



Engineering & Product
Design Education

Exploring Diversity in Engineering & Product Design Education

Proceedings of the 28th International Conference
on Engineering & Product Design Education

2nd-4th September 2026

Hosted by the

School of Civil, Aerospace and Design Engineering

In collaboration with the

Engineering Education Research Group at The
University of Bristol

Editors

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Editors: Jeff Barrie, Thea Morgan, Joel Ross, Becky Selwyn, Chris McMahon, Lyndon Buck, Ross Brisco, and Erik Bohemia.

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E&PDE 2026 Foreword

Exploring Diversity in Engineering and Product Design Education

The 28th International Conference on Engineering and Product Design Education (E&PDE) with the theme 'Exploring Diversity in Engineering and Product Design Education' was held at the University of Bristol, on the 3rd and 5th of September 2026. The conference was hosted by the School of Civil, Aerospace and Design Engineering in collaboration with the Engineering Education Research Group. 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).

Since its inception in 1999 in the United Kingdom, the E&PDE conference has grown into a leading international forum. Established as a global event in 2004, it alternates annually between the UK and partner institutions abroad. Its mission is to connect educators, researchers, and industry professionals who are passionate about advancing engineering and product design education. The conference provides a platform to exchange expertise, explore contemporary and emerging methodologies, and discuss the evolving relationship between academia, industry, and society.

In 2019, E&PDE introduced visual papers, in which sketched images play the central role in communicating insights, with text providing a supporting function. These contributions continue to expand the conference's knowledge base by capturing ideas in ways that are particularly relevant to design education and research.

Conference theme

Equality, diversity, and inclusion (EDI) are three interconnected concepts that aim to create a fair and welcoming environment for people in education and the workplace. While the gender divide in engineering is acknowledged and faces its own unique challenges to promote gender equality and meet growing industry demand for skilled and professional engineering, according to Represent Recruitment Agency, the design workforce in the UK remains well over three-quarters male. This is substantially higher than the 53% national average. Women are not only likely to be paid worse than male colleagues, but they are also likely to be in less senior positions: with only 17% of design managers who are female. For people who come from Black, Asian or Minority Ethnic (BAME) backgrounds, they make up just 13% of jobs in the industry. BAME staff make up just 12% of senior positions and the pay gap can range up to 17%.

There are also issues around sexuality, especially around what can be perceived as male-dominated, heterosexual professions. LGBTQ+ engineers make up a very small percentage (around 5%) with the design industry doing slightly better (11.7% according to a AIGI census survey from 2019). Nonetheless, there are complex issues around visibility and recognition around sexuality.

While universities are now adapting to accommodate for an increase of neuro-divergent students, and those with learning disabilities, how can engineering and design industries benefit from graduates who see the world differently?

The design industry is also facing demographic challenges, with the vast majority of design professionals in their 20s and 30s. There is a distinct lack of older professional designers.

There are also disparities around socio-economic diversity between engineering and design, with a decline of school age students undertaking Design & Technology (D&T) at GCSE and A-level.

With diversity in a design or engineering team, it can be argued that the result is better products, services, and appropriate solutions. The challenge of this conference is a rally call to ask the difficult questions, acknowledge and address the complex problems and provide solutions that inspire to go beyond characteristics, statistics and data.

The Proceedings

The call for papers invited contributions that:

- explore innovative educational concepts and strategies to prepare students and graduates for future design challenges
- share best practices in transferring knowledge between academia and industry;
- identify and address skills gaps between higher education and professional practice
- provide a platform for diverse voices and perspectives within the design education community.

This year's conference sub-themes included:

- Novel methods for accommodating diversity and inclusivity in multidisciplinary and group-based students' engineering design projects
- Challenges and opportunities for educators to foster an inclusive learning environment for students with diverse needs
- Critique of design methods used in product and service design education
- Fostering EDI through engineering design educational methods
- Educating students in considering equality, diversity and inclusivity in product and service design development
- Integrating the knowledge of diverse designers and cultural nuances in the design phases of products and services
- Innovative approaches promoting EDI principles in engineering and product design education
- Collaborative design education practices fostering the appropriate design of products and services
- Opportunities for AI to enhance diversity in engineering and product design education
- Industry and academia collaborative models for fostering diversity
- Understanding students' experiences from school to higher education, to industry in order to acknowledge and tackle the challenges and barriers faced by designers from minority Ethnic and Heritage communities as well as low socio-economic status

The 2026 conference attracted 132 abstracts, including one visual contribution and 13 student submissions. Following a rigorous double-blind peer review process, 96 papers were selected for inclusion in these proceedings. Over the two-day event,

more than 110 participants from 24 countries engaged in four workshops and 92 paper presentations, creating a vibrant space for exchange and collaboration.

Keynotes

The conference featured two keynote speakers who provided compelling perspectives on diversity within engineering and design industries.

Sunny Panesar, Head of Sales at Ensera Design, shared insights from his career in medical product design consultancy industry and the need to improve diversity in the sector. He provided an overview of the Ethnic Diversity Excellence Program, supported by other UK design consultancies, as well as measures of its success and reflections from his own personal experience.

Laura Tuck, R&D Lead at The Washing Machine Project, spoke about her work in empowering women in off-grid communities using appropriate technology and feedback, as well as her involvement in FemTech product development and advocating inclusive spaces for women.

Acknowledgements

The success of E&PDE 2026 is the result of the dedication of many individuals and organisations. I wish to express my sincere gratitude to the conference co-chairs, Prof Chris McMahon, Dr Thea Morgan, Dr Becky Selwyn and Dr Joel Ross for their support throughout the organisation of the event. Special thanks are also due to Jo Winslow, Ross Brisco, Lyndon Buck, Erik Bohemia, and Francesca Mattoli, for their continued guidance and support.

I am indebted to the members of the international scientific review board for their reviews, which ensured the high quality of the papers presented. Appreciation also goes to Lauren Duvall and Catering and Events team for their organisational support, as well as other professional services staff who contribute tirelessly to the daily workings of the University.

I thank all participants (old and new) for their contributions and engagement. Your commitment, friendship and passion continue to make the E&PDE conference a unique and dynamic forum for advancing engineering and product design education worldwide.

I dedicate this foreword to the late Prof Jason Arday, who took his own life on the 14th of August 2026 after accusations of plagiarism and subjected to relentless public scrutiny by the British media and online platforms; which has deeply shocked the academic community. Prof Arday provided a compelling keynote address at the 2024 Bristol Institute of Teaching and Learning (BILT) 'Voice and Choice-student agency, empowerment and co-creation'. Arday's keynote was titled 'Reasons to be cheerful: is higher education becoming a more inclusive space?' which discussed the continued challenges faced by the sector, with a view to providing a roadmap to future sustained interventions and mobilise greater inclusion and equality. Arday's death is a wake-up call to the higher education sector to re-evaluate how diverse, inclusive and equal they truly are, against what they perceive to be. To fellow academics who have faced unfair discrimination due to age, race, gender, sexuality or religion, we hear you, we see you-and E&PDE will continue to be a welcoming and inclusive space for all.

As a young, black professor with autism, Jason's life story was full of hope and aspiration to anyone who grew up thinking that life in academia was not for them, including myself, which sadly came to a tragic and unjustly end. Rest in Power.

Jeff Barrie

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4th September 2026



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 bimonthly 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 www.ied.org.uk



The Design Society is a global community of researchers, educators and practitioners dedicated to advancing the science and practice of design, established in 2000 as a successor to the Workshop Design-Konstruktion (WDK) group 1981. By connecting leading minds across academia and industry, the Society promotes innovation, collaboration and knowledge exchange in engineering design, product development and design research.

Through its internationally recognised conferences, including the flagship International Conference on Engineering Design (ICED), and the Engineering and Product Design Education series (E&PDE) the Society provides a platform for presenting cutting-edge research, sharing best practice, and building lasting professional networks.

Beyond conferences, the Design Society supports a vibrant international research community through Special Interest Groups, publications, doctoral development activities, awards and professional networking opportunities. Whether you are an established researcher, industry professional or emerging scholar, the Design Society offers a forum to collaborate, learn and help shape the future of design.

Why should you engage with the Design Society?

- Connect with a global network of leading researchers, educators and industry professionals working across engineering design, innovation and product development.
- Stay at the forefront of emerging topics including AI in design, sustainability, systems engineering, design methods, creativity and human-centred design.
- Join Special Interest Groups (SIGs) to collaborate with experts who share your research interests and contribute to focused communities within the wider design field.
- Access high-quality research outputs and conference proceedings that showcase the latest developments in design research and practice.
- Develop your professional network through workshops, seminars, conferences and online community activities.
- Support your career development through opportunities aimed at doctoral researchers, early-career academics and established professionals.
- Help shape the future of design research and education by participating in one of the world's most influential engineering design communities.

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DIVERSITY IN FINAL YEAR PRODUCT DESIGN PROJECTS: WHO ARE WE DESIGNING FOR?

Abi BATLEY and Tim REYNOLDS
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ABSTRACT

This paper explores the diversity of final year product design projects completed from 2007 through to 2026 at Bournemouth University. By analysing approximately 450 projects, we examine not only the technical and creative breadth of topics but, crucially, the diversity of users and communities for whom students are designing. Are products primarily aimed at mainstream consumer markets, or do they increasingly address the needs of underrepresented groups such as ageing populations, people with disabilities, or marginalised communities? Through thematic coding of project briefs and outcomes, we map trends in inclusivity, empathy, and social impact within student-led innovation. The paper considers how this diversity of design focus reflects broader societal shifts and the growing recognition of design as a force for equity and wellbeing. We also discuss the implications for how future designers may shape more inclusive and sustainable practices within industry. In reflecting on whether these projects challenge conventional market priorities or reinforce them, the study highlights the role of education in expanding students' perspectives on who deserves to be designed for. Ultimately, the paper argues that encouraging greater diversity in project focus not only enriches the learning experience but also holds the potential to influence the future trajectory of product design, steering it towards more socially responsive and equitable outcomes.

Keywords: Diversity, design education, social impact, inclusive design

1 INTRODUCTION

Product design has historically centred a particular kind of user: able-bodied, economically empowered, geographically privileged, and culturally normative. While the rhetoric of user-centred design has long been embedded in educational and professional discourse, the question remains: *which* user is centred? Who is imagined, prioritised, and legitimised within the pedagogical structures that shape future designers?

This paper explores these questions through a longitudinal analysis of final year product design projects in which we examine not only the technical and creative range of topics but, crucially, the diversity of users and communities for whom students are designing. The final year project represents a significant moment in undergraduate design education: it is often the most self-directed, research-led and personally meaningful body of work that students undertake. As such, it offers insight into both the values embedded within the curriculum and the socio-cultural priorities students perceive as legitimate design concerns.

