data derived from physical testing, real world costing and production processes, simulation will further improve in terms of trustworthiness. Bringing CAD modelling and simulation together (ModSim) enables design changes to be simulated very quickly. A logical progression is for CAD software to pre-emptively anticipate the kind of changes a designer might make and to have simulated the consequences sufficiently to suggest those changes.

Beyond that, an engineering designer might accept a simulation tool trying to iterate towards improvements to match a profile of performance parameters, seeking to maximise overall merit. For this, merit functions would need to be established for each performance parameter. As this is not common, AI might be used to devise tests to elicit from stakeholders the relative importance of utility, cost, aesthetic and tactile appeal for example. However, testing human responses for a novel or unfamiliar designs is difficult until they are embodied. So, test results are likely to be imprecise until a physical embodiment can be experienced. Even then test conditions are unlikely to be fully valid – what measurements represent the welfare of users of a design and how many test cases are needed to explore and quantify or 'understand' what makes users productive, healthy, happy and occasionally delighted? More importantly should a designer trust a tool to predict the harm of an issue arising down the line? For engineers to take responsibility for their designs they need to continue to understand sufficiently the validity and limitations of decision-making to evaluate designs and present favourable choices.

<sup>&</sup>lt;sup>1</sup> TRIZ, 'the theory of inventive problem solving', is a systematic method for problem solving using analysis and forecasting, created by Genrich Altshuller observing patterns of invention in patents.

#### 3.3.5 Solution specification for communication

Specification of an engineering design will either use an engineering drawing to control variation of material properties and geometry, or Model Based Definition where tolerances are defined directly alongside geometric parameters. MBD aids tolerance modelling and verification by 3D measurement. Through learning what is understood from examples of applying engineering drawing language, AI can assist in creating engineering drawings. Autodesk<sup>®</sup> Automated Drawings in Fusion 360<sup>®</sup>, "will provide the ability to create fully dimensioned 2D drawings from 3D models with the click of a button." [7] As with any language, though the conventions of engineering drawing appear highly standardised, if we are to minimise costly misunderstanding, it is as well to remain proficient by being involved in a process of checking drawings, and to be ready to adapt them to suit those receiving the communication.

# 3.4 What do we need to teach so students can create and refine solutions? *3.4.1 Solution finding*

To prime solution generation, we generally expose students to a limited set of examples of what should work as an engineering design solution and offer a limited range of experience in testing their usefulness. Students therefore adopt and adapt limited solutions. They need to constantly examine how (well) the engineering designs they see work. Through such evaluation, they can develop their judgement and apply it early in the design process, to decide what design precedents are relevant and which principles can best generate alternative solutions.

Teaching what a TRIZ tool is doing may still be interesting to students, so using TRIZ manually with AI-enhancements in due course, is an option. Acquiring knowledge to use it well can follow as needed. With the performance specification and any design precedents and solving principles in mind, some concept ideas can be generated. Experimenting with text-to-design tools will be interesting, as well as interpolating from design precedents and initial concepts. However, we intend students to develop engineering judgement also in relation to parameters in a new performance scenario and to introduce novelty in all cases. Teaching techniques to broaden their choice of creative concepts remains valuable.

#### 3.4.2 Sourcing information relevant to a Performance Specification such as external supplies

As AI tools evolve to enhance searching for information and supplies, and suppliers further improve their content to be found more easily, no new skills in sourcing engineering supplies appear to be needed.

#### 3.4.3 Solution embodiment, evaluation - analysis and choice

To embody design concepts, engineering students need to practice sketching as a means to visually communicate design ideas, both to themselves and to others. Given the number of permutations to explore can be large, even anticipating AI-enhanced navigation of some of the options cf. BlankAI offering semantic prompts, simulation can best assist decision making once the figurative blank sheet of paper contains a sketch, effectively annotated to attribute meaning as far as possible.

Then, to refine the concept as bodies are split into parts and mechanisms applied, students need to start to use CAD to experiment with state-of-the-art modelling and simulation functionality initially through exercises and then while creating their own system designs at a manageable scale. With material choices applied in CAD, simulation of functional performance and manufacturability as well as cost estimating, and the first phases of a life cycle environmental impact assessment become reasonable for students to practice. AI will assist with processing and presenting data for evaluation against the performance specification, sufficient to inform both changes to develop each option and choices between options.

Seeking to finally validate designs by seeking stakeholders' responses to the predicted and tested performance of novel designs, can contribute to extending the training of AI for wiser decision-making. Students practicing design development should learn their craft sufficient to train and recognise where they can learn from virtual assistants, as they would in their interactions as a team comprising members with complementary capabilities. Students who learn to make, break and tinker in workshops, extend their understanding of the potential and limitations of production, even if AI tools can feed back CAM and suppliers' responses into CAD. Students learn that a final design specification comes with uncertainties and risks. To address this testing is needed ahead of final specification for manufacture.

#### 3.4.4 Solution specification for communication

Unless Model Based Definition becomes pervasive and legacy drawings are converted, students need to develop proficiency in using engineering drawing language, suited to different industry preferences.

#### **4** CONCLUSIONS

As engineering design methods evolve, partly with AI tools applied where they can achieve faster and better quality, we see and anticipate changes in some methods applied during the double diamond process stages of discovering and defining requirements and creating and refining solutions. These changes can inform developments in the teaching of engineering design, though the intent and steps in the process, as well as many of the capabilities engineering designers value, remain the same.

AI tools are suited to probabilistically associating language, image, or other data such as material geometries with meaning, enabling semantic inputs to generate text, images or 3D models. There may be assistance in capturing the relevant aspects of a new scenario (with an unexplored combination of environments, conditions and behaviours), but human interactions are needed to characterise many typical performance requirements and to speculate sympathetically with a wide range of stakeholders.

Like engineering students, AI needs to learn with access to data valid for a performance scenario and feedback on merit during decision-making, to learn from design precedents and from design principles akin to those applied during invention. Anticipating text-to-design tools which will offer sensible-looking outputs, in new design spaces human understanding of multivariate decision making is hard for machines to learn, especially when empathy for welfare and delight are difficult to generalise and codify in merit functions to evaluate performance. Hence students need to continue to learn to characterise performance requirements from a wide range of stakeholders through analysing results from the kind of human interaction which may not already be expressed in accessible sources.

AI is already improving productivity in collating information relevant to discovering and defining requirements for specifying performance and information on design precedents and available supplies. It can also improve the validity of simulation during the creation and refinement of design solutions and automate the application of engineering drawing language to a final design specification.

# **5 RECOMMENDATIONS**

While seeking to ensure the validity of these approaches, we recommend that engineering design teaching offers students the chance to continue to,

- 1) learn to characterise performance requirements from a wide range of stakeholders through the kind of human interaction which may not already be expressed in accessible sources,
- 2) gain knowledge as to how (well) and why existing engineering designs work,
- 3) practice sketching as a means to visually communicate design ideas,
- 4) start to use CAD to experiment with state-of-the-art modelling and simulation functionality while creating their own system designs at a manageable scale,
- 5) develop proficiency in engineering drawing language, unless MBD becomes pervasive, and,

6) learn to make, break and tinker in workshops and explore the potential and limitations of production. therefore, to continue on a similar path to evolve teaching while also sharing experiments with AI.

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# A FRAMEWORK FOR CULTURALLY ORIENTED PRODUCT DESIGN

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# ABSTRACT

Global corporations expanding business across different local markets have identified cultural insensitivity to be a potent barrier for expansion. The degree of acceptance by local consumer cultures has become an integral part of the success and failure of their operations. The integration of cultural aspects into the product development process has become an important aspect of design practice. The goal of this paper is to provide a culturally oriented design (COD) framework for designers to research the culture of intended users beyond their first-hand experience. The framework outlines a three-step process to research intended users' cultural context, synthesize situated cultural differences and identify and translate cultural values to new design concepts.

*Keywords:* Cross-cultural design, product design, situated cultural differences, design framework, cultural product design.

# **1** INTRODUCTION

Global era designers are increasingly challenged to design for cultural context that requires empathizing with users from an unfamiliar social, cultural, and economic background. A variety of methods, tools and techniques have been adopted in design to promote empathetic understanding of user needs in related contexts. In most reported work, designers and users have been from the same culture and empathetic methods have provided individual and anecdotal perspective of user insights often missing to provide a larger understanding of the cultural context [1]. Researchers [2],[13] and [7] have highlighted the need to develop frameworks that contextualize user insights within a larger cultural context and provide methodological ways to integrate cultural aspects into the product development process. The proposed culturally oriented design (COD) framework is designed to investigate regional and/or ethnicity-based cultural groups and provides a methodology to investigate users' culture, identify and translate cultural values in product forms.

# **2 LITERATURE REVIEW**

# 2.1 Culture

Culture, one of the most difficult words (and ideas) to define in the English language [3], is a complex concept that has been studied within various disciplines. Culture is often used to refer to a broad range of groups –national, ethnic, regional, social, lifestyle, professional—with a particular way of life that highlights group values, establishes boundaries, and mobilizes individual and group identities. In some cases, culture refers to national, ethnic, or regional groups with "longstanding differences established over many generations and centuries" [4]. In others, culture refers to social groups such as organizational, lifestyle or professional groups around certain consumption patterns. For example, Apple brand loyalist, Harley Davidson or Volkswagen Bettle users are a sub-culture with unique values, practices, and behaviours shaped around consumption patterns. In this paper, culture primarily refers to research and design for regional and/or ethnic cultural groups. The proposed framework can also be used to study lifestyle or social groups formed around particular activities or consumption patterns.