The study asks: Are projects primarily aimed at mainstream consumer markets? Do they increasingly address the needs of underrepresented or marginalised groups? How have patterns of user focus shifted over two decades? What does this reveal about the evolving relationship between design education and equity, diversity and inclusion (EDI)?

By mapping changes in user diversity and contextual awareness, the paper explores how design education may contribute to broader transformations in the discipline's social orientation. Ultimately, we contend that encouraging diversity in project focus not only enriches the student learning experience but may also influence the future trajectory of product design practice, steering it toward more inclusive and socially responsible outcomes.

2 DESIGN, POWER AND INCLUSION

2.1 The “Default User” and Normative Design

Design is never neutral. As scholars such as Winner [1] and Norman [2] have argued, technologies and products embody assumptions about users. Historically, many everyday objects—from medical devices to transport infrastructure—have been designed around a normative body and lifestyle, often marginalising those who fall outside this imagined centre.

The concept of the “default user” refers to this unexamined baseline: frequently able-bodied, male, economically secure and located in the Global North. Such normative design frameworks can perpetuate structural inequalities by rendering other users as exceptions rather than central stakeholders. From an EDI perspective, normative design education risks reproducing structural exclusion when standards of “good design” are implicitly aligned with dominant cultural and bodily norms. Dolmage [3] highlights how ‘academic ableism’ operates through institutional expectations, assessment practices and disciplinary cultures that privilege able-bodied, neurotypical and culturally dominant perspectives, thereby shaping what kinds of design projects are recognised as valuable or legitimate within design education.

2.2 Inclusive Design, Universal Design and Design Justice

Inclusive Design and Universal Design have sought to broaden participation and accessibility. Inclusive Design emphasises designing for the widest possible range of users, particularly those at the margins, while Universal Design promotes environments and products usable by all without adaptation.

More recently, Design Justice [4] has pushed the conversation further, foregrounding power, participation and structural inequity. Rather than merely accommodating difference, design justice calls for centring those most impacted by systems of oppression in design processes.

These frameworks are particularly relevant in educational contexts, where students’ understanding of who “counts” as a user is being formed.

2.3 Design Education and Value Formation

Design education plays a formative role in shaping professional identity. Studio culture, project briefs, assessment criteria and tutor expertise all contribute to what can be described as the “hidden curriculum”—the implicit values conveyed through practice. Building on the work of Rossi [5], contemporary design education increasingly positions EDI not only as a curricular topic but as a value system embedded within studio pedagogy, assessment culture and project framing. This perspective supports the interpretation of final-year projects as expressions of how students internalise or challenge institutional values around equity, diversity and social responsibility in design practice.

Final year projects, typically self-initiated, provide a lens through which to examine how students interpret design responsibility. They reveal not only personal interests but also the boundaries of what is considered legitimate or valuable design work within a programme. This study therefore positions final year projects as artefacts of educational values, offering insight into how EDI principles manifest in practice over time.

3 METHODOLOGIES

3.1 Research Design and Sampling Strategy

This study adopts a longitudinal, retrospective content analysis of final year undergraduate product design projects at Bournemouth University. Rather than analysing every year between 2007 and 2026, projects were sampled across three consecutive-year clusters at defined intervals in order to capture temporal shifts while maintaining analytical depth. The sampled periods were:

- 2007–2009 (approx. 150 projects)
- 2017–2019 (approx. 150 projects)
- 2024–2026 (approx. 150 projects)

These clusters represent snapshots across the 19-year span, enabling comparison across distinct educational, social and global contexts.

The dataset comprises approximately 450 projects in total. For each project, the primary data source was the end-of-year degree show brochure, which included the student-authored project title and outline description. For 2026, where final projects were still in development at the time of writing, project proposals submitted for approval were used instead. While proposals may differ slightly from final

outcomes, they clearly articulate intended users and design focus, which are the primary variables under investigation.

All final year Product Design projects within the selected years were included, except where critical contextual information was missing.

3.2 Data Extraction and Coding Framework

Analysis focused on the declared design intention as expressed in project summaries. An inductive coding process identified recurring patterns across four analytical dimensions:

1. **Primary User Group**
(e.g., general consumers, children, older adults, disabled users, occupational groups)
2. **Inclusion Dimension**
(e.g., disability, age, gender-specific health, mental health, global development, socio-economic context)
3. **Market Context**
(mainstream consumer, niche enthusiast, clinical/medical, humanitarian, occupational, environmental/systemic)
4. **Geographic Specificity**
(generic/unspecified vs explicitly contextualised region)

Projects could register across more than one inclusion dimension (e.g., maternal health within low-resource contexts), but each project was assigned a single dominant thematic category for longitudinal comparison. Ten overarching themes emerged through clustering of coded data:

1. Inclusive & Assistive Design
2. Age-Specific Design
3. Cognitive & Mental Health
4. Chronic Illness & Medical Management
5. Maternal & Gender-Specific Health
6. Global Development & Low-Resource Contexts
7. Climate & Environmental Systems
8. Occupational & Context-Specific Tools
9. Sport & Performance Markets
10. Lifestyle & Consumer Convenience

These themes were applied consistently across all three-time clusters to enable structured comparison.

3.3 Analytical Approach

Following coding, projects were analysed chronologically to identify shifts in user focus and thematic prevalence across the three sampled periods. Rather than conducting statistical hypothesis testing, the study adopts a comparative descriptive approach suitable to educational trend analysis. Emphasis is placed on directional change (e.g., increasing specificity of user groups, growth of condition-specific health design, emergence of climate-adaptive systems) rather than precise quantitative modelling.

3.4 Limitations

The study relies on student-authored summaries rather than full dissertations, ethnographic documentation or evidence of participatory engagement. As such, findings reflect how projects were *framed* and communicated, rather than the depth of user involvement or real-world implementation. Additionally, topic selection is influenced by faculty expertise, institutional priorities, global events and prevailing discourse (e.g., sustainability, mental health awareness). The analysis therefore maps shifts in declared design focus within an educational context, rather than attributing causality to specific curricular interventions.

Despite these limitations, the dataset provides a rare longitudinal snapshot of how future designers conceptualise who design is for, offering insight into evolving value formation within product design education.

4 FINDINGS: SHIFTS IN WHO IS BEING DESIGNED FOR

4.1 2007–2009: Functional Consumer Focus

Projects in the late 2000s largely centred on domestic convenience, incremental efficiency and lifestyle enhancement. Examples included energy-saving kettles, portable shower units, bike accessories and

household cleaning tools. While assistive devices were present—such as mobility aids or tools for reduced dexterity—these tended to focus on physical function rather than broader social contexts. Sustainability projects largely addressed energy efficiency rather than systemic environmental concerns. User groups were often described generically (“over 65s,” “homeowners,” “cyclists”), suggesting a relatively broad and mainstream framing of design problems.

4.2 2017–2019: Expanding Inclusion and Global Awareness

Mid-decade projects show increased engagement with prosthetics, stroke rehabilitation, dementia support and water access in low-resource settings. Projects targeting specific global regions—Bangladesh, Tanzania, South Asia—become more common. Mental health begins to emerge as a theme, with breathing regulators, mindfulness tools and ADHD aids appearing more frequently. The user profile becomes more defined, and marginalised groups gain greater visibility.

4.3 2024–2026: Contextualised, Condition-Specific and Climate-Aware Design

The most recent decade shows a marked shift toward:

- Dementia management systems
- Neurodiversity and behavioural regulation tools
- Maternal and postpartum health devices
- Sensory inclusion for deaf and visually impaired users
- Climate adaptation technologies
- Environmental monitoring systems

Projects increasingly specify context (“under 2s in rural Bangladesh,” “MS sufferers,” “female soldiers in field conditions”), reflecting deeper engagement with lived realities. This period also sees a rise in condition-specific medical devices (e.g., Raynaud’s relief, insulin storage for cold climates, chemotherapy-related devices), indicating granular attention to health diversity. Table 1 provides a summary illustrating the shift in project emphasis over the periods under review.

Table 1. Project Emphasis Summary

Period	Mainstream Consumer	Condition-Specific	Global/Low Resource	Climate/Systemic
2007–2009	High	Low	Rare	Limited
2017–2019	Moderate	Growing	Emerging	Moderate
2024–2026	Reduced	High	High	High

5 INTERPRETING THE SHIFTS

5.1 From Consumer Convenience to Socially Situated Design

Across the sampled periods, the most significant shift is from mainstream consumer optimisation toward socially situated and condition-specific design. Projects from 2007–2009 largely focused on convenience, efficiency and incremental product improvement. Assistive devices were present but typically framed in functional rather than systemic terms.

In later clusters, particularly 2024–2026, projects increasingly centre lived experience. Dementia management, neurodiversity, chronic illness and postpartum recovery become prominent themes. The emphasis moves from improving product typologies to improving conditions of living. Users are framed less as abstract consumers and more as individuals navigating complex health and social realities. The rise of invisible and chronic conditions further indicates greater specificity in identifying legitimate design users. Rather than broad demographic categories, later projects demonstrate nuanced attention to cognitive, behavioural and long-term health contexts.

5.2 Expanding Context: Climate, Gender and Globality

Recent projects also reflect widening contextual awareness. Sustainability evolves from incremental efficiency improvements to engagement with climate adaptation and environmental systems. Gender-specific and maternal health needs become more visible, suggesting attention to historically overlooked bodies. Geographic specificity increases, with projects more frequently identifying defined regions or socio-economic contexts rather than generic users. This shift from market segments to situated communities signals a broader understanding of design as embedded within social, environmental and cultural systems.

5.3 Market Logics and Their Limits

Despite this diversification, most projects remain framed as product-based solutions operating within existing market structures. Even socially oriented briefs are typically articulated as commercially viable artefacts. Explicit engagement with structural inequality or overtly political domains remains limited. While integrating marginalised users into mainstream product design may represent progress, it also raises questions about whether product-led approaches sufficiently address systemic challenges. Students are expanding who they design for, but implicit limits may persist around how far design can interrogate dominant socio-economic frameworks.

6 EDUCATIONAL IMPLICATIONS

6.1 Curriculum, Studio Culture and Value Formation

Final year projects reflect value formation within design education. The observed shifts likely respond both to wider societal discourse and to evolving curricular priorities around sustainability and inclusion. As themes such as mental health and climate gain legitimacy, students appear increasingly motivated to pursue them.

Studio culture and assessment structures shape this trajectory. The growing visibility of marginalised users suggests that inclusion is no longer peripheral within the programme's implicit value system. At the same time, the relative absence of systemic critique highlights the need to embed critical and structural perspectives more explicitly within the curriculum.

6.2 Limits and Future Responsibilities

If inclusive design is to move beyond trend responsiveness, it must be structurally embedded rather than dependent on individual student initiative. This may involve integrating user-diversity criteria into briefs and assessment and introducing tools for stakeholder and power analysis earlier in the programme. Design education therefore carries responsibility not only for technical competence but for shaping assumptions about who design serves and how responsibility is framed.

7 CONCLUSIONS: EDUCATION, INDUSTRY AND FUTURE PRACTICE

Across two decades, final year projects reveal a clear expansion in who is being designed for. From mainstream consumer convenience, student work increasingly engages with marginalised communities, invisible conditions, gender-specific health needs and climate-related contexts.

Diversifying intended users may also reflect changing market conditions, as contemporary product markets are often saturated, making incremental innovation or aesthetic differentiation insufficient for strong unique selling points. For final-year students, whose projects often serve as portfolio highlights in a competitive job market, demonstrating originality is particularly important. Designing for mainstream consumer products can risk redundancy unless supported by significant technological innovation. In contrast, focusing on underrepresented communities, condition-specific health contexts, or geographically defined user groups can provide clearer differentiation and stronger narrative positioning. Engaging with niche or overlooked markets therefore supports both social impact and strategic advantage by addressing unmet needs in crowded design sectors.

These shifts suggest that design education can influence how future designers define relevance and value. Graduates trained to centre dementia patients, neurodivergent users or low-resource communities may broaden professional priorities within industry. However, sustaining this trajectory requires deeper integration of inclusive and critical thinking within curricula.

The central issue is not only who students are designing for, but how educational structures define legitimacy and responsibility in product design. In shaping these definitions, programmes contribute to the future orientation of the discipline itself.

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METHOD FOR ASSESSING THE INGENUITY OF LOW-TECH DESIGNERS IN THE CONTEXT OF A STUDENT HACKATHON

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ABSTRACT

In response to socio-ecological challenges, various alternative design approaches have emerged, each bringing a different set of pedagogical practices to pass on to future designers. One of the most recent of these is the Low-Tech approach, characterised by the ingenuity designers demonstrate in creating solutions within constraints. However, the capacity for ingenuity in this context has not yet been studied, nor is there a method for assessing it. This hinders its transmission to future designers. Against this backdrop, and within the framework of emerging teaching practices to introduce the Low-Tech approach, this study proposes investigating and characterising two components of ingenuity as factors in the success of a design project: the influence of handyman-engineer logics, and the self-imposition of ethical constraints in the design process. The experiment involved tracing the evolution of these components in students over two Low-Tech hackathons. Data was collected from students and coaches using questionnaires and semi-directive interviews. An evaluation grid was also sent to the hackathon jury to assess the Low-Tech characteristics of the solutions. This research aims to characterise and evaluate the components of ingenuity in a Low-Tech context as part of an innovative educational approach and offer initial ways to facilitate their transmission to future designers.

Keywords: Ingenuity, low-tech, education, assessment, design for sustainability

1 INTRODUCTION

In response to socio-environmental challenges, various alternative design approaches have emerged [1, 2], bringing with them a variety of pedagogical practices to pass on to future designers. Among the most recent approaches, the Low-Tech approach [3, 4] is still struggling to become more widespread. Several factors, such as a lack of clarity surrounding its definition [5], can explain this phenomenon and the subsequent difficulty in creating pedagogical approaches aimed at transmitting it. To address this issue, this study focuses on a common trait of low-tech designers: their ingenuity. In the scientific literature, ingenuity is defined as follows: 'The ability to create innovative solutions within constraints using limited resources and imaginative problem solving' (adapted from [6]). The results of this paper are based on previous research defining the ingenuity of Low-Tech designers [7], which proposed two elements that distinguish this ingenuity from that found in more conventional contexts (e.g. industry). Low-tech designers' ingenuity is characterised by self-imposed ethical constraints during the design process, and by a closer proximity to the logic of the bricoleur than to that of the engineer. As the underlying aim of this work is to contribute to the development of teaching practices that communicate this ingenuity to new generations of designers, the next step is to assess the impact of the components of ingenuity in a pedagogical context. This paper has the dual objective of testing a method for assessing ingenuity components and an educational framework for applying this method: the hackathon. The next section provides an overview of the state of the art, setting out the background to the various theoretical elements studied in this work. The method used to build the evaluation system is then described, followed by the results of the various evaluations conducted during the hackathons. Finally, the discussion will question the evaluation method and the relevance of the hackathon framework for this evaluation of ingenuity, before drawing conclusions.

2 LITERATURE REVIEW

To better understand this research, it is necessary to explain the two components of Low-Tech designers' ingenuity. Siqueira and Honig [8] add self-imposed ethical constraints to the main constraints that characterise ingenuity (structural, resource and time constraints [6]), defining them as follows: 'Restrictions on the behaviour of individuals deriving from moral, social and environmental responsibility' [8]. Lederlin [9] updated the logics of the bricoleur and the engineer based on Claude Lévi-Strauss's work in the 1960s [10]. These two logics propose two a priori contradictory ways of thinking, driven by divergent visions. In the engineer's logic, the end — the solution to the problem — is defined using a scientific approach (e.g. calculations and protocols), and then the means to achieve the solution are allocated (fixed solution). In the bricoleur's logic, the solution is initially vague and then materialises according to the available resources (an evolving solution as the project progresses). While the engineer looks for performance (economic, technical, etc.) through various means of optimisation, the bricoleur produces robust solutions that are in tune with their environment [10]. Although creativity and innovation are widely assessed using established methods such as the Torrance Tests of Creative Thinking (TTCT), the Creativity Assessment Packet (CAP) and the Innovation Competence Barometer [11, 12], there is a lack of assessment tools for ingenuity in the scientific literature. Furthermore, the core components of ingenuity in Low-Tech contexts are either insufficiently addressed as ethical considerations [8] or entirely overlooked as the practices of tinkerers and engineers. Consequently, a novel assessment method for low-tech ingenuity was required. The practical constraints of conducting an initial experiment, combined with the availability of two hackathons, resulted in the decision to adopt the hackathon format. These brief, intensive team events focus on developing solutions and facilitate the rapid transition from concept to prototype within a condensed timeframe.

3 METHODOLOGIES

The data was collected during two hackathons held in eastern France in summer 2024. The first took place in Châlons-en-Champagne over five days, and the second in Nogent over three days. The Châlons hackathon was organised as part of a European research project aimed at developing educational practices around Low-Tech. Around 30 students from three countries (France, Ireland and Belgium), who were nearing the end of four- or five-year engineering, management and design courses, took part. The Nogent hackathon involved 14 students who were in their first year of engineering studies. The study includes three of the six groups from Châlons (12 students) and all of the students from Nogent (four groups, 13 students). At the end of both hackathons, the students had to give a short presentation to a jury to showcase their solutions. The two hackathons were conducted in markedly different ways. In Châlons, students had to select one of eight topics identified in a study of local residents and authorities. In contrast, the Nogent hackathon involved the students choosing from a list of everyday product-related topics to which a Low-Tech approach was to be applied. Table 1 shows the subjects chosen by all the groups in both Châlons and Nogent. During both hackathons, the students were given periods of autonomy interspersed with coaching and theoretical input on Low-Tech concepts. However, this theoretical input was too different to be comparable. In Châlons, the hackathon was organised in partnership with a 'ressourcerie' and a 'matériauthèque': places where people can store and reuse donated second-hand materials. The students had the opportunity to select objects from these two places to use in creating prototypes of their solutions. Another difference compared to the Nogent hackathon is that the students in Châlons were already well aware of socio-ecological and Low-Tech issues.

Table 1. Distribution of groups, coaches and juries

Hackathon	Group	Number of students	Subject
Châlons	1	4	Promoting Local Agriculture and Reducing Packaging Waste
Châlons	2	4	Promoting Local Agriculture and Reducing Packaging Waste
Châlons	3	4	Digital Inclusion and Sufficiency in Rural Areas

Nogent	4	3	The private swimming pool
Nogent	5	3	The coffee machine
Nogent	6	3	The headlamp
Nogent	7	4	The camping tent

As the definition of the first component, 'self-imposed ethical constraints', is very broad, it has been adapted for this study, which is focused on pedagogical practice. It was therefore decided that the ability to self-impose ethical constraints would be equated with designers' mastery of certain Low-Tech-specific skills. To this end, this work is based on an initial Low-Tech designer skills reference framework [13], which was developed as part of a European project. This framework is based on a literature review of the different skills required of a sustainable engineer, which was then adapted to the Low-Tech context (see Table 2). The 11th skill, 'Topical Knowledge', was not assessed because the areas of knowledge involved are not clearly defined.

Table 2. LT4Sustain Low-Tech designer's skills model [13]

Skill 1	Systems thinking
Skill 2	Futures and anticipatory thinking
Skill 3	Values thinking and ethics
Skill 4	Strategic thinking
Skill 5	Interpersonal management
Skill 6	Multi-disciplinary problem-solving
Skill 7	Implementation (Design, Action & Assessment)
Skill 8	Intra-personal competence/Self efficacy
Skill 9	People-centeredness and behavioural change
Skill 10	Commons management and solution scaling
Skill 11	Topical knowledge

Then, three levels of acquisition have been defined for each macro-skill, accompanied by validation aids for each level. These levels were defined based on the reference framework for sustainable engineering competences of the University of Technology of Troyes. Table 3 shows the different acquisition levels for Skill 1 as an example. For the second component, as the bricoleur/engineer logic is an emerging topic, the authors did not have a reference framework with which to evaluate it. Therefore, it was deemed too complex to ask trainers or students to carry out an in-depth evaluation.

Table 3. Presentation of acquisition levels for skill 1

Skill	Systems thinking
Definition	Be able to work in your field as part of a complex system that is closely related to other domains like your society, economy, and the environment; and to be able to think about your field on different scales from local to global.
Level 0	No knowledge
Level 1	Identify the contours of the system under study (impacts on planetary limits, impacts on the local economy, on user behaviour, etc.)
Level 2	Understanding and analysing a prospective scenario and its context
Level 3	Have a systemic vision and the ability to analyse critically

The proposed method, presented in Figure 1, involves gathering data on the bricoleur/engineer positioning of students within the different groups studied, as well as their level of proficiency in Low-Tech skills. In order to assess ingenuity, it is also necessary to determine which groups produced solutions that were most in line with the Low-Tech model. The method was based on self-assessment by the students, while retaining critical evaluation by experts (coaches and juries). The evaluation took place in two stages: at the beginning and end of the hackathon, to identify any possible changes.