# 2.2 Culture dimensions and design-oriented models

The complex and multi-dimensional nature of culture has often made the task of integrating cultural factors into the product development process extremely challenging, leaving researchers apathetic and overwhelmed towards the topic. To address this, scholars have classified culture into several dimensions

(See [5] for a comprehensive review of culture-classification models); providing a diagnostic tool for systematic investigation of cultural dimensions. Stewart and Bennett [6] classify culture into objective dimensions that refer to observable and tangible aspects including institutions, arts, crafts, literature and others, and subjective dimensions that refer to intangible aspects such as values and assumptions. Similarly, Hoft [5] suggested an iceberg model to classify culture where the visible part of the iceberg refers to the tangible, observable and behavioural aspects of culture while the large invisible part of an iceberg refers to core values, beliefs, and assumptions of a cultural group. Hofstede [7] classified culture into four layers representing concentric rings of an onion. The outer layer represents rituals, the intermediate layer represents heroes and symbols, and the inner core of the onion represents core values of a cultural group. Hofstede [7] argues that cultural practices, the fifth layer, connects all layers of the cultural onion from core values to the outer ring of rituals and behaviours. Researchers [1], [8], [9] have agreed that classification models provide a systematic framework to investigate culture aspects but have questioned its capacity to integrate cultural aspects into the design process. These classification models present a 'spatial perspective' of culture but do not offer ways to investigate interdependencies between layers. In addition, these models do not acknowledge the role of design and material objects in shaping individuals' cultural context and offer insufficient methodological direction to integrate cultural aspects into product design. In addition, the classification models "postulates that an individual has clear and independent cultures or value sets" [9] and fail to acknowledge the interdependencies between the tangible, observable, behavioural aspects of culture and how they could be shaped by core values, assumptions, and beliefs of a cultural group [8]. The following section presents cross-cultural studies that address some of the limitations of the cultural classification models and offer a step-by-step methodology for translating cultural insights into new design concepts. These studies provide a direct way to adapt culture-classification models into product design that lead to design-oriented models that aid in designing for diverse cultural context.

In their study of the Taiwanese aboriginal material culture, Hus, Lin, and Lin [10] outline three cultural layers and the corresponding design features. The outermost layer represents physical/material aspects of Taiwanese material culture including appearance, pattern, and form of artifacts. The mid-behavioural layer includes aspects related to user-product interaction such as functionality, usability, and safety. The inner layer represents intangible aspects of storytelling, emotions and meanings associated with material objects within the culture. The authors use cultural classification (and corresponding design features) as the source to design a ten-step design process for translating Taiwanese cultural attributes into tangible product features. In a similar study, Lin et al., [11] proposed a design-oriented model to translate Taiwanese cultural features into modern product design. First, the authors classify culture into three lavers: physical/material, social/behavioural and spiritual/ideal. Second, they propose a three-step methodology-- identifying cultural features, translating information to design elements, and designing new cultural products-for translating cultural features into culturally-relevant product form. Moalosi, Popovic and Hickling-Hudson [2], [12], and [13] conducted a series of studies in Botswana to develop a culture-oriented design model that integrates cultural aspects into product development process. This culture-oriented model starts by analysing indigenous products to understand the underlying sociocultural factors that shape the material culture. The authors classify socio-cultural factors into three themes: material artefacts, emotional factors, and social practices. The second part of the model translates socio-cultural factors into product features such as functionality, significance, knowledge, mediation, gender, and aesthetics. The last part focuses on designing products that not only satisfy user needs, but also represent Botswana's symbolic, social, and cultural values.

# **3 CULTURALLY ORIENTED DESIGN (COD) FRAMEWORK**

The COD framework includes three key elements: 1) a biaxial map for researching users' cultural context, 2) cultural situated difference: a methodological tool to direct research inquiry into each of the four cultural quadrants and 3) a step-by-step process for translating cultural values to product forms.

#### 3.1 Biaxial map for researching users' cultural context

The proposed biaxial map demonstrates how the culture of intended users' can be studied within the context of product design. The horizontal axis represents a continuum from material to behavioural aspects of culture and the vertical axis represents the observable and the symbolic aspects of intended users' culture. The four cultural quadrants are interconnected and overlapping and hence should be researched in relation to each other. The goal of this biaxial map is to simplify the overwhelming task

of addressing a multitude of design related cultural attributes into smaller, more manageable information chunks.



Figure 1. Biaxial map of cultural dimensions

#### 3.1.1 Quadrant 1: Material-observable aspects of culture

The first quadrant focuses on the material-observable aspects of users' culture. Research in this quadrant includes examination of two interrelated aspects: 1) product attributes and 2) manufacturing processes. The study of product attributes includes examining form, colour, textures, graphic markings, and materials as indicators of ideas expressed by designers and/or users within a particular culture. Manufacturing processes include studying specific making practices, choice of materials and role of technology in a particular cultural context.

#### 3.1.2 Quadrant 2: Behavioural-observable aspects of culture

Research in this quadrant should include interactions of individuals with products and social interaction and relationship among people within a culture. Human-product interactions should include cognitive and physical ergonomic considerations, as well as product attributes that communicate affordances, character, and function of products. It is also important to study social interaction and how cultural practices and norms are established within a cultural context as a cumulative result of individual interactions.

#### 3.1.3 Quadrant 3: Behavioural -symbolic aspects of culture

This quadrant guides researchers to study symbolic aspects of consumption that establish social status, self- and group-identities. Commodities are not solely used to satisfy needs; they are used to communicate social status, self-identity and stabilize group identity. Group identities mediated through products becomes a medium to understand shared meanings and establishes practices that act as boundaries among different cultural groups. For example, in a culture, the act of buying a car is not necessarily for the sole purpose of mobility; it could be an act to communicate social status or stands as way to align with a particular social identity. The act of buying "environmentally sustainable" products can promote certain self-identity and mobilize group identity of "environmentally responsible citizens."

#### 3.1.4 Quadrant 4 Material -symbolic aspects of culture

Objects do not just acquire meaning through use or exchange, but through comparisons with other objects [14]. The material-symbolic quadrant includes understanding product semantics, product personality and branding. Product semantics explain the mechanism by which objects acquire meaning (and how humans assign meanings to things) and the role that design plays in this process [15]. Product personalities provide insights into the symbolic characteristics associated with products shared among individuals of a cultural group. Product personalities can be shaped by national culture (S. Korean,

European, Japanese), period style (Art Nouveau, Mid-century, post-modern), corporate design style (Nike, Apple, Braun) or word associations (boxy-organic; emotional-rational; geometric-curvilinear) attributed to products. Symbolic meanings of objects cannot be studied in isolation as user interactions (quadrant 2) are key in shaping meanings ascribed to objects that help establish individual and group identities (quadrant 3).

#### 3.2 Culturally situated differences

The proposed COD model recommends that researchers should utilize situated cultural differences as a common diagnostic tool when synthesizing insights from different dimensions of culture (biaxial map with quadrants). Culturally situated differences are "differences in relation to something local, embodied, and significant" [16] that "either express, or set the groundwork for, the mobilization of group identities." Situated cultural differences become a frame of reference for emphasizing local, embodied differences that represent cultural values and mobilize group identity. Situated cultural differences becomes a diagnostic mode to categorize everyday experiences into meaningful cultural categories. For example, using manufacturing processes as a diagnostic mode will result in a continuum from *hand-crafted* to *mass-produced*. Manufacturing processes in a particular cultural context can be mapped on a continuum to understand if certain underlying values shape the selection of materials and manufacturing processes shape individual and group identity in a particular cultural context. Situated cultural differences do not replace anthropological methods; it provides a common methodological tool for conducting and visually summarizing research.

# 4 CULTURALLY ORIENTED DESIGN (COD): A STEP-BY-STEP FRAMEWORK

# 4.1 Step 1: Research users' cultural context

At the onset of a study, researchers should identify intended users' cultural context and utilize the four quadrants of culture (biaxial map) to conduct cultural inquiries. Both primary and secondary research methods--such as interviews, observations, contextual inquiries, participatory codesign, surveys, market research, competitors benchmarking, content analysis--should be used to investigate the four cultural quadrants and the dynamic interdependencies between the material, behavioural, observable, and symbolic aspects of intended users' culture. Researchers should continue to use anthropological methods such as observations, participatory design methods, contextual inquiry, surveys, and others to understand intended users' needs, behaviours desires, emotions, and values. How can designers understand the underlying values that shape everyday user interactions? Researchers should utilize situated cultural differences to identify local embodied differences that mobilize group identities. Using situated differences is a two-step process. First, from the research identify criteria or differences that classify everyday experiences into culturally meaningful categories. Second, identify the resulting group identities (local and significant) established by situated cultural differences. For example, if product attributes are used as a diagnostic mode (situated difference), products from a culture can be categorized on a continuum from utilitarian on one side to ornamental on the other. Figure 2 and 3 provides examples of continuum based on various situated cultural differences in four cultural quadrants. The following examples not an exhaustive list; researchers are encouraged to identify situated cultural differences relevant to their studies.

#### 4.2 Step 2: Synthesize situated differences to identify values

In this step, researchers synthesize multiple semantic differentials/continuums identified from step one. For example, for a cultural group, one can identify continuum such as traditional/futuristic, utilitarian/ornamental, masculine/feminine, vibrant colours/neutral tones, self-oriented/group oriented, low/high social status, individualistic/shared experience, etc. Researchers [17][18] have suggested that these situated differences or cultural dimensions mapped on a semantic differential always contain an element of value. Values are defined as "a broad tendency to prefer certain states of affairs over others" [19]. Cultural values provide intensity and direction and represent two opposite ends of a semantic differences from various quadrants to generate a set of values that represent intended users' cultural context. For example, identifying situated differences and values in quadrant 1 (material forms and manufacturing processes) can shape form development, product styling, and selection of culturally appropriate manufacturing processes. Similarly, researchers should identify values that shape user interactions and

behaviours (quadrant 2), self and group identities (quadrant 3) and symbolic meanings of products (quadrant 4).