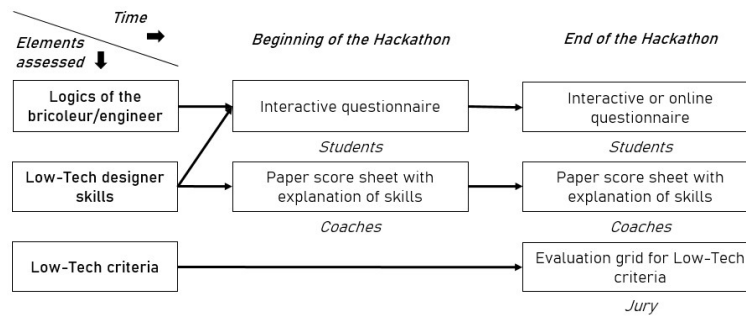


Figure 1. Data collection process

Only the students assessed the bricoleur and engineer logics. The low-tech skills were assessed by both the students (individually) and the coaches (in groups) to obtain two opinions. Skill 8, 'Intra-personal competence/self-efficacy', was assessed only by the students, as it was too personal for an external judgement to be relevant. Self-assessment in the form of interactive questionnaires was chosen to allow students to ask questions about elements they did not understand. The questionnaires began with a short introduction to the bricoleur and engineering logics, followed by a request for the students to position themselves. This was followed by a presentation of the Low-Tech skills and a self-assessment for each skill. The coaches carried out an evaluation at the beginning (end of day 1 or 2) and at the end of the hackathons (and halfway through for Châlons), using paper assessment forms created for this purpose. For the two hackathons, a panel of juries assessed the final solutions based on the deliverables according to the Low-Tech Criteria Grid. This grid was created using literature [3] and comprises eight low-tech evaluation criteria and their definitions. In Nogent, the jury comprised the two coaches and two external members who were considered experts in Low-Tech. In Châlons, the jury comprised eight external members: Two Low-Tech experts (practitioners); four members with an interest in or close links to Low-Tech; and two novice members (their ratings were not taken into account for reasons of consistency).

4 RESULTS

The assessment of the solution at the end of the hackathons (Figure 2) shows that, on average, the groups in the Châlons hackathon (shades of blue) are better rated than the groups in the Nogent hackathon (shades of orange). Furthermore, greater disparities in final marks have been observed in Nogent. This is not surprising, given that students from Châlons come from programmes with a stronger focus on sustainability. This minimises inconsistencies in their understanding and implementation of related concepts, as illustrated by the more varied marks achieved by the Nogent groups. Unfortunately, the Châlons scores were compiled without one jury member who did not follow the marking instructions, and without another jury member for group 2 as he did not mark this group. This has a detrimental effect on the validity of the results.

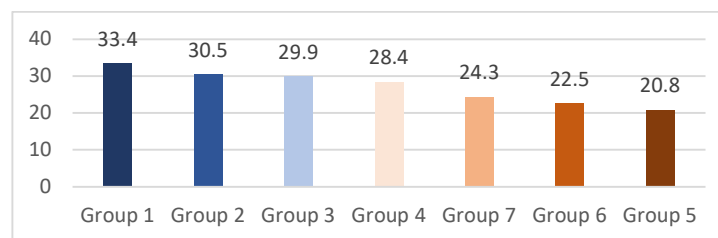


Figure 2. Jury ratings for group solutions based on Low-Tech criteria (marks out of 40)

The results of the Low-Tech designers' skills assessment demonstrate that the Châlons teams obtained higher average scores at the start of the hackathons, according to both students and coaches (see Figure 3). However, for the Nogent groups, the comparison was only made for skills 1, 2 and 4, as the coaches were unable to observe skills 3 and 5–10 at the start of the hackathon. This severely limits the interpretation of the results. For example, due to the significant amount of missing data, it is not possible to substantiate the hypothesis that a better starting level in Low-Tech skills leads to a better rating by the final jury with confidence. Nevertheless, it can be observed that, in general, students and coaches do not agree on these assessments. With the exception of groups 3 and 4, coaches rated students notably

lower across all groups. It could be argued that, as the coaches were considered more experienced in Low-Tech and related skills, the students may have overestimated their abilities in relation to their actual level. This may be because the students were unfamiliar with Low-Tech skills and only had a few minutes to self-assess.

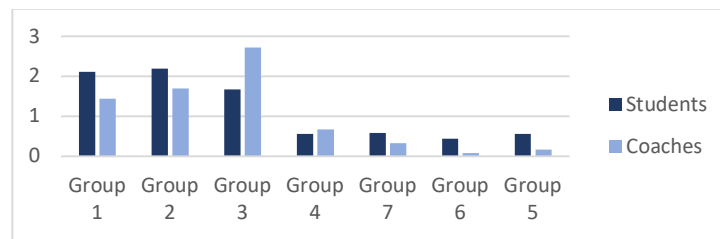


Figure 3. Comparison of skills levels between students and coaches' assessments (except for skill 8 as only the students rated it)

With regard to the influence of bricoleur and engineer logics, Figure 4 shows that there is no correlation between proximity to the ingenuity component (i.e. being closer to the bricoleur logic) and a better rating by the final jury. However, all the groups were relatively heterogeneous, with the exception of group 2. The research method and sample size do not permit identification of the actual influence of each individual and their logic within the groups. Nor do they enable verification that the logic claimed by each designer is the same as that which they actually followed during the hackathon.

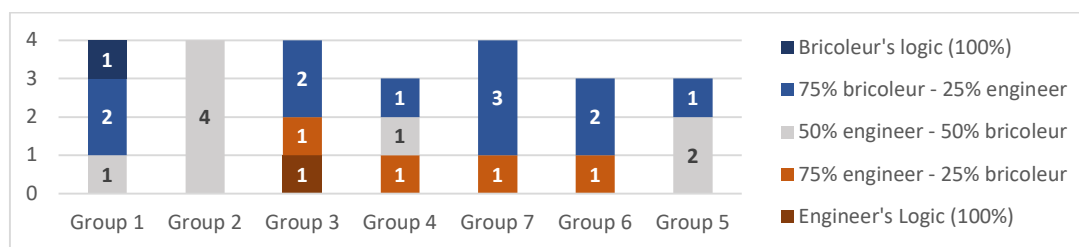


Figure 4. Positioning of students on the bricoleur/engineer logic at the start of hackathons

Finally, the cumulative progress of each group in all the skills over the course of the hackathons was calculated (negative progress results were excluded from the sum of progress). Unfortunately, despite various reminders, three students from the Châlons hackathon and four students from the Nogent hackathon did not complete the end-of-hackathon questionnaire. One student in groups 2–5–6 and two students in group 1–7. For the Nogent groups, the coaches' ratings did not provide a reliable average for skills 3, 6 and 7. For other skills, if one of the coaches has selected 'competence not observed' for a group, only the other coach's mark is considered. Consequently, the Nogent group results exclusively encompass skills 1, 2, 4, 5, 9 and 10. In contrast, the Châlons groups (1 to 3) comprise all skills except skill 8, thereby effectively constraining comparability between the two samples. The proportion of missing data is so high that it is difficult to draw any conclusions about changes in skills. However, it appears that all the groups have made progress, according to the coaches and students.

5 DISCUSSIONS

This study introduces a preliminary approach to assessing ingenuity. Although it is subject to inherent biases and lacks extensive prior research, it enables a partial evaluation and identifies key factors. Adopting a multi-perspective approach, with students and coaches assessing skills and a panel evaluating solutions, helps mitigate biases, particularly those arising from self-assessment. The findings suggest that the methodology requires comprehensive revision and highlight several potential improvements. Enhancing the assessment method may require an increased sample size, more diverse data sources and addressing missing data. The Low-Tech Skills Model also has limitations: coaches found some skills to be too broad, poorly defined or unsuitable for the hackathon context, which makes reliable assessment difficult — especially for skills 2, 3, 6 and 7. Consequently, refinement of the skills model is necessary. Additionally, initial qualitative findings reveal complex and poorly understood interactions between bricoleur and engineer logics. This indicates a need for clearer definitions and

observable markers for each logic. Examples of these markers could be the use of scrap materials for the bricoleur and the production of precise documentation for the engineer [9]. While the hackathon format encompasses multiple design stages, it is too brief for the in-depth evaluation of ingenuity required, and logistical constraints complicate data collection. Thus, the relevance of the hackathon for developing or assessing Low-Tech skills remains unproven. Future work should consider applying the assessment method in other educational contexts, particularly over a longer period to better evaluate changes in Low-Tech skill indicators, or even moving beyond the student environment into the professional world to improve indicator reliability and validity

6 CONCLUSIONS

The aim of this work was to propose and test a method for evaluating the ingenuity of Low-Tech designers but also to test a framework for applying this evaluation method. The method used was designed to assess the 2 components of ingenuity as factors in the success of a Low-Tech project during hackathons: the influence of bricoleur-engineer logics and the self-imposition of ethical constraints during the design process. This work contributes an initial method for assessing ingenuity in a Low-Tech context, as well as experimenting with this method in the context of a hackathon. It opens up many possibilities as further refinement of the method is required to minimise bias and improve its validity, but also to enable a more accurate assessment of ingenuity. The relevance of the hackathon format for assessing ingenuity remains questionable, opening the door to experimentation in other contexts, both with students and with experienced designers in professional settings.

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SUPPORTING DIVERSITY IN CIVIL ENGINEERING EDUCATION: EXPERIENCES OF STUDENTS WITH VOCATIONAL AND ACADEMIC BACKGROUNDS

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ABSTRACT

This paper investigates how students with diverse backgrounds experience the Civil Engineer Education at University of Agder (UiA), Norway. Students are being recruited based on vocational qualifications or qualified directly through upper secondary school. One of UiA's focus areas has been to create different entries for various student groups to provide more people with the opportunity to pursue higher education. This creates diversity within the student group, contributing valuable perspectives and competencies to the learning and teaching environment. At the same time, experiences show that students face different challenges. Those with a vocational background often possess strong practical skills but may encounter greater difficulties with theoretical subjects. In contrast, individuals from an academic upper secondary school generally master the theoretical aspects more easily yet often lack practical experience. Additionally, vocationally qualified students are frequently in different life situations, being more established and older compared to peers coming directly from upper secondary school. The study aims to map how these different backgrounds affect students' experiences regarding priorities, and overall satisfaction with the programme. The focus will be on exploring how to support students with a vocational background to stay in the programme and completing their degree, including their views on which elements should be expanded, and which should be reduced. Data will be collected through a survey, and the results are expected to provide insights into how the programme can be adapted to support diversity and enhance learning outcomes for all student groups.