Figure 2. Synthesizing situated differences and identifying values

#### 4.3 Step 3: Translate values to product form

In this step, a set of values (identified in the previous phase), are translated into culturally appropriate product semantics: "the study of the symbolic qualities of man-made forms in the context of their use and the application of this knowledge to industrial design" [20]. Gros [21] outlines four key semantic functions of products: practical, formal aesthetical, indication, and symbolic. Practical semantic function relates to the material-observable (quadrant 1) aspects of culture and indication function can be derived from the behavioural-observable (quadrant 2) aspects that includes interactions, affordances, character, product category. Similarly, symbolic semantic function relates to the symbolic-behavioural (quadrant 3) and symbolic-materials (quadrant 4) quadrants of the biaxial map.



Figure 3. Step-by-step culturally oriented design framework

# **5 CONCLUSIONS**

The proposed COD framework is an essential link that connects anthropological methods, culturecentred design, and product semantics. The proposed model does not replace the current use of anthropological methods used to investigate culture; instead, it advocates using these methods to investigate the four quadrants of cultural context. The goal of the COD framework is to provide students and educators with a step-by-step framework to study various aspects of culture, synthesize situated cultural differences, and translate cultural values into product forms. The proposed framework can be used to strengthen cross-cultural product design studio projects were student design for users from unfamiliar social and cultural contexts.

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# COMPUTATIONAL TEAM DYNAMICS AND CREATIVE TENSION BALANCE INDEX IN NEW PRODUCT DEVELOPMENT TEAMS

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# ABSTRACT

Teamwork is an extremely effective pedagogical tool in engineering education. New Product Development (NPD) has been an effective strategy of companies to streamline and bring innovative products and solutions to customers. Thus, Engineering curriculum in many schools, some collaboratively with business schools, have brought NPD at graduate level. Teamwork is invariably used during instruction where students work in teams to come up with new products and solutions. They need to be creative as a group and generate a breadth of ideas and innovative solutions. They also need to be very efficient in their teamwork and work cohesively. These two distinctive traits of the teams for have and manage ideational creativity and effective teamworking introduce different creative tensions in the team members - ideational conflicts and tensions thereof, and relational conflicts and interpersonal tensions thereof. Teams that foster and effectively manage these creative tensions are successful and teams that are not, show poor team performance. In this paper we explore the network structural analysis of these tensions and propose a Creative Tension Balance (CTB) index along the lines of Degree of Balance in social networks that has the potential to highlight the successful (and unsuccessful) NPD teams. Team's emails are analysed to generate the social networks for analysis. CTB index is computed, and this is used to correlate to the overall NPD team performance. It is found to capture the signatures of high and low performing teams.

*Keywords: New product development, NPD teams, team creativity, social network analysis, structural balance* 

# **1** INTRODUCTION

Across industries one of the ways to be and remain innovative is through the introduction of new products. Companies place a lot of emphasis on New Product Development (NPD) and the company's very survival and competitive advantage lies in the success and effectiveness of their NPD. This imposes a lot of emphasis and pressure on the teams to be creative, innovative, and effective. The superimposition of the conflicting requirements on the team in terms of them being creative as a group, which translates to their discussions being more diverse and having more breadth in terms of ideas and topics / content, and at the same time the team members being on the same page and working very closely for an effective and efficient teamwork to develop the product and prototype impacts the team dynamics significantly. This divergence and convergence phenomenon of NPD process has been studied with respect to design documents and email communication by other researchers from this group [4]. The study conducted, discussed and presented here however focuses on the effects and impact of such a divergent / convergent (in a semantic coherence sense) phenomenon on the team dynamics over the entire NPD process and a metric that captures these creative tensions and their balance in the team. In this study team communication is analysed and patterns of team interaction that manifests in terms of team dynamics are identified. The different tensions (interpersonal tensions) that arise out of this divergent-convergent phenomenon / requirement among the team members and the spread of these tensions among the team is captured and analysed through a social network analysis technique called Structural Balance. A measure of this residual creative tension balance in the team, Creative Tension Balance (CTB) index, along the lines of structural balance, is proposed and this index is then associated with the team performance and team reflections to identify the signatures of high performing and low performing teams and explore the potential of this index to be a team creativity metric.

#### 2 BACKGROUND AND LITERATURE REVIEW

There is a whole body of research on various aspects that contribute towards understanding the factors affecting New Product Development success and its effectiveness. Effectiveness research has focused on various aspects of NPD effectiveness and the factors influencing them. Wind and Mahajan [12] provide a good status of NPD research, the broader context of it, and the issues related to managing NPD in organisations. Creativity is consistently mentioned as a key ingredient and component of NPD in the literature [11][12]. There are three areas of research and literature that is relevant here: Teamwork and Team Dynamics, Team communication and Interaction, and Group Creativity.

Poole et al., [7] synthesise over 50 years of theoretical advances in *Small Group Research* from various disciplines into a set of NINE general theoretical perspectives. Yang and Tang in [14] take a social network perspective to show the team structure and team performance in Information Systems teams. Team climate is often cited when it comes to creativity in teams. Isaksen and Lauer [5] go on to define the nine dimensions of climate that support creativity. The concepts of Idea time, Idea support, Debate, and Conflict from these dimensions are the themes that are drawn upon in this research.

Morrissette [6] was one of the earliest to investigate the group tension and its correlation to group effectiveness. His work also defines a metric of identifying the balance of these tensions in the group, structural balance and degree of structural balance. The work of Morrissette is extensively used in this research and is used as a basis for extending it to characterise the creative tensions in teams and an index is defined and hypothesised to capture the signatures of successful and creative NPD teams and serve as a metric. Wortham [13] did extensive research and presented an analytic framework based on Social Network Analysis (SNA) to analyse computer-mediated communication in small groups. Agogino et al., [1] triangulated research from different methods and artifacts of NPD teams to identify indicators of successful teams. They analysed design sketches, email communication, and design documents using LSA (Latent Semantic Analysis) for coherence and shared understanding.

Team communication and interaction has been researched for quite a while and different techniques used to analyse the interactions including social network analysis (SNA) are found in the research literature. The research track that we outline here is mostly of team interaction where communication is the media of interaction. Of particular interest is the structural balance techniques of SNA as applied to communication within teams and their effects on the receiver. There was a lot of interest in SNA techniques and structural balance as a metric to capture various psychological aspects of interactions and their impact in the mid to late sixties [6][10]. As computer-mediated communication became more prevalent, the techniques of SNA applied to study team communication were explored further and can be seen in the many research literature [13][3]. [13] is comprehensive research that provides an analytical framework based on social network analysis to analyse computer-mediated communication in small groups. Generic SNA techniques and how to convert communication data into SNA representable data is also clearly laid out.

Team communication especially those that are based on content of communication does reflect the relationships between members quite accurately. Gorman [3] provides a semi-automatic measurement from team communication using Latent Semantic Analysis (LSA) and sequence analysis to analyse cognition. They consider the content and quantity of communication as well as flow of communication as a method of analysing team interaction. They have shown that LSA can be successful in assessing teams for communication content-based analysis. [2] describes and details the Latent Semantic Analysis and Indexing.

The connection of NPD to creativity and research on this angle of NPD can really be traced back to 1999 [8] where he outlined two dimensions of creativity, level and style, and studied effective NPD leaders from this angle. Later research started focusing more on the factors that influence team creativity, the activities that cause / generate / encourage creativity in teams like brainstorming, debate, the differences between them, the effects of these on team members and the influence of that effect (resulting as tensions, stress etc.) on team creativity and team dynamics. The value of deliberation and criticism in team creativity is very important to NPD teams.

#### **3 DATASETS, PROCESSING, AND METHODOLOGY**

#### 3.1 Datasets

The dataset used in this research comprises of team communication in the form of emails between team members of New Product Development teams. The NPD teams are student teams from multiple semesters of the same course ME 290P / BA 290A – Managing New Product Development, which is a

graduate level course offered at UC Berkeley School of Engineering and Haas School of Business. This course is offered jointly by Haas School of Business, College of Engineering, School of Information Systems & Management, and the California College of Arts at San Francisco. 11 of these NPD teams of this course from one semester and 12 teams of another semester were chosen for this study. All the teams in this study comprised of four or five members. Teams that used email as their primary mode of communication are considered for this research. The course is project-based wherein the students work in teams towards a semester long project. Students work in small teams of four or five members. Teams are multi-disciplinary and students from these different disciplines aim to join forces on small product development teams to identify a user need and come up with a product solution to address the need. They then go through the new product development process in detail to develop the concept into a fully working prototype and gain valuable knowledge and experience along the way.

#### 3.2 Data Processing and Analysis

#### 3.2.1 Team Communication Content-based Social Network Analysis

Traditional Social Network Analysis (SNA) mostly uses frequency of communication as a means of measuring the interaction between actors. As in this small team setting, emails are addressed to a common listserv email address and the content of an email are meant for multiple team members, the content of communication is used rather than the frequency. The content of communication is analysed using the Latent Semantic Analysis (LSA). Topic segmentation and clustering are done on the LSA vector subspace and the actual content measure of each of the emails is then computed. This content measure of email is used to determine the content-based interaction with other members and aggregating it over all the emails exchanged to arrive at the total level of interaction of a member with another team member is computed. Tabulating these scores between the members gets the adjacency matrix used to arrive at the social network graph.

#### 3.2.2 Social Network Adjacency Matrix (AM) and Tie-Strength

After levels of interaction between members are arrived at based on the content of email communication, a matrix is generated specifying these levels of interaction as matrix cell values. The cell values  $a_{ij}$  of the matrix corresponding to the *ith* row and *jth* column of the matrix and represent  $a_{ij}$  = interaction between member *i* and member *j*. This matrix is termed as Adjacency Matrix of the network of the team. Each team will thus have a separate adjacency matrix. Adjacency matrices of all the teams are computed. For visual representation of the network graph, the adjacency matrix is transformed into a symmetric matrix with average interaction strength representing tie-strength between the members. In another research paper, [9] have outlined the methodology to arrive at visual representation of these team interactions using this social network analysis and tie-strengths. In these visual representations, the thickness of the line between the nodes is proportionate to the tie-strength between the members

#### 3.2.3 Dichotomised Adjacency Matrix (DAM)

Social network analysis provides many techniques to transform the network adjacency matrices to amplify stronger interaction arcs and attenuate weaker interaction arcs, thus providing a sharper interaction diagram for the team. One such analysis technique is the dichotomisation of the adjacency matrix of the team. This dichotomisation is a technique wherein every cell value of the matrix is compared with a given average value and if the cell value is higher than the average, it replaces it with a 1 and for cells that have a cell value lower than the average value it is replaced with a cell value of 0. Thus, the new dichotomised adjacency matrix would just contain arcs between members who have more than the average level of interaction and would drop those interaction arcs for those where the level of interaction is lower than the average. Density of the social network provides a good metric for the average interaction level or average tie-strength of the team's network and this value is used in the dichotomisation of the adjacency matrix. This Dichotomised Adjacency Matrix (DAM) is computed for each of the teams from considered in this study.

#### 3.2.4 Structural Balance Computation – Degree of Balance

A transformation of the adjacency matrix is used as the base matrix for identifying cycles and semicycles which are the basis for balance computation. This transformed matrix is one whose values are from the set  $\{+, 0, -\}$ . Each of the cell values from the original adjacency matrix is used and compared with the network density ( $\Delta$ ) value. If the original adjacency matrix cell value is greater than  $\Delta$  then the value in the cell of the transformed matrix is '+'. If it is less than  $\Delta$ , then the value in the transformed matrix cell is '-' and '0' if it is exactly equal in value to the network density value  $\Delta$ . A slightly different transformation matrix is used for the degree of structural balance and for this the transformation matrix has numbers instead of just signs and '0'. Network Density ( $\Delta$ ) value again is used as the transformation matrix cell is computed. The new cell values of the adjacency matrix the value of the transformed matrix cell is computed. The new cell value is just the value that is greater or lesser than the  $\Delta$  value. So, values will be signed real numbers. This matrix is called the Degree-Structural-Balance Matrix.

The cycles and semi-cycles of the team's social network are listed in the same way as explained earlier. The cycle / semi-cycle strength is computed as the algebraic product of the cycle's arcs taken from the Degree-Structural-Balance matrix. Morrissette's degree of balance is one of the popular degrees of balance and is computed as per the equation (1) below:

Morrissette's Degree of Balance of a Graph.

$$\boxed{b(G)} = \frac{\sum_{k=1}^{r} p \sigma Z_k}{\sum_{k=1}^{r} |\sigma Z_k|}$$
(1)

#### 3.2.5 Creative Tension Balance (CTB) Index Computation

Creative Tension Balance index measures the residual and interpersonal creative tensions in teams. Creative Tension Balance Index is essentially a function of the Residual Creative Tension (RCT) and the Interaction Factor (IF). The value of CTB index is computed for every team as per the formula. The Creative Tension Balance Index (CTB) is given by the equation (2) below.

$$CTB = [1.0 - (RCT * q_1 + IF * q_2)]$$
(2)

where  $q_1$  and  $q_2$  and weight constants that combine the two factors. For four member teams,  $q_1 = 1.0$ ,  $q_2 = 0.2$  and for five member teams  $q_1 = 0.7$ ,  $m_2 = 0.3$ .

#### 4 RESULTS AND DISCUSSIONS

The Creative Tension Balance (CTB) index computed for all teams are correlated with the team performance in the semester as assessed through their final semester numeric grade and the grade categories. The correlations first measure through a Pearson's correlation metric whether there is a correlation in the list of values of CTB and team grade numbers. Then the correlations look into the ability of the CTB metric to correlate to the top performing and lowest performing teams. These correlations are presented in this section.

We first present the results of correlation of Creative Tension Balance with the team grade. The results are presented in table 1 for all the teams. At the end of the table the Pearson's product moment correlation coefficient, r, between the Creative Tension Balance and the team grades is computed and the value displayed. Pearson's product moment correlation coefficient between two array of numbers is given by the equation (3) below.

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}}$$
(3)

The values of r range between -1.0 and +1.0 indicating the linear relation between the two arrays. The table also shows the computed T-Test probability associated with Student's T-Test for 1-tailed distribution and the type of T-Test being two-sample unequal variance (heteroscedastic). This aids in arriving at the statistical confidence measure of the correlation value computed. The T-Test probability and the statistical probability measures are also shown in the table.

		Creative Tension
Team	Grade	Balance (CTB)
А	115	0.33
В	117	0.38
С	107	0.54
D	90	0.05
Е	115	0.40
F	109	0.44
G	120	0.67
Н	115	0.10
Ι	108	0.42
J	115	0.52
Κ	106	0.09
L	85	0.49
М	85	0.40
Ν	90	0.41
0	90	0.48
Р	85	0.56
Q	90	0.54
R	90	0.40
S	85	0.39
Т	85	0.38
U	85	0.24
V	90	0.45
W	95	0.64
	<b>Pearson Correlation</b>	0.564278782
	<b>Statistical Confidence</b>	
	Measure	p < 0.001

Table 1. Correlations of Creative Tension Balance (CTB) with Team Grades (Performance).Green boxes indicate highest performing team in the class and orange-coloured boxesindicate lowest performing team in the class

# **5 DISCUSSIONS & CONCLUSIONS**

We have shown here through a social network analysis of the NPD teams and standard network analysis techniques of structural balance a means of extending the degree of balance to include the effects of team dynamics, patterns of interaction and residual creative tensions to arrive at an integrated index called the Creative Tension Balance (CTB) index. This paper provides the specification and definition of Creative Tension Balance index that characterises the balance of ideational and relational tensions in teams.

The Creative Tension Balance metric is associated with the student team's final overall grade. The two semesters grading differed a bit and teams L through W had mostly an overall low, medium, and high grade levels only. However, in both the semesters, the best performing team was announced and the teams having a lot of issues in terms of the various measures were provided feedback. The Creative Tension Balance index is able to clearly point the high performing teams and also highlight the lowest performing teams consistently. The overall correlation coefficient, however, is just a 0.56 as the spread of the grades between teams in one of the semesters was quite low. The ability to capture the signatures of high and low performing teams using the Creative Tension Balance can clearly be seen.

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# THE IMPACT OF USER PARTICIPATION IN THE DESIGN PROCESS ON NEW PRODUCT DEVELOPMENT: IMPLICATION TO DESIGN EDUCATION

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# ABSTRACT

Participatory Design (PD) emphasises the potential importance of user participation in enhancing the effectiveness of New Product Development (NPD). The article focuses on two main aspects within participatory product design: "the Conceptual Positioning with User Participation" and "the Relationship between User and Designer." The results indicate that, in the design process of NPD, "Information Exchange," "Knowledge Co-creation," "Identification-Activation of Creative Users," and "Responsible Behaviour of Users" all positively influence the effectiveness of NPD. However, the intensity of these effects and the moderating effect of "Enterprise Absorptive Capacity" depend on the actual implementation of user participation. This study provides new perspectives and data support for the theoretical research and practical application of participatory design and also offers recommendations for PD education in universities in China.

Keywords: Participatory design, users, degree education, empirical study, NPD

# **1** INTRODUCTION

Scholars in the field of design advocate that for enterprises to foster breakthrough innovation they should utilise external stakeholders such as users to inform its NPD processes. Thus, it is suggested to extend the internal design expertise to those outside of the companies including the "future users" [1]. This study specifically selected the "Users" among external stakeholders, and to emphasise the importance of "Participation", as advocated by the proponents of the "Participatory Design" (PD) method. Nigel Cross pointed out, the goal of design is to find an appropriate solution, rather than finding a "correct" answer [2]. In this case, user perception is crucial because they are the ones with the authority to judge whether the design is appropriate for "them".

The important purpose of design education is to cultivate designers' design literacy, which is understood as the ability to "read" (understand design products) and engage in design activities [3]. Educational researchers are showing a growing interest in Participatory Design and other collaborative co-design approaches [4]. In PD, participants typically need to assume two roles simultaneously: that of end-users of the product and proposers of solutions. Designers, on the other hand, should act as both executors of design solutions and guides of the design process [5]. The significance of PD in design education lies in its emphasis not only on enhancing students' own design literacy but also on cultivating their ability to elevate the design literacy of PD participants through participatory design processes, thereby leveraging their tacit knowledge to guide product design innovation. In the current context of design disciplines, "design" has shifted from a reactive, artefact-based practice to a more proactive, with emphases on the social practices [6]. Design education seeks to break through the boundaries of schools to address this trend, allowing design literacy education to permeate non-designer groups (citizens) [7]. This impact is expected to be expansive and enduring.

A review of the literature reveals that there is a significant amount of case studies and empirical research internationally. For example, Niels Hendriks et al. explored how designers establish relationships with users and how these relationships influence their design decisions through a case study involving dementia patients participating in the design process [8]. Ozkil conducted empirical research on the

collective design platform (Thingiverse), confirming that such platforms can help designers identify primary users in their respective fields and discover potential needs from different sub-communities or geographical regions [9]. Aytekin and Rızvanoğlu proposed the application of participatory design methods to design education using a qualitative multi-method approach, suggesting that it can help build "Learning Bridges" and assist in the transfer of implicit knowledge and experience [10]. However, such design research is relatively scarce in China, leading to a lack of clarity among Chinese enterprises regarding the specific impact of user participation in the design process on the output of NPD projects. This study limits its investigation to designers in China who have product design experience with user participation, aiming to conduct empirical research. The study conducted a survey of the curriculum design in 10 Chinese universities. The study holds significant practical implications for Chinese enterprises and also it provides valuable insights for Chinese Higher Education.

#### 2 RESEARCH HYPOTHESES AND RESEARCH MODEL

Through a literature review, two key issues in PD discussions can be identified. Firstly, a substantial body of research has demonstrated the significant role of PD in the conceptual positioning stage of product development, particularly concerning the aspects of Information Exchange and Knowledge Cocreation [18]. Secondly, the discussion about the relationship between users and designers [19] has consistently been at the core of PD-related studies, further classified into perspectives from both designers and users. This study focuses on these two critical issues and incorporates them, along with the output effectiveness of new product projects, as three measurement dimensions, thereby extracting six variables (one of which is a moderating variable) requiring measurement. Variables and their codes can be found in Table 1.