Keywords: Vocational background, learning environment, survey, civil engineering education

1 INTRODUCTION

The Norwegian government wants more focus on practical and experience-based competence in engineering education [1]. There is currently lack of qualified workforce in the fields of science, technology, engineering, and mathematics (STEM) [2], and this is a growing concern internationally, often referred to as a 'STEM crisis' [3]. Despite strong recruitment to these fields, the dropout rate is high. A study conducted by Yi Ding et al. [4] estimate that approximately 50% of students who start a bachelor's degree in STEM either drop out or change their field of study. From 2018 to 2021, only about 50% of engineering students in Norway completed their studies within the nominal time [5]. The problem is particularly pronounced in engineering education, where as many as 41% of students leave the programme during the first year [4]. To address this crisis, it is crucial to understand the factors that influence students' success and persistence.

A central theory for understanding students' adaptation is Holland's theory of vocational personality types [6]. Research [4] shows that a large proportion of engineering students, nearly 40%, identify with the Realistic (R) personality type. These students are often described as 'doers' who prefer practical, hands-on work with physical objects rather than theoretical ideas. While practical aptitude is essential for an engineer, studies show a negative correlation between a realistic personality type and academic grade point average (GPA). A plausible explanation is that university assessment methods are often heavily theoretical and analytical, meaning that students with a practical orientation are not given the opportunity to demonstrate their competence through traditional written examinations.

The challenges are further intensified for students who come from a vocational background, often referred to as TVET (Technical and Vocational Education and Training) [7]. Although these students initially seek practical competence, their educational pathways are often characterised by a lack of

resources, equipment, and skills training. Many end up as passive observers rather than active participants in practical instruction. When these students encounter the university's theoretical demands, combined with academic difficulties in core subjects such as mathematics and physics, the risk of dropout increases considerably.

Students in the civil engineering programme at University of Agder (UiA) are recruited either through vocational qualifications or directly from upper secondary school. UiA has introduced multiple admission pathways to increase access to higher education, resulting in a diverse student group with different strengths and needs. Because students from the vocational pathway often take different introductory subjects, first-year study groups are typically formed based on admission routes, which leads students to collaborate mainly within their own pathway and reduces opportunities to benefit from each other's complementary competencies. The study aims to examine how these differing backgrounds and life situations influence students' experiences, academic priorities, and overall satisfaction with the programme. The goal is to identify how the programme can better support students with vocational background, both academically and socially, and how the diverse competencies within the cohort can be used more effectively to improve learning outcomes for all.

2 METHODOLOGIES

The method used in this study was a survey conducted with the programme SurveyXact. The target group consisted of active students enrolled in the three-year bachelor's degree programme in civil engineering. The survey was distributed through the learning platform used at the University of Agder. Students may be admitted to the programme through three different pathways: the V-path (for applicants with a vocational certificate), TRES (for applicants lacking mathematics/physics competency from upper secondary school), or direct admission from upper secondary school (SO). The survey differentiates between these admission routes, as well as the extent of relevant practical experience the students possess. This study focuses on V-path and SO-path students, as the SO pathway represents the standard entry route to engineering programmes. TRES students are broadly comparable to SO students in terms of age and educational background; however, to enable a clearer comparison between more distinct groups, they were excluded from the analysis. In the survey, students were asked about their experiences with the study programme, including what they would like to have more or less of, and their overall satisfaction with the programme. In addition, the survey included three open-ended questions where students could provide further comments. A total of 80 students completed the entire survey, while 5 students did not finish the final question, and additional 6 students did not finish the two last questions. In total, 232 students received the survey, resulting in a total response rate of 35%. The survey remained open for 48 days (October 16th – December 3rd). Table 1 shows the number of respondents.

Table 1. Overview respondents

Respondents	Number
SO-path	43
V-path	23
TRES-path	24
Other	1
Total	91

Quantitative data were analysed using descriptive statistics; no further statistical analyses were conducted. Qualitative data were analysed using a thematic, interpretive approach; responses were reviewed manually, and excerpts were selected based on their ability to illustrate recurring themes, serving as illustrative rather than exhaustive examples.

3 RESULTS AND DISCUSSION

The results from the survey show that students with a vocational background and students admitted through SO have different strengths and face different challenges related to practical and theoretical subjects. Among V-path students a majority have substantial relevant work experience. Specifically, 26% report having 5-10 years of relevant practical experience, while 35% report more than 10 years. In comparison, 74% of SO students report having no relevant practical experience. These differences are reflected to some extent in how students experience various subjects, as can be seen in Figure 1. In a first-year subject, where practical experience with drawings, construction, and building assemblies may

be advantageous, only 5% of V-path students report finding the subject difficult or very difficult, compared to 18% of students admitted through SO. Similarly, 20% of V-path students describe a second-year subject considering how buildings interact with outdoor and indoor climates as easy or very easy, compared to only 5% among SO students. This indicates that practical experience may provide an advantage in subjects more closely related to construction practice, as opposed to mathematically oriented subjects. Several V-path students also report that such subjects are perceived as meaningful and relevant, which may contribute to increased motivation and engagement in the programme. V-path students are often characterised by a Realistic personality type [4], which may help explain why they find construction-related subjects easier than more theory-heavy subjects. Even when these subjects do not involve hands-on practical problem-solving, students may draw on their prior practical experience to contextualise and explain the theoretical concepts they encounter. Such subjects may therefore also function as an arena where students can integrate practical knowledge with academic theory, supporting both understanding and persistence in the programme. This may give the V-path students the possibility to share their knowledge instead of being a passive observer as stated by Mtshali [7]. By taking a more active role in the class, the students may be able to bridge the gap between the theoretical students, and the practical ones and help each other, reducing the likelihood of dropouts.

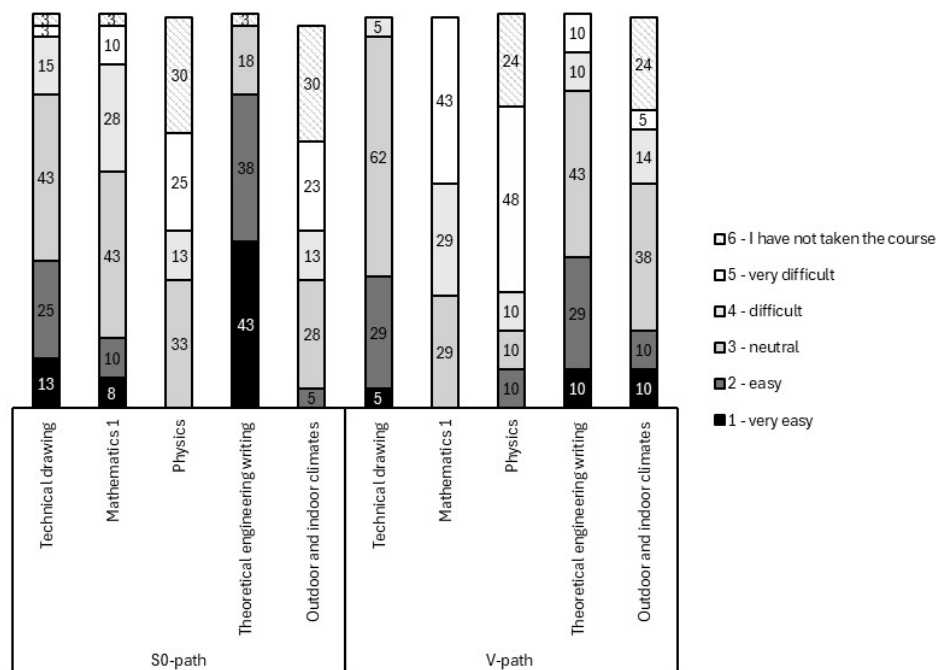


Figure 1. Response distribution in % regarding the perceived difficulty of the courses. Some courses are included in the figure based on the selection used in the analysis.

In more theoretically demanding subjects, however, the challenges faced by V-path students become more apparent. In Mathematics 1, as many as 72% of V-path students report the subject as difficult or very difficult, compared to 38% of SO students. A similar pattern is found in Physics, a subject characterised by a high degree of abstraction and theoretical reasoning, where 48% of V-path students describe the subject as very difficult, compared to 25% among students admitted through SO. Conversely, the results show that students from SO generally master theoretical skills to a greater extent, which reflects descriptions of Realistic personality types as struggling more with abstract theoretical levels compared to other personality types. In the theoretical engineering writing subject, 81% of SO students describe the subject as very easy or easy, and none report it as difficult. Among V-path students, however, 20% find this subject difficult or very difficult. This suggests that the transition from practical work to academic, abstract learning still represents a barrier for V-path students, despite dedicated admission pathways. This also underscores the research done by Ding et al. [4], who concludes that Realistic students (V-path) negatively correlate with GPA and struggle with the current assessment methods. At the same time, this may help explain why V-path students more frequently request support in the form of guidance, exercise sessions, and collaborative learning.

Differences in academic experiences must also be understood in light of students' life situations. There are clear differences in age and overall life circumstances between the two groups. Among V-path students, 57% are over the age of 26, compared to 19% of SO students. This indicates that V-path students are often more mature students with prior work experience. They tend to be more used to structured workdays and fixed working hours. Regarding housing and family situation, 30% of V-path students live alone or in shared housing with friends, while the rest are established with families. Among SO students, 61% live alone or in shared housing, while a smaller proportion have family responsibilities. This confirms that V-path students report spending more than 40 hours per week on their studies, compared to 23% of SO students. This may indicate that V-path students need to invest more time to cope with academic demands, particularly in theoretical subjects, while at the same time having less flexibility in their daily lives. These structural conditions also appear to influence students' satisfaction with the programme (Figure 2). Some differences are observed between the groups regarding overall satisfaction. Among V-path students, 53% report being satisfied or very satisfied with the programme, while 37% report being neutral. Students admitted through SO report higher satisfaction with the programme itself, with 71% being satisfied or very satisfied and only 20% reporting neutral satisfaction. This may have several explanations. V-path students are required to attend more scheduled teaching activities due to their academic background. SO students report that they find academic content easier to manage and have greater flexibility in their schedules. In contrast, V-path students are accustomed to fixed working hours, and evening lectures may therefore be challenging in relation to family life. In addition, students admitted through SO are generally more familiar with school-based tasks, as the majority enter directly from upper secondary school, making the transition to higher education easier. However, satisfaction with the learning environment is lower among SO students, with 63% reporting being satisfied or very satisfied. At the same time, as many as of V-path students 84% are satisfied or very satisfied with the learning environment. This suggests that although many V-path students experience academic challenges, they perceive the social and learning environment as overall positive.