Dimensions	Factors	Code
the Conceptual Positioning with User	Information Exchange	А
Participation	Knowledge Co-creation	В
the Relationship between User and	Identification-Activation of Creative Users	С
Designer	Responsible Behaviour of Users	D
Moderating Variable	Enterprise Absorptive Capacity	Е
Output Effectiveness	New Product Development Effectiveness	F

Table 1. Factors Coding

#### a) The conceptual positioning with user participation

The significant characteristic of PD lies in the thorough consideration of user perception as a decisive evaluative factor for new products, serving as the starting point for the process of product conceptual positioning. "Information Exchange" primarily emphasises the quality (effectiveness) of communication. Participatory Design researchers commonly emphasise the potential value of individuals and elements outside the design team, with particular emphasis on the value of users. Participatory innovation can be understood as the result of "cross-intention negotiation," where the process of this cross-intention negotiation is also referred to as information exchange [11]. Although the association between the design team and participants during this process may involve destructiveness, it also brings about new possibilities for innovation [12]. Knowledge co-creation refers to the process in which users and design teams collaboratively create new knowledge and solutions to achieve product innovation. The design product serves as an intermediary between user logic and design logic [13], and the process of knowledge co-creation involves the integration and refinement of information from multiple sources, emphasising the utilisation of users' unique experiences and insights.

Hence, this study proposes the following research hypotheses:

H1a. There is a positive correlation between information exchange and NPD effectiveness.

H1b. There is a positive correlation between knowledge co-creation and NPD effectiveness.

#### b) The relationship between user and designer

In PD, the relationship between users and designers is innovative, and this relationship requires to be sustainable and systematic to ensure the generation of design concepts and solutions required for innovation [14]. This close connection enables timely feedback on NPD projects upon market entry, providing a foundation for further product improvement. From the perspective of designers, the key to fostering this relationship lies in identifying and activating creative users. From the perspective of users, their actions in the design process are essentially a form of "responsible behaviour." When participants in the design process realise they are part of a NPD project, a sense of responsibility emerges. Some

scholars regard the responsible behaviour of users in participatory design as a prerequisite for achieving value co-creation [15].

Therefore, we propose:

c)

H2a. There is a positive correlation between the identification-activation of creative users and NPD effectiveness.

H2b. There is a positive correlation between responsible behaviour of users and NPD effectiveness. **The moderating role of enterprise absorptive capacity** 

A significant portion of participatory product design research overly focuses on the participation process within PD projects, while neglecting the evaluation of actual project outcomes, leading to a misalignment between theoretical research and practical application [16][17]. In addition to the two aspects mentioned above that may directly impact the development effectiveness of new products, it is also necessary to consider whether there is a moderating effect of third-party factors between these two influence paths. In the design process of NPD, the initial distribution of various resources is relatively discrete or even implicit. From the perspective of the enterprise, the unique resources provided by participants are considered external resources. The ability to integrate, transform, and successfully apply multidimensional external resources to product design is referred to as enterprise absorptive capacity. This study posits that there are differences in absorptive capacity among different enterprises, and this difference will affect the strength of the two aforementioned influence relationships. The research model is illustrated in Figure 1. This study then proposes the following hypotheses:

H3a. Enterprise absorptive capacity positively moderates the relationship between information exchange and NPD effectiveness.

H3b. Enterprise absorptive capacity positively moderates the relationship between knowledge cocreation and NPD effectiveness.



#### Figure 1. Research Model

The impact of user participation in the design process on NPD is assessed from the perspective of the project, making project designers and enterprise managers the evaluators. It is difficult for insights generated by users to penetrate to this level. Therefore, this study selected designers/ members in design teams who have experience in assisting NPD design practices through user participation as the survey subjects. The questionnaire was divided into two main sections: basic information and variables-measurement (24 questions). The measurement scales used to measure latent variables are mainly adapted from well-established scales used by other scholars (all using five-point Likert scales). Specifically, the Conceptual Positioning with User Participation section is adapted from Drain, Shekar and Grigg [18]; the Relationship between User and Designer section is adapted from [15]; the enterprise absorptive capacity section is adapted from [20]; and the NPD Effectiveness section is adapted from [21].

To ensure the reliability of the survey questionnaire and the validity of the items, this study conducted a pilot survey using an online research method, resulting in a total of 53 valid responses. Reliability analysis conducted using SPSS and SmartPLS revealed the following:

1. Reliability: The Composite Reliability (CR) of each factor exceeded 0.8, and Cronbach's alpha coefficients ranged from 0.772 to 0.853, all exceeding 0.7. Furthermore, after deleting specific items, the alpha values did not significantly increase, indicating that the scale design in the questionnaire is reliable.

2. Validity: The results from SmartPLS showed that the loadings of each item ranged from 0.626 to 0.885, all exceeding the standard value of 0.5. The Average Variance Extracted (AVE) for each latent variable, except for variable B (which was 0.494), exceeded the standard value of 0.5. Based on the literature, when the AVE value is less than 0.5 but the CR exceeds 0.6, the convergent validity of the questionnaire can still be considered good [22].

# **3 RESULTS**

The formal survey stage began in December 2023 and was completed in February 2024, resulting in a total of 252 valid responses collected. Most of the respondents hold a bachelor's degree or higher (87%, n=219). Approximately 82% (n=207) of respondents are primarily engaged in virtual product design and service & experience design, while the remaining respondents are from the field of tangible product design. Table 2 displays the results of the direct effects of each latent variable on the dependent variable F and the moderating effects of the moderator variable E.

Path	β	Т	Р	2.5%	97.5%	Results
A→F	0.114	2.833	0.004	0.035	0.193	H1a: supported, positive effect
B→F	0.300	6.174	0.000	0.203	0.395	H1b: supported, positive effect
C→F	0.265	6.091	0.000	0.184	0.353	H2a: supported, positive effect
D→F	0.163	3.684	0.000	0.072	0.247	H2b: supported, positive effect
E*A→F	-0.137	3.752	0.000	-0.207	-0.063	H3a: rejected, negative effect
E*B→F	0.045	1.286	0.198	-0.022	0.113	H3b: rejected, not significant

Table 2. PLS-SEM test results

# **4 DISCUSSIONS**

According to the computational results from SmartPLS, we found that "Information Exchange," "Knowledge Co-creation," "Identification-Activation of Creative Users," and "Responsible Behaviour of Users" all exert positive influences on NPD effectiveness. Among them, the effects of B and C are relatively stronger, while the effects of A and D are relatively moderate. In terms of moderating effects, both hypotheses H3a and H3b are rejected. The test results indicate that E\*A→F's moderating effect is even negative. This study attributes this result to the fact that all survey respondents are professionals in product design with experience in user participation in the design process. Their judgments on each item are based on the cognition and stance of designers. Designers often equate their own cognition with that of end users, thereby mistakenly believing that the information exchange phase has been completed when, in reality, it has not reached the level required for PD to function effectively. Similarly, when respondents are asked to evaluate their own company's absorptive capacity, the aforementioned cognitive differences may lead to misjudgements. Under the influence of these deviations in judgment, this survey research has yielded conclusions that deviate from the predefined expectations. This also reflects that Chinese companies and product designers still lack a deep understanding of the core of PD. The results of this study can be regarded as a validation of the viewpoints proposed by scholars such as Steen within the design environment in China [23]. It suggests that when participatory/co-design is merely treated as a buzzword, it fails to make the necessary contributions to design projects. Additionally, it supports the viewpoint that "the varying degrees of user participation have different impacts on knowledge co-creation," [24] indicating that only when users are deeply involved at the emotional interaction level and the knowledge they contribute is heterogeneous compared to the existing knowledge system of the enterprise, can the expected effects of this moderating effect be achieved.

# **5 IMPLICATIONS TO DESIGN EDUCATION**

As prospective talents for enterprise design teams, the education of students majoring in design at universities is particularly important. Drawing on the existing university ranking index in China, this study selected the top 10 universities with majors related to design and conducted an investigation of their course arrangements. It was found that the direct offering of courses named Participatory Design or Co-Design is almost non-existent currently. This indicates that most Chinese universities have not yet established a systematic approach to educating students about the concept and methods of PD. However, some universities have already integrated the concept of user participation into other specialised courses. In China, there have been numerous academic studies exploring "User Participation," these studies predominantly focus on participation relationships existing mainly between students and teachers. Despite an increase in student participation levels within the scope of the curriculum, there is a lack of genuine "User-Side" knowledge input during the processes of Information Exchange and Knowledge Co-creation.

As an example, the course "Design Management and Planning" offered by the Design School of Nanjing University of the Arts for master's students is divided into three modules: Design Thinking, Entrepreneurship, and Final Project. Specific subjects include explanations of the product design process, design thinking, NPD processes, financial statements, and practical exercises such as "Improving Web Page Design" and "E-Bicycle NPD Project Plan." The course emphasises the importance of "Users" and mentions that PD methods can stimulate creativity. However, in this course, the term "Users" refers to personas simulated based on preliminary user research. Obviously, this simulation cannot meet the requirements of "User Participation" in PD, and the course still fails to guide students to transition from being designers to facilitators. In this scenario, the concept of "Users" as participants is based on the simulation and assumption of designers, and true "Creative Users" no longer exist in the product design process. However, this teaching model has been considered as a step forward because, compared to traditional teaching methods in universities in China, it enhances the interaction between students and teachers.

Based on the test results and the current development status in China, this study proposes the following recommendations for degree education in design-related disciplines in universities in China:

- 1. Improve the effectiveness of communication between students (future product designers) and participants. Instructors can appropriately monitor students' PD execution in design practice activities and establish quantitative assessment checkpoints.
- 2. In the early courses of degree education, it is necessary to strengthen education on PD concepts, methods, and systematic design processes, while design practice should follow these foundational courses.
- 3. Utilise the resources of industry-education integration and collaboration between universities and enterprises to provide students with practical opportunities in participatory product design processes based on real design projects.
- 4. Complete PD project is not the only form of educational value; students' independent experimentation and failure have immense potential value. Therefore, educators should encourage them to independently identify and engage users in their design practice.

For a minority of universities at the forefront of PD education, this study holds greater significance. Based on the conclusions of this research, under the condition that students have a comprehensive understanding of the basic concepts and common methods of PD, their application and evaluation abilities regarding the four elements can be improved. Diverse teaching methods can be integrated, such as using cards, role-playing, and scenario-based simulations commonly employed in PD methods [25]. Guided by the principle of PD, design education can cultivate more "facilitator-type" designers. In addition to effectively enhancing the innovation efficiency of enterprise NPD, the more significant contribution lies in infusing creativity vitality into the entire society. As PD design education becomes more refined, it is expected that the impact effects outlined in this study will become stronger, and Enterprise Absorptive Capacity can then play its positive moderating role.

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# APPLYING A FRAMEWORK TO CONDUCT ETHICAL DESIGN RESEARCH AND PRACTICE WHEN WORKING ON SENSITIVE TOPICS WITH VULNERABLE PARTICIPANTS

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# ABSTRACT

In a world where generative AI has become pervasive it is important that we maintain ethical standards when conducting design research and practice and even more so when that is around sensitive topics and or with vulnerable participants. This paper builds on previous research [1] where a framework was developed to guide students when conducting research and practice. This paper explores how the framework is adopted across four case studies of student design projects where the topics have been sensitive and involved vulnerable participants at various stages and to varying degrees. Case study analyses follows a description of these projects in applying the framework.

This paper firstly reintroduces a framework developed by the authors that guides design students when conducting design research. Case studies are presented showing how the framework was implemented and an analysis follows where a discussion unpacks key questions around the efficacy and effectiveness of the framework. These questions address how useful the framework is in guiding the student as to when it was appropriate to involve participants; how it did or did not provide the most useful methods to work with participants; what alternative methods of research and testing are appropriate and sufficient; how participant's expectations were managed, and guidance around means of payback for people's participation. The paper continues by evaluating the appropriateness and usefulness of the framework to facilitate and guide students over the course of a project while also protecting vulnerable participants, before concluding by offering a revised version of the framework.

*Keywords: Design research, ethics, product design, design education, vulnerable participants, sensitive topics* 

# **1** INTRODUCTION

This article builds on a previous study [1] where a framework was developed to guide design students when conducting research and practice. The application of this framework is evaluated in this paper to understands its ability to act as an ethical guide to support design students and supervisors when researching and designing with vulnerable participants on projects where the topics may also be sensitive.

Current research advocates that design research should be conducted with end user groups to ensure that solutions developed meet the needs and expectations of those most impacted by the issues [2]. When conducting design research around sensitive topics we need to establish guidelines to ensure ethical practices to protect both participant and researcher [3] and participatory design projects must adhere to robust ethical principles and be conducted with integrity and rigor [4]. However, when people are involved in a participatory capacity (as experts, users, and other key stakeholders), the parameters of design projects are often dynamic and changeable [5]. Standard and generic ethics procedure within academic institutions might not be sufficiently flexible to cover the unfolding and diverse activities across the design process and the changing role of the participants. Conversely, the ethical approval process might be protracted and overly complex for shorter projects particularly at UG level [6]. Therefore, there needs to clear rules of engagement for researchers and supervisors when involving participants at the outset of design projects which considers the different roles of the participants across

the full project with the possibility of alternative participants and methods to be employed if deemed more appropriate.

# 2 METHOD

# 2.1 Case Studies

Four undergraduate product design projects were chosen that involved both sensitive topics and the involvement of potentially vulnerable participants. The projects are the work of final year UG on a BSc. Product Design & Technology. Therefore, a certain level of design experience and standard of work was assumed. The level of involvement of participants varied across the projects due to access and availability of participants, designer engagement and project direction. The case studies involved interviews with each of the students and their project process books which document the entire project in both visual and written format were also a source of data. The process books were analysed, and this data was triangulated with transcripts and field notes taken by design tutors during interviews and over the course of the projects. Through examining these cases the researchers could explore the process and methods undertaken by the designers when working with participants across all project stages and the measures undertaken or overlooked, when working with these vulnerable participants.

Case	Project Title	Types of participants	Participatory methods	Additional and alternative
study	, , , , , , , , , , , , , , , , , , ,		used	methods used
1	Menopause - Relieving	Women who are in	Convenience sampling	Instagram, Forums & online
	people of daily	perimenopause or	Purposive sampling.	blogs, podcasts.
	discomfort & creating	menopause.	Interviews.	Simulated testing with
	awareness of symptoms	Peers and own network.	Focus groups.	proxy user.
	& treatments.		User diaries	
2	Exploring design	Women who are	Purposive sampling.	Forums & online blogs.
	opportunities related to	breastfeeding or have	Snowball sampling.	Scenario role play.
	a more positive	breast fed within the past	Interviews, survey	Simulated user testing with
	breastfeeding	5 years.	observations, 'show	proxy users.
	experience, for mother	Experts & clinicians in	me' with use of current	
	and child.	birth and postpartum care.	products.	
		Own network	Expert interviews, user	
		Proxy users	diaries,	
			User feedback and	
			testing	
3	Postpartum Recovery	Women who have given	Purposive sampling.	Simulated testing with
		birth between 3 and six	Snowball sampling.	proxy users.
		months prior to the	Survey, Interviews,	Empathy mapping.
		research.	Expert interviews,	Social media, Online
		Experts & clinicians in	Journey mapping.	forums.
		birth and postpartum		Testing with self,
		care.		
		Own network		
4	Menstruation – a	Women who are	Convenience sampling,	Online forums, Empathy
	solution to aid in	menstruating	Purposive sampling and	research.
	dealing with symptoms		Snowball sampling	Simulated testing.
			Survey, Interviews,	
			focus groups.	

# 3 FINDINGS

# 3.1 Ethical 'Approval'

Ethical approval was sought for all projects and was completed at a school rather than faculty level for expedience. We found that all student researchers demonstrated deep sensitivity and empathy for their research participants:

"A lot of the topics they discussed with me they never discussed with anyone before, I wanted to make sure the participants felt comfortable and at ease, so I took a more conversational approach to the interview questions."

Extra care was also taken to consider the well-being of the participants, for example in one case the health service executive contact details and mental health hotlines were supplied should participants be affected in reliving these experiences. However, one observation made was that it is important to protect the researcher as much as the participants. many young researchers will not have the experiences of their participants and we found that our participants were impacted by the stories that they heard.

"I stopped kind of researching things ... because I was a little bit like, Oh my God! Literally because it was just so like, I'd never want children."

"I had to like, emotionally withdraw myself from that because I'm like, ok, that's very traumatic and that freaks me out as a person."

The students also stated that it was very important to be well informed on the topic in advance of undertaking the research to be sensitive and aware of what participants may have experienced and to also prepare themselves for what they might hear.

"I do feel like you needed, like I needed to be educated going into those conversations. Like, if I

did not really understand my research, I wouldn't have been able to, like, lead the conversation." In some cases, it was also not appropriate to target somebody who was having a difficult experience for example someone who has just had a baby and was still in recovery. In this case it was agreed that the researcher would only interview participants within six months of recovery (Case 3). The following are revised guidelines for ethical approval in bold:

# Guidelines:

- *Ethical training is essential for design educators.*
- Formal but 'lighter' ethics approval must be sought that outlines plans for participant involvement, highlights any potential risk and describes measures to overcome these.
- Researchers should be made aware by their supervisor /tutor that the research stories may impact them and that they must consult with their tutor to agree a pause or alternative methods or topic.
- In advance of primary research researchers need to be well informed on the topic.
- Avoid recruiting participants as they are experiencing a difficult experience and recruit those who can contribute to the experience when it is over.

# 3.2 Recruiting participants

All students followed convenience sampling and recruited from their own close networks, choosing a topic that had a personal stake for a family member or close contact. All researchers applied snowball sampling where at least one participant recruited another. However, in two of the four cases the researchers did not approach any experts, organisations, or anyone outside of their own network. Some students felt uncomfortable about approaching people when the topic was so sensitive or the participants vulnerable. This may also be a confidence issue with younger researchers. All participants felt that they couldn't keep going back to their initial interview participants to participate in evaluations and testing.

"I think since they gave me their time and they did find it interesting; I think they more wanted their story to be told than continue with the project."

All students used surveys as a means of recruiting people for interview by asking people to include their email address if they were willing to be contacted for an interview. This was a successful method in all cases, even if some students didn't follow up with further contact.

# Guidelines:

*Close tie participants should be balanced with objective or critical participants at key points in the design process (e.g. user testing & evaluation)* 

- Caution needs to be exerted to avoid 'over-using' vulnerable participants across long duration projects. Proxy users could be used to step in for early-stage testing and evaluation.
- Snowball recruitment is very effective for expert participants.
- Access to participants can be made through liaison and support groups or other stakeholders.
- Assessment and grading should consider different project types and that some students may not be able to access or feel comfortable enough to recruit participants therefore alternative methods such as social media accounts, blogs and forums should be considered as alternatives to primary research.

- Tutors/supervisors should ensure that the researchers have direct access to the participants.
- Participants can be recruited for interviews through surveys.

# 3.3 Gatekeepers

To gain direct access to vulnerable participants about sensitive topics at times it was necessary to go through gatekeepers as per the framework guidelines. In Case 2 the researcher approached The La Leche League of Ireland a non-profit organisation dedicated to supporting mothers who want to breastfeed or provide their infants with human milk. Through this organisation, the researcher gained direct access to breast feeding mothers who were happy to assist the researcher. However, two of the lactation consultants did act as gatekeepers by cautioning the researcher about imposing design solutions that could potentially undermine or patronise mothers' natural instincts and abilities. This was very useful feedback for the researcher who was very conscious of this at the solution phase.