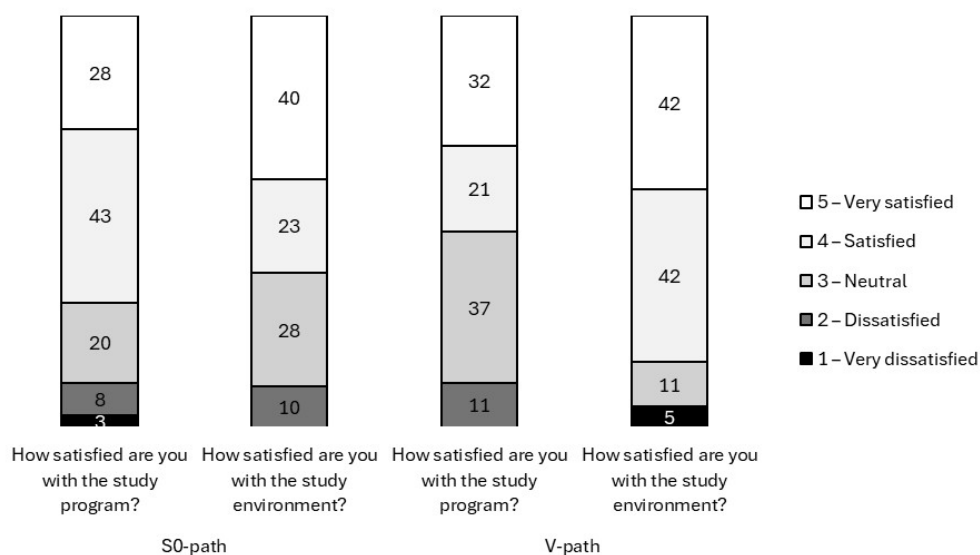


Figure 2. Response distribution (in %) to the questions “How satisfied are you with the study programme?” and “How satisfied are you with the study environment?”

Figure 3 shows the preferences for different elements of the study programme, categorised into prefer less, prefer more and satisfied. Differences emerge with respect to group work. Among V-path students, 37% wish for more group work, and none wish for less. In contrast, 23% of SO students want less group work, while only 15% want more. This may indicate that V-path students place greater value on collaboration as a learning strategy, particularly as support when dealing with theoretical subjects. These findings can be interpreted as reflecting different learning strategies and needs. For V-path students, group work may function both as academic support in theoretical subjects and as a familiar working method from professional practice. Their generally higher motivation and clearer goal orientation may

also help them manage group dynamics more effectively, rather than responding to difficulties by working alone or changing group members, which several students reported doing in a previous research conducted at UiA [8]. At the same time, differences in motivation and goal orientation between student groups may contribute to group work being perceived as less beneficial by SO students. Students admitted through SO report limited knowledge about the types of jobs civil engineers hold and how the construction industry functions. Some indicate that they chose the programme rather randomly and are not necessarily strongly interested in the field. This aligns with findings [8], showing that most students experience challenges in group work, including free riding, varying ambition and skill levels, and disagreements among group members, challenges that become more pronounced as students' progress through their studies. This is not reported as a challenge among V-path students, who are generally more dedicated, goal-oriented, and motivated to complete their degree. Such differences may lead to student groups with very different levels of motivation, which could partly explain why V-path students express a stronger preference for group work than SO students. Strong peer collaboration may also help explain why V-path students report higher satisfaction with the learning environment than SO students.

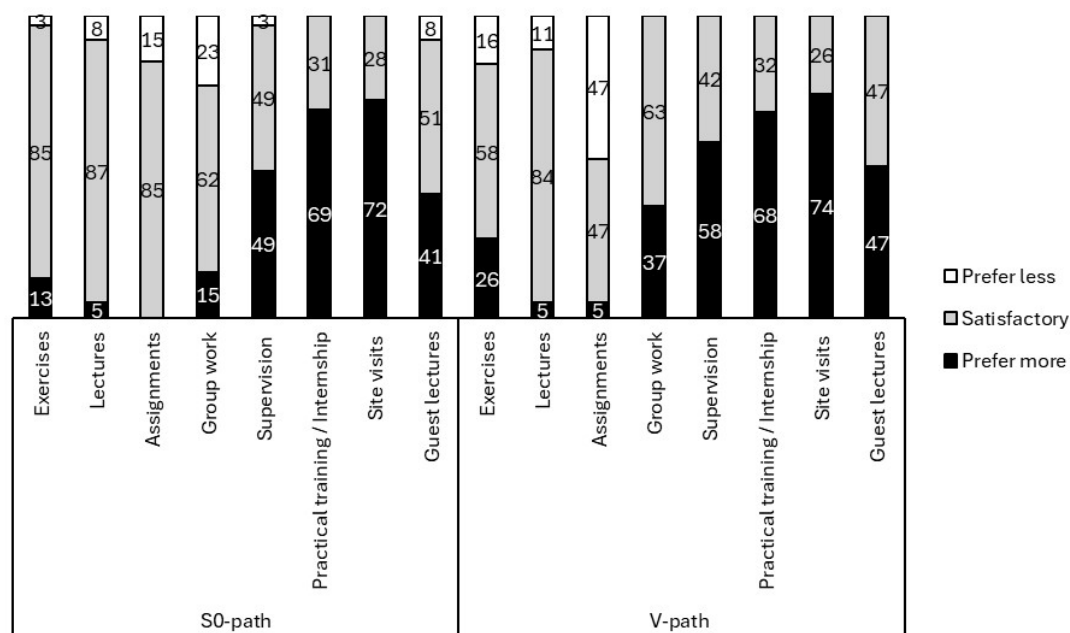


Figure 3. Preferences for different elements of the study programme

The results provide indications of which measures V-path students believe could contribute to improved learning outcomes and higher completion rates. A majority (58%) request more academic guidance, and 26% want additional exercise sessions. At the same time, 47% wish to have fewer mandatory assignments, which may be related to limited time resources and a high overall workload. Several V-path students also call for more student assistants or mentoring arrangements that can provide concrete support with assignments and exercises. Such initiatives may also help ease the transition from a practically oriented work background to a more academically focused learning environment.

Furthermore, our findings suggest that it is a need for increased flexibility in the study structure, particularly for students with family obligations. This includes the timing of lectures and the general availability of campus-based activities. Digital teaching materials are suggested as a potential means of increasing flexibility; however, some students express concern that extensive use of digital solutions could negatively affect the already strong learning environment. Students admitted through SO express somewhat different priorities. Many wish for less group work and more guidance, although to a lesser extent than V-path students. In addition, SO students want a clearer introduction to what engineers actually do in professional practice, as well as more practically oriented teaching related to how buildings are constructed. Since SO students report fewer difficulties with theoretical subjects, while V-path students have stronger insight into engineering practice, increased collaboration between the two groups could potentially benefit both. However, there is also a risk that students may be unwilling to

work together due to differences in motivation, expectations, and working styles, which could reduce the effectiveness of such collaboration if not carefully facilitated.

4 CONCLUSIONS

This study demonstrates that students with vocational and academic backgrounds bring different but complementary strengths to civil engineering education. V-path students benefit from extensive practical experience, which enhances learning, motivation, and engagement in construction-related subjects, and they place strong value on group work as a familiar and supportive working method. At the same time, they face significant challenges in theoretically demanding subjects such as mathematics, physics, and academic writing, consistent with research linking the Realistic personality type to difficulties in abstract, theory-based assessment systems. When combined with family responsibilities and limited flexibility, these challenges may increase the risk of dropout. Differences in students' structural conditions also influence overall satisfaction. While students admitted through SO report higher satisfaction with academic content and greater schedule flexibility, V-path students, despite experiencing more academic challenges, report particularly high satisfaction with the learning environment. This suggests that strong social integration and collaborative learning play an important role in supporting vocational students. Overall, the findings underline the need for flexible study structures, varied working methods, and targeted academic support that recognises diverse student backgrounds and leverage group work to strengthen both learning outcomes and persistence in engineering education.

Further studies need to be carried out in order to validate the results, given the small sample size and relatively short observation period. Additional methods could also be employed. For instance, this could include an examination of completed credits, grades, and completion rates among V-path and SO students. This study is currently based solely on self-reported data, and supplementary methods could contribute to a clearer understanding of the topic.

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CROSS-CULTURAL LEARNING IN ENGINEERING EDUCATION: A BINATIONAL CASE STUDY ON INTERCULTURAL COMPETENCE AND SUSTAINABLE POLYMER PROCESSING

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ABSTRACT

This paper presents educational outcomes from a binational case study involving Baden-Wuerttemberg Cooperative State University (DHBW Loerrach), Germany, and Universidad Politécnica de Querétaro (UPQ), Mexico. Six engineering undergraduates – three per institution – collaborated for approximately one year to optimise the processing of recycled polypropylene, guided by one professor from each institution. The project followed a hybrid model combining two intensive two-week residential phases (one at each partner institution) with extended digital collaboration via MS Teams, WhatsApp and email. Roles including project management, material analysis, production, simulation, experimental design and design tasks were deliberately distributed to create clear responsibilities. A post-project questionnaire (n = 6) captured student perceptions using Likert-scale and open-ended items. Given the small cohort, findings are interpreted as illustrative case evidence rather than statistically generalisable results. Students rated the face-to-face phases as highly helpful (mean 4.83/5) and hands-on experimental activities as equally valuable for understanding sustainable engineering (mean 4.83/5). Digital collaboration received more mixed feedback (mean 3.67/5), with open responses citing time-zone coordination and differing work rhythms as key challenges. Students reported substantial self-assessed gains in intercultural communication (mean 4.33/5) and awareness of cultural diversity in engineering practice (mean 4.67/5). Faculty reflections highlight the value of early alignment sessions and stricter work-package definitions for future iterations. This case study demonstrates how binational hybrid projects can make diversity a lived experience within engineering curricula, offering a replicable framework for sustainability-oriented, cross-cultural education.

Keywords: Engineering education, intercultural learning, project-based learning, digital collaboration, polymer recycling

1 INTRODUCTION

Engineering and product design education are increasingly expected to prepare graduates for work in culturally diverse, globally distributed teams tackling complex sustainability challenges. At the same time, educators seek formats that integrate authentic research experiences, digital collaboration, and explicit attention to equality, diversity and inclusion within already dense curricula.

Polymer recycling provides a concrete and industrially relevant context in which such demands intersect: engineers must optimise materials and processes under real-world constraints while considering environmental impact and circular-economy principles. Working with recycled polypropylene, in particular, exposes students to trade-offs between mechanical performance, processing parameters, and resource efficiency that are central to sustainable product and process design. Against this backdrop, a binational project was established between Baden-Wuerttemberg Cooperative State University (DHBW Loerrach) in Germany and Universidad Politécnica de Querétaro (UPQ) in Mexico, bringing together three German and three Mexican engineering students. The primary project goal was to address a research question in the field of polymer recycling by collaboratively optimising the processing of recycled polypropylene, supported by one supervising professor at each partner institution.