"One person did actually kind of warn me, that you might receive backlash as you go about this, because you're coming from a design point of view. She said, you know, there is a little bit of like an anti-design movement maybe in breastfeeding. It's maybe coming from like the formula companies and things like that. That's just, you know, people trying to promote I guess things outside of breastfeeding."

While the other researchers may not have recruited through organisations to access a gatekeeper, they tended to have one close contact from their own network who acted as a gatekeeper and connection to other participants. In Case 3 the researcher recruited a physio through a friend of her stepmom. The stepmom who was herself nine months post-partum, was the main participant and helped to recruit other people from her friend group.

"I had my mom actually read through my questions as well to make sure that she considered them empathetic."

Interestingly the close contact gatekeepers were also the ones that the researcher felt that they could return to over the course of the project to evaluate and test solutions. *Guidelines:* 

- Gatekeepers or Advocates are essential for engagement with vulnerable participants. This protects both the participant and the designer.
- Gatekeepers can have deeper involvement in the design process providing expert feedback throughout,
- Gatekeepers can provide independent evaluation on the appropriateness of solutions being proposed.

# 3.4 Alternative participants

In all of the cases the researchers needed to recruit alternative or proxy users and in some of the cases to compliment the targeted end user. In Case 3, the designer conducted retrospective interviews with people who had experienced post-partum recovery in the past but were no longer considered vulnerable (e.g. former patients). In most other cases the researchers relied on close friends, family, and their student peer group. They found it was easier to ask more of these close tie connections questions on sensitive topics. The participants found that as the projects developed, they were more inclined to ask the proxy users to test solutions for them. There were several reasons for this: the researchers felt uncomfortable about repeatedly asking for input from the people who participated at the researchers fage; the researchers felt that it would not be appropriate to use low fidelity or rough prototypes with end users or ask them to iteratively test minor changes. Many of those participants were not always accessible or nearby and in one case the participants while "happy to have their stories heard" were not interested in following the design phase when they did not see an outcome for them.

"But I don't think I'll go back to people who I went to for ideation and concept development because I think like for designers it can feel like it's moved on a lot, but maybe for a user group it's as if the project hasn't."

"I haven't tried that on other people. I think when I have more higher fidelity models I will." *Guidelines:* 

Alternative participants might include:

- *Proxy users, family, friends, and peers.*
- Participants who have experienced an issue but who are no longer vulnerable, for example someone who was a patient but is no longer undergoing treatment or care.

- Liaison with support groups, charities.
- *Experts such as those providing services or care for the vulnerable participants can provide user insights where users themselves cannot.*

# 3.5 Workarounds – Additional and alternative methods

In all cases the students used additional methods during interviews with participants and when it was not possible to use participants. In Case 2 the researcher created a series of hypothetical scenarios in relation to breastfeeding situations and asked the participants to speak around these. In Case 3 the researcher used existing menstrual products as a talking point to open the conversation on menstruation.

"Scenario role-play was a useful technique to understand more about the obstacles that are in place for breastfeeding mothers."

During testing at the ideation and concept development phase participants employed a variety of methods to simulate testing. This involved creating rigs to recreate the human anatomy (Case 1), Creating a liquid to replicate blood (Case 4), and using minimalist clothing such as leggings to test a perinium plaster solution (Case 3). In all four cases the researchers used proxy users to roleplay with solutions. However, testing could only be done to a point. In Case 1 the student developed a vaginal applicator to release hormones. In this case the proxy user could only role play using the device to the point of insertion and wearing clothes, and therefore a simulator to test the insertion had to be created.

# 3.6 Giving back

In all cases the researchers, through their consent forms with participants made it clear that they were working on student projects which managed the expectations of the participants that there would not necessarily be implementable solutions. The researchers found that some participants wished to be informed about the project progress and that it was important to ask this at the end of a survey or at the end of an interview. Feedback was given at stages via WhatsApp and text. Reimbursement of participants was found to be dependent on the relationship of the participants to the researcher and the nature of their participants. Participants not connected to the researcher's network were bought chocolates or tea/coffee. Peers in a classroom were able to participate in each other's projects, quid pro quo, so reimbursement was not necessary.

Guidelines:

- Designers must be explicit about the type of project being undertaken (UG college project) and manage the expectations of participants accordingly.
- Acknowledging the participant's input through continuous feedback loops demonstrates respect and can strengthen involvement.
- Participants can be asked on surveys and during interviews if they would like to receive feedback on the project and on the preferred format for this feedback.
- Reimbursement is advisable in the form of a simple box of chocolates, a coffee or tea or a return favour.

# **4** CONCLUSIONS

In this study we applied an ethics guide previously developed by [1] to student research projects involving sensitive topics and vulnerable participants. This paper explored how the framework was adopted across four student design projects. The findings overall showed that the guide was a robust framework to guide student researchers over a very nuanced process. The process of managing sensitive topics and vulnerable participants requires deep sensitivity and empathy by the researchers. In student projects this requires careful management by supervisors and the framework can provide support for that. We found that the researchers also require protection and supervisor/ lecturers need to protect the student and allow for flexibility for alternative methods to be employed or to encourage a project to pivot in a different direction.

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## THE CHALLENGES OF TEACHING CREATIVITY USING ARTIFICIAL INTELLIGENCE

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#### ABSTRACT

In recent years, we have quickly entered a new era that has challenged all areas of life. It seems that some old methods are less efficient than modern methods for doing various things. Educational fields should be updated for future generations, especially design education and related specialties. This research explores methodologies for teaching creativity while preserving the innate human capabilities of designers and examines the use of artificial intelligence (AI) as a creative teaching aid. A problem was presented to three student groups during a brainstorming session, and their ideas were compared to solutions generated by AI platforms. The results show that while students produced a greater variety of creative ideas, their familiarity with the problem's context led to some differences compared to the AI, which lacked environmental context. The challenges of teaching creativity using AI can vary based on psychological, geographical, cultural, and economic factors. Critically analysing AI results requires expertise in creativity. Group meetings can effectively teach critical and multifaceted thinking to Generation Z students. The research suggests that intelligent and thoughtful integration of AI in design education, combined with human feedback and guidance, can enhance the creative problem-solving process.

Keywords: Education, creativity, industrial design, artificial intelligence, brainstorming

## **1** INTRODUCTION

Presenting new ideas is the most important professional duty of designers and for this reason, it is necessary to identify creativity and problem-solving methods in order to achieve design goals. in the rapidly advancing digital era, artificial intelligence (AI) has permeated various fields, including design education, presenting both challenges and opportunities for training the next generation of designers. As digital natives heavily reliant on technology, today's students must develop creative and critical thinking skills before engaging with AI platforms.

In this research, while holding ideation sessions by students, it is tried to teach the variety of viewpoints of dealing with issues and factors affecting them. This research investigates methods for nurturing creativity while leveraging AI as a teaching assistant, aiming to address key questions:

- What are the challenges for teaching creativity using AI?
- How do the quantity, diversity, and quality of student-generated ideas compare to AI-generated solutions?
- What is the most suitable method for using artificial intelligence in design education?

## 2 LITERATURE REVIEW

As we progress into an era increasingly shaped by artificial intelligence (AI), it becomes crucial to interrogate how AI might impact design education, both as a potential threat to and an augmentation of human creativity. Today, most undergraduate and graduate students are one of the first generations to grow up in a fully digital world, with easy access to technology, smartphones, the Internet and fast communication from the youngest age. They have witnessed the emergence of social media platforms, instant and extensive digital communication, and as a result, they are heavily dependent on technology in the digital world and information and communication in global networks and are used to using them. The burgeoning field of AI in education has demonstrated the potential for AI to streamline tasks, adapt instruction, and provide personalised support [1], [2]. Gen Z may not have great critical thinking or information literacy skills [3], [4]. Institutions should focus on creating learning environments that foster

the development of digital literacy and technological skills, along with providing opportunities for students to apply their learning in real-world contexts.

Given that literature has found Gen Z to be more likely to trust information found online due their lack of critical thinking skills [5], it is important to ensure students are able to recognise instances in which information may be disingenuous or inaccurate and when fact-checking and validation is necessary.

Design thinking's reliance on divergent thinking and subjective interpretation presents challenges for AI, necessitating a careful mapping of its strengths and limitations in creative problem-solving. Starting with simple brainstorming methods and examining the challenges for both students and AI can help determine the advantages and disadvantages at each step.

#### 3 METHODOLOGIES

Based on several years of teaching experience and knowledge of creativity training methods, it was decided to make a comparison between students' brainstorming and the possibility of artificial intelligence brainstorming. Therefore, the most common individual and group brainstorming techniques were selected, and a comparison was made at each stage. Training individual brainstorming methods based on Tony Buzan's instructions from the book "Head First! You're Smarter Than You Think" [6] were selected.

Task design: The stages of the task were defined and implemented in several stages as follows:

- Participation of volunteer students in a creativity training course,
- Formation of multiple teams to participate in the brainstorming session,
- Stating the topic of the brainstorming session and presenting ideas to solve the related problem,
- Classifying ideas from different perspectives,
- Presenting the topic by each group to the accessible artificial intelligence platform using mobile,
- Summarising the results of students' work and comparing them with the answers of artificial intelligence,
- Repeated use of top three AI platforms OpenAI (GPT4), Google (Gemini 1.5) and Anthropic (Claude3 Opus).

#### 3.1 Brainstorming by Students

Three problems were presented to eight student groups (1-1 to 1-8) in brainstorming sessions. Participants were undergraduate (ages 20-24) and graduate (ages 25-30) industrial design students. Groups 1-1 to 1-5 had prior training in creative thinking, with varying environmental conditions and problem familiarity. Groups 1-6 to 1-8 had different levels of prior creativity training and brainstormed under varied conditions. Table 1 summarises the group conditions and ideation results, showing the impact of educational background, environment, and mental state on idea quantity, quality, and categorisation.

The question or description of the topics of each group is as follows:

- 1. What can be done to help a blind person cross the street safely?
- 2. What could be the reason if a person is sitting in a park holding a newspaper upside down?
- 3. Many people smoke cigarettes every day in a specific green space and the cigarette smoke bothers the employees of the ground floor in the adjacent building. How can this problem be solved?
- 4. Repeat the same problem number 3-1-3.
- 5. Repeat the same problem number 3-1-3.
- 6. Repeat the same problem number 3-1-3 with the difference that the environment where the problem occurred was unspecified and the definition of the problem was presented as follows: Imagine an unspecified green space and an imaginary modern building and the ideal conditions for implementing any idea (group consisting of first semester undergraduate students who did not have experience with creative thinking enhancement exercises).
- 7. Repeat the same problem 1-6 for first-year graduate students who all had positive energy.
- 8. Repeat the same problem 1-6 for first-year graduate students who had a little stress.

In all meetings, the number of members of each group was eight people and the idea generation time was 20 minutes. The total time of each session was about an hour for the gathering and preparation of the meeting and the operation after it.

Group Code	Question and Problem Posed for Brainstorming	Environmental Conditions	Familiarity with Creativity Methods	Number of Ideas	Number of Classifications
3-1-1	Help a blind person cross the street	Suitable and no stress Yes		72	-
3-1-2	A person with an upside- down newspaper	Suitable and no stress Yes		81	-
3-1-3	Office employees and cigarette smoke problem	Crowded and tolerable stress	Yes	93	5
3-1-4	Office employees and cigarette smoke problem	Crowded and tolerable stress	Yes	47	2
3-1-5	Office employees and cigarette smoke problem	Crowded and tolerable stress	Yes	59	8
3-1-6	Office employees and cigarette smoke problem	Crowded and tolerable stress	No	19	2
3-1-7	Office employees and cigarette smoke problem	Crowded and tolerable stress	Yes	80	7
3-1-8	Office employees and cigarette smoke problem	Crowded and tolerable stress	Yes	36	5

Table 1. Comparison of students' brainstorming conditions and Number of Ideas

According to Table No. 1, the comparison between the idea generation results of different groups of students shows that the difference in educational background, environmental conditions, and mental state can be effective in the quantity and quality of ideas, their classification and variety.

These are some of the challenges of teaching creativity in ordinary situations. The comparison of the results of each group showed the students that with different lenses and perspectives of dealing with the subject, different results can be reached. After completing the idea generation, the students were asked to categorise their group's ideas and choose the titles of each category.

Group	Number of Categories	Category titles	Cat. Codes	Group	Number of Categories	Category titles	Cat. Codes
	<u>U</u>	Product	А	210	2	logical	L
		Jokes	В	3-1-0	Z	illogical	М
3-1-3	5	Change of activity	С		7	Architecture	D
		displacement	D			culture	N
		Impossible ideas	Е	217		Technology	A
214	2	possible ideas	F	3-1-7		Movement	D
3-1-4	Z	Impossible ideas	G			policy	K
		Practical tools	А			product	A
		Jokes	В			Hygiene	0
3-1-5		Creating attraction in the environment	D			Inexpensive	Р
	8	Creating repulsion in the environment	D	3-1-8	5	Expensive	Q
		Remove the problem statement	Н			non- executive	F

Table 2. The titles of categories of students' ideas

	incentive system	Ι		executive	G
	Punishment system	J		creative	R
	Legislation	K			

#### 3.1.1 The results of students' ideation

Considering the variety of classification of ideas, it can be seen that the participation of students in the group meeting increases the ability to present ideas with different points of view. According to the defined task groups 3 to 8, immediately after the completion of ideation, have categorised their ideas from various points of view (Table 2), which can be summarised under the following headings: a) product design, b) changes in the environment, c) policy making, d) behavioural and cultural, e) economic, f) jokes, g) non-executive ideas. Attending groups and exchanging work results is very effective in increasing the horizons of beginner students, but it takes at least 60 minutes to manage the meeting and complete the entire work.

#### 3.2 Using Artificial Intelligence

The same brainstorming questions were posed to the AI platforms using two methods:

#### 3.2.1 Zero-Shot Questions (ZS)

In this method, the AI model is asked to generate responses to the brainstorming questions without being given any explicit instructions or examples of what is expected. It's similar to asking a person to come up with ideas off the top of their head, without providing them with any guidelines or prompts. The AI relies solely on its existing knowledge and training to understand the question and generate relevant ideas. This approach tests the AI's ability to interpret and respond to questions without additional guidance.

#### 3.2.2 With Instruction: (Max\_token=4000, Temperature=1.0, Method=CoT)

This method involves providing the AI model with specific instructions and parameters to guide its idea generation process. It's like giving a person a detailed brief or a set of rules to follow when brainstorming. The researchers specify factors such as:

- The methods or techniques the AI should use to generate ideas (e.g., mind mapping, lateral thinking)
- The number of ideas the AI should generate for each question.
- How the AI should categorise or organise its generated ideas

By setting these parameters, the researchers can control and optimise the AI's output to better suit the task at hand. This approach is also known as "prompt engineering," as the instructions given to the AI are carefully designed to elicit the desired type and quality of responses. Providing more context and guidance can help the AI generate ideas that are more relevant, diverse, and aligned with the researchers' expectations. Table 3 compares the number of AI-generated ideas using both methods, showing that detailed instructions yield more results. Table 4 assesses the quality of AI responses based on expert ranking, demonstrating the importance of human feedback in selecting appropriate solutions. Figures 1 and 2 illustrate the improvement in AI performance with instruction and the comparison between engineered prompts and zero-shot questioning.

#### 3.2.3 Selected Questions

- 1 What can be done to help a blind person cross the street safely?
- 2 What could be the reason if a person is sitting in a park holding a newspaper upside down?
- 3 Many people smoke cigarettes every day in a specific green space and the cigarette smoke bothers the employees of the ground floor in the adjacent building. How can this problem be solved?

We don't need to set stress or education levels for AI so there are only three questions.

Table 3 shows the results of two methods of using three selected AI tools. The numbers in the columns clearly indicate that more results from AI responses can be achieved by using engineered instructions and more detailed explanations.

Overtions	OpenAI (GPT-4)		Google (	Gemini 1.5)	Anthropic (Claud 3)		
Questions	ZS	Instruction	ZS	Instruction	ZS	Instruction	
1	10	100	16	22	8	30	
2	8	40	10	36	7	70	
3	8	39	11	27	6	30	

Table 3. Comparison Number of ideas generated by AI

The results of the responses of the three AI platforms are shown in Table 4. The number of categories and the number of selected answers is written in each row. For the qualitative ranking of the answers, it is necessary to use human feedback and here the experience of a subject matter expert (SME). The ranking results are based on the number of answers and their quality selected by an expert.

AT Madal	Output	Structure	SME	Result	
AI Model	Category	Selection	Ranking		
OpenAI (GPT-4)	3-4-2	12-12-8	3	Useful	
Google (Gemini 1.5)	5-6-5	15-3-10	2	Average	
Anthropic (Claud 3)	3-4-10	6-16-30	1	Strong	

Table 4. Quality of ideas generated by AI



Figure 1. improvement in AI Generated Ideas with Instruction or Prompt Engineering

Figure 1 shows the enhancement of AI-generated ideas by instruction or prompt engineering. Despite the improvement of the statistics of the number of answers, human feedback should be used to make decisions and select answers.

## **4 RESULTS**

The analysis reveals the influence of students' environmental conditions and academic status on ideation. The 29 identified idea categories highlight the diverse perspectives humans bring to problem-solving. While AI can generate a large volume of responses, their novelty, creativity, and quality require careful evaluation. Controlled, precise commands can enhance the quality of AI-generated ideas. Table No. 5 shows the most important positive and negative aspects between the students' idea creation and the production of artificial intelligence answers.

Aspect	Students	AI		
	- May have Multifaceted thinking	- High speed responses		
Desitive	- More creative ideas	- Real-time classification of responses		
Positive	- Strong imagination	- No limitation for presenting new responses		
	- Influenced by sympathy	- Not affected by environmental factors		
	- Lack of self-confidence	- May be biased		
Negative	- Affected by environment	- Full energy consumption		
Negative	-Affected by psychological factors	- Ideas depend on imported data		
	- Fear of ideas being ridiculed	- Possible mistakes		

Table 5. Comparison between students and artificial intelligence

## **5 DISCUSSION AND CONCLUSION**

Teaching creativity using AI presents challenges across psychological, geographical, cultural, and economic dimensions. Demonstrating the value of group meetings in fostering critical and multifaceted thinking is crucial for engaging Generation Z students. Lack of experience in working with AI may lead to inaccurate results, necessitating the guidance of creativity experts. The perceived novelty of ideas may vary across geographical contexts, emphasising the importance of AI's access to diverse resources. Economic disparities can limit access to high-speed internet and AI tools, impacting the quality of results. This research highlights the potential of thoughtfully integrating AI in design education while underscoring the indispensable role of human expertise and collaboration. The educational application of this research includes using AI as a personal assistant for brainstorming training, expanding the quantity and diversity of ideas generated, and strengthening students' critical thinking abilities through AI collaboration. By leveraging AI's capabilities and human guidance, educators can create a learning environment that nurtures creativity, critical thinking, and adaptability in the next generation of designers, equipping them with the skills necessary to navigate an increasingly complex professional landscape.

## ACKNOWLEDGEMENTS

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# **Rise of the Machines** Design Education in the Generative AI Era

The E&PDE 2024 conference will bring together representatives from education and industry who have an interest in sharing new perspectives on design education. It will provide a forum for educators, practitioners and students from engineering and product design fields to discuss current and future educational issues. Professionals and students from other disciplines are also invited to contribute and participate.