The project was designed as a long-term, hybrid learning experience spanning approximately one year, with the majority of collaboration taking place online and two intensive two-week face-to-face phases

hosted in Mexico and Germany. Within the student team, roles such as project management, material analysis, production, simulation, experimental design, and design-related tasks were deliberately distributed to ensure clear responsibilities and to mirror professional engineering practice in distributed project teams.

This paper reports on the educational outcomes of this binational project, with a particular focus on students' development of intercultural communication and collaboration skills, their understanding of sustainability and research methodology in polymer engineering, and their experiences with digital teamwork. Drawing on post-project questionnaire data from the six student participants and faculty reflections, the paper discusses how the project design supported or hindered these learning goals and reflects on implications for integrating similar cross-cultural, sustainability-oriented projects into engineering and product design curricula.

2 CONTEXT AND RELATED WORK

Project- and problem-based learning (PBL) has become a central pedagogical approach in engineering higher education, because it engages students in authentic design and research tasks and supports the development of teamwork, problem-solving and communication skills [1, 2]. Recent reviews of PBL in engineering underline that such formats are particularly powerful when they address complex, real-world challenges related to sustainability, international collaboration and professional practice [1]. International project-based courses in engineering further show that working in diverse, geographically distributed teams can deepen students' technical understanding while simultaneously fostering project management skills and confidence in global collaboration settings [3].

In parallel, universities increasingly emphasise the development of intercultural competence and global citizenship as explicit learning outcomes, using virtual exchange, global virtual teams and other online collaboration formats [4]. Studies on international or cross-cultural online projects report that carefully designed virtual teamwork, combined with guided reflection, can significantly improve students' intercultural awareness, attitudes towards diversity and readiness to work in multicultural engineering environments [4]. Research-based learning initiatives in industrial and engineering project management additionally highlight that involving students in authentic research questions strengthens their understanding of methodology, data analysis and the research–practice interface, especially when projects are embedded in real organisational or industrial contexts [5]. The binational recycled-polypropylene project discussed in this paper builds on these strands by combining PBL, international and intercultural teamwork, virtual collaboration and research-based learning around a concrete sustainability challenge in polymer recycling.

3 PROJECT DESIGN AND METHODOLOGY

The project was implemented as a binational collaboration between Baden-Wuerttemberg Cooperative State University Loerrach (DHBW Loerrach), Germany, and Universidad Politécnica de Querétaro (UPQ), Mexico. Six engineering undergraduate students participated, three from each institution, studying in fields such as mechanical engineering, mechatronics and advanced manufacturing. The technical focus of the project was the optimisation of processing conditions for recycled polypropylene in order to investigate how process parameters influence mechanical performance in a sustainability-oriented polymer recycling context.

The project spanned approximately one year and was designed as a hybrid learning experience with two intensive face-to-face phases and an extended online collaboration phase. One two-week residential phase was hosted at UPQ in Mexico and one two-week phase at DHBW Loerrach in Germany, providing opportunities for joint laboratory work, planning sessions and intercultural exchange. The intervening months were characterised by predominantly digital collaboration, using tools such as Microsoft Teams, WhatsApp and email for coordination, document sharing and synchronous or asynchronous meetings.

The overall structure of the binational hybrid project, including the two face-to-face phases and the extended online collaboration, is summarised in Figure 1.

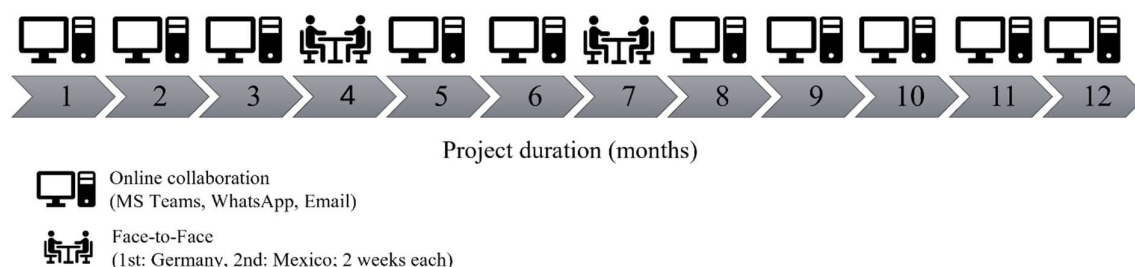


Figure 1. Overview of the hybrid binational project design

Within the student team, roles were deliberately distributed to mirror typical responsibilities in an industrial engineering project. Students took on functions such as overall project management, material characterisation, production and processing, simulation, experimental design and design-related tasks. This role allocation was intended to create clear lines of responsibility, foster ownership of sub-tasks and require students to coordinate their work across disciplinary and cultural boundaries. The project was jointly supervised by one professor at DHBW and one professor at UPQ, who provided guidance on both the technical polymer-engineering aspects and the collaborative processes.

To investigate the educational outcomes of this binational project, a small-scale case-study design was adopted. At the end of the project, a post-project questionnaire was administered to all participants in order to capture their perceptions of the project structure, their learning outcomes and their experiences of intercultural and digital collaboration. The survey consisted of Likert-type items using a five-point scale, covering the helpfulness of the face-to-face phases, the effectiveness of the digital collaboration phase, the clarity of research goals and experimental procedures, the usefulness of hands-on experimental and data-analysis activities, and perceived gains in intercultural communication, awareness of cultural diversity and preparedness for future sustainable engineering projects. In addition, open-ended questions invited students to describe main challenges in coordinating the project across countries and time zones, as well as key insights regarding research methodology and sustainability engineering. A potential source of response bias should be noted: as student participation and travel were financially supported by the Baden-Württemberg Stiftung, participants may have felt reluctant to provide critical feedback. The questionnaire was anonymous and voluntary, and open-ended items actively invited critique; nonetheless, this limitation should be kept in mind when interpreting the results. Quantitative items were analysed descriptively, calculating frequencies, means and standard deviations for each Likert-scale question. Qualitative responses were read repeatedly and coded inductively to identify recurring themes related to collaboration challenges, perceived benefits of the hybrid structure and students' reflections on research methodology and sustainability. The combination of descriptive statistics and thematic analysis provided a basis for interpreting how the project design supported or constrained the intended learning outcomes.

4 RESULTS

The post-project questionnaire yielded six responses from the student participants. Given the small cohort size, all findings are interpreted as case evidence only and do not support statistical generalisation. Overall, students rated the hybrid binational project very positively, particularly with regard to the intensive face-to-face phases at UPQ in Mexico and at DHBW Loerrach in Germany and the hands-on experimental work on recycled polypropylene.

Figure 2 summarises ratings for the main Likert-type items (five-point scale, 1 = very low, 5 = very high).

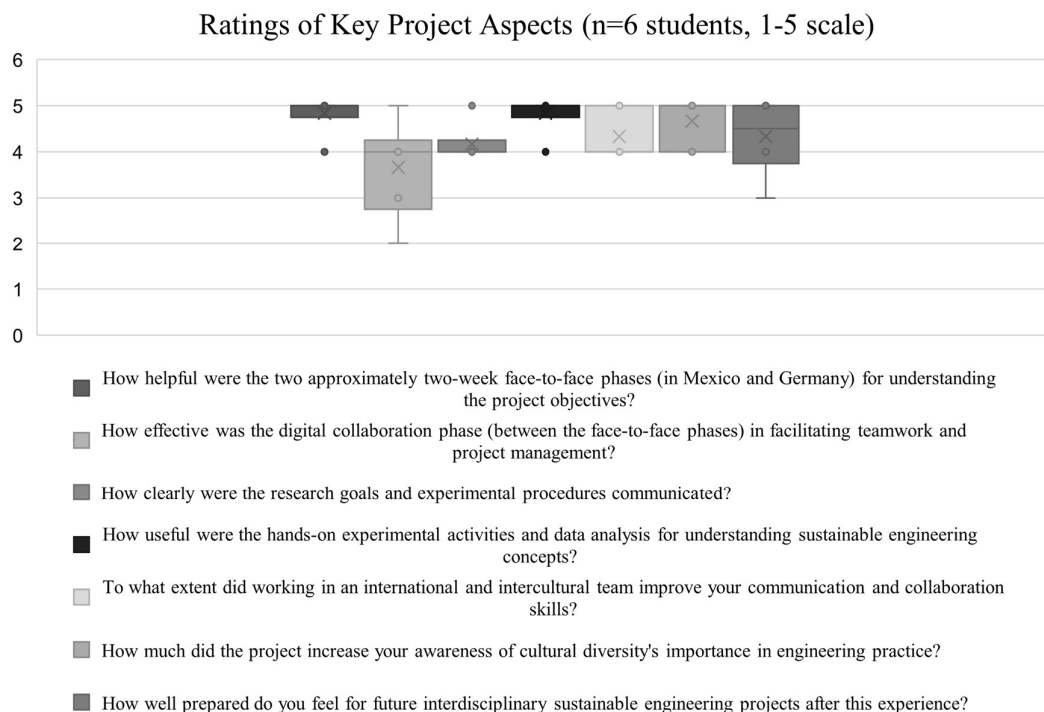


Figure 2. Descriptive statistics for key survey items (students only, five-point scale)

Students perceived the two approximately two-week face-to-face phases in Mexico and Germany as extremely helpful for understanding the project objectives (mean 4.83, range 4–5) and rated the hands-on experimental activities and data analysis as equally valuable for understanding sustainable engineering concepts (mean 4.83, range 4–5). Perceived clarity of the research goals and experimental procedures was also high (mean 4.17, range 4–5).

In contrast, experiences with the digital collaboration phase were more mixed. The mean rating of 3.67 (range 2–5) corresponds to a medium effect size relative to the neutral midpoint, suggesting that students overall saw online collaboration as somewhat effective, but with substantial variation between individuals. Open-ended responses highlight typical challenges of distributed collaboration, such as scheduling meetings across time zones, aligning different course loads and work rhythms, and perceived differences in reliability or work ethic between partners.

At the same time, students reported substantial perceived gains in intercultural and sustainability-related competencies. Based on the post-project survey, participants reported self-assessed improvements of approximately 36% in intercultural communication, 28% in confidence in scientific communication, and 33% in understanding of sustainability. These global gains are consistent with the high end-of-project ratings for items on intercultural communication and collaboration (mean 4.33, range 4–5), increased awareness of cultural diversity in engineering practice (mean 4.67, range 4–5), and preparation for future interdisciplinary sustainable engineering projects (mean 4.33, range 3–5).

Qualitative answers further illustrate these developments. Several students explicitly mentioned the Design of Experiments (DoE) approach as a powerful tool for planning and interpreting the experiments on recycled polypropylene and noted that working with real process parameters and material data deepened their understanding of how processing conditions influence mechanical behaviour and sustainability trade-offs. One student remarked that “seeing the actual material change under different settings made sustainability feel real, not just theoretical.” Others emphasised that collaborating in a mixed DHBW–UPQ team made cultural differences in communication styles, expectations and reliability visible, but also helped them to develop concrete strategies for addressing such challenges, such as clearer role definitions, a single central communication channel, and earlier in-person alignment. A recurring theme in open responses was the value of the residential phases as relationship-building moments: students noted that trust established face-to-face made subsequent online work considerably

smoother. From the faculty perspective, both supervising professors observed that the deliberate role distribution helped to maintain student ownership and momentum throughout the year-long collaboration. The DHBW supervisor noted the importance of establishing shared expectations for communication frequency and documentation standards during the first residential phase, while the UPQ supervisor highlighted that the mixed-discipline team composition – spanning mechanical engineering, mechatronics and advanced manufacturing – required explicit guidance on integrating diverse technical viewpoints. Together, the quantitative and qualitative findings suggest that the project effectively combined technical learning about polymer recycling with research-methods training and the development of intercultural collaboration skills in a realistic hybrid project setting.

5 DISCUSSION AND IMPLICATIONS

The findings from this binational hybrid project align with prior work on project-based learning (PBL) in engineering education, which consistently shows that authentic, hands-on tasks in real-world contexts foster deep understanding of technical concepts and research methodologies [1, 2]. The very high ratings for the usefulness of experimental activities and data analysis in understanding sustainable engineering concepts (mean 4.83) underscore how working with actual recycled polypropylene and process parameters made abstract sustainability principles tangible. These technical results, including the optimisation of mechanical properties through process-parameter variation, were published at IEEE TEMSCON Global 2025 [6]. Similarly, the strong perceived helpfulness of the two face-to-face phases (mean 4.83) confirms that intensive residential blocks provide critical opportunities for laboratory work, planning and relationship-building that cannot easily be replicated online [3].

The more mixed ratings for digital collaboration (mean 3.67), however, echo findings from global virtual team (GVT) and virtual exchange studies, which frequently report challenges with time-zone coordination, scheduling, and perceived differences in work rhythms and reliability [4, 5]. The qualitative responses mentioning meeting schedules and work-ethic differences illustrate these dynamics in a concrete engineering context. It is also important to acknowledge that students whose travel and participation were financially supported may have felt inclined to give more favourable feedback. While the open-ended items and anonymised format were designed to mitigate this, future iterations should consider independent evaluation approaches. At the same time, the high intercultural competence gains (mean 4.33) and increased diversity awareness (mean 4.67) suggest that the deliberate role distribution, joint supervision and structured hybrid format provided sufficient scaffolding to turn these challenges into learning opportunities.

These results have several implications for designing cross-cultural, sustainability-oriented projects in engineering and product design education. First, hybrid formats combining short intensive residential phases with extended online collaboration appear particularly effective for simulating distributed engineering practice while mitigating some limitations of purely virtual work. Second, clear role allocation and joint faculty supervision across institutions emerge as critical enablers for small, binational student teams to maintain momentum and address intercultural challenges productively. Third, embedding authentic research tasks such as polymer process optimisation within such projects creates powerful opportunities to develop both technical sustainability expertise and methodological competencies alongside soft skills.

Future iterations of this project will incorporate student suggestions such as earlier face-to-face alignment, a central communication platform and stricter work-package definitions to further improve the digital collaboration experience. The model also holds potential for scaling to larger cohorts or adaptation to other sustainability challenges in materials engineering and product design, provided that institutional partnerships and funding support (such as the Baden-Wuerttemberg Stiftung) remain in place.

6 CONCLUSION AND REFLECTIONS

This paper has presented the educational outcomes of a binational hybrid project in which six engineering students from Germany and Mexico collaborated for approximately one year to address a research question in polymer recycling. The project design, combining two intensive face-to-face phases with extended online collaboration, successfully fostered high levels of student engagement with both the technical content and the intercultural teamwork process.

The survey results provide clear evidence that students perceived substantial learning gains across multiple dimensions. The face-to-face phases and hands-on experimental work on recycled

polypropylene received the highest ratings, confirming their value for understanding sustainable engineering concepts and research methodologies. Students also reported strong improvements in intercultural communication skills and awareness of cultural diversity's role in engineering practice, despite acknowledging challenges in the digital collaboration phase such as time-zone coordination and differing work rhythms.

These findings demonstrate that carefully structured binational projects can make diversity and internationalisation tangible within core engineering curricula, rather than treating them as peripheral add-ons. The deliberate role distribution, joint supervision across institutions and hybrid format proved effective in supporting small student teams to navigate both technical complexity and intercultural dynamics productively.

Reflections from the supervising faculty highlight several areas for refinement in future iterations. While the residential phases provided irreplaceable opportunities for laboratory work and relationship-building, the digital phase would benefit from earlier face-to-face alignment, stricter work-package definitions and a single central communication platform to reduce coordination friction. Assessment strategies could also be enhanced by incorporating more frequent progress check-ins and peer-evaluation components to maintain accountability in distributed teams.

Limitations of this study include the small sample size ($n = 6$) from a single project cohort, which precludes statistical generalisation. The study is best understood as a case example highlighting lessons learned. Potential response bias due to funded participation is acknowledged. Future work will involve replicating the model with larger groups, incorporating independent evaluation methods, exploring longitudinal effects on students' career trajectories, and adapting the approach to other sustainability challenges in materials engineering and product design. Three key takeaways emerge for educators considering similar binational projects: first, a two-phase residential structure is highly effective for establishing trust and shared working norms before transitioning to extended online collaboration; second, clear role allocation from the outset, agreed jointly by faculty at both institutions, is essential for maintaining accountability and momentum in small distributed teams; and third, embedding an authentic technical research question creates synergy between sustainability learning, research-methods training and intercultural competence development, making all three goals mutually reinforcing rather than competing. The project thus offers a replicable framework for engineering educators seeking to integrate sustainability research, intercultural competence and digital collaboration into their curricula, with diversity becoming a lived experience rather than an abstract curriculum objective.

ACKNOWLEDGEMENTS

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FROM DIVERGENCE TO CONVERGENCE: A STUDY ON THE CO-CREATIVE PROCESS OF MULTICULTURAL TEAMS ADDRESSING SOCIAL DESIGN ISSUES

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ABSTRACT

This study explores how multicultural student teams transform culturally grounded divergence into integrative design outcomes when addressing social loneliness. Drawing on a six-month Global Project-Based Learning (PBL) programme involving Japanese and Estonian students, the research integrates cultural framing theory, relational reconciliation, boundary object mediation, and intergenerational capital. Using a qualitative case study supported by survey data, it identifies a non-linear three-phase process: culturally distinct problem framing, artifact-mediated negotiation with emergent cultural brokers, and convergence through hybrid integration rather than compromise. Findings reveal that generational differences created greater difficulty during solution development than cultural differences, while intensive face-to-face interaction strengthened trust and communication. The proposed Multilayered Reconciliation Model conceptualises cultural diversity as an epistemic resource activated through relational infrastructure, demonstrating how divergence can generate innovation in societal design collaboration.

Keywords: Multicultural co-creation, societal design, loneliness, cultural framing

1 INTRODUCTION

Loneliness has become a pressing social issue across societies shaped by aging populations, digital mediation, and shifting family structures. Yet loneliness is not merely an individual psychological state; it is culturally embedded in norms of belonging, autonomy, and relational obligation. In collectivist contexts, it may be framed as social withdrawal or failure of communal integration. Whereas in individualist contexts, it is often understood as emotional isolation despite structural independence. Such culturally situated interpretations shape problem definitions, responsibility, and intervention logics.

Multicultural Project-Based Learning (PBL) has emerged in design education to cultivate culturally sensitive innovation. PBL is an educational approach in which learners collaboratively address complex real-world problems through iterative inquiry and practical implementation. However, while diversity can enhance creativity, it may also generate misunderstanding, negotiation friction, and power asymmetries. The key paradox remains: how does cultural divergence become integrative innovation rather than fragmentation?

Existing research often treats culture as a static variable and focuses on communication barriers or outcome measures, leaving micro-process mechanisms underexplored. This study addresses that gap by examining how multicultural student teams reconcile divergent framings of loneliness through relational mediation, boundary objects, and generational dynamics, proposing a Multilayered Reconciliation Model of integrative convergence.

2 LITERATURE REVIEW

Cross-cultural collaboration is frequently associated with enhanced creativity and innovation, particularly in complex design contexts. Early cultural dimension theory conceptualised culture as a relatively stable attribute shaping communication styles and decision-making patterns [1]. While influential, such models risk essentialising actors and overlooking situational variability. In contrast, Swidler [2] reconceptualised culture as a dynamic interpretive “toolkit” activated through interaction. In design collaboration, this perspective highlights how culturally embedded problem framings shape

divergent understandings of social issues. Problem framing is central to design practice [3], especially in societal challenges such as loneliness, where relational norms and moral assumptions vary across contexts. Loneliness may therefore be interpreted differently depending on cultural expectations surrounding belonging and interpersonal relationships.

Research on team diversity presents a well-known paradox. The information/decision-making perspective argues that diversity enhances cognitive resources and creativity [4], whereas social identity theory emphasises risks of fragmentation through in group dynamics [5]. Yet both perspectives often treat diversity as an input and performance as an outcome, neglecting the relational processes that mediate between them. Trust and psychological safety have been identified as enabling conditions [6] but trust alone does not explain how epistemic divergence becomes integrative innovation.

Within design education, globally networked collaborative learning has been discussed as an approach for fostering intercultural collaboration and distributed co-creation [7]. However, previous studies have primarily focused on communication and coordination challenges, leaving the reconciliation process through which divergent cultural framings become integrated outcomes relatively underexplored.

Relational reconciliation provides a process-oriented lens by conceptualising difference as a dialogical resource rather than a problem to suppress [8]. In design contexts, reconciliation unfolds through iterative reinterpretation of problem definitions and solution criteria, aligning with theories of knowledge co-production [9]. Boundary object theory further specifies material mediation: artifacts flexible across social worlds enable shared reference without full consensus [10]. Cultural brokerage complements this process, as liminal individuals translate meanings across contexts [11]. Finally, intergenerational capital highlights how age and experience structure authority gradients during convergence [12].

Integrating these perspectives, this study conceptualises multicultural societal design collaboration as a multilayered reconciliation process structured by cognitive, relational, material, and structural dynamics. The proposed Multilayered Reconciliation Model integrates these dimensions to explain how multicultural teams move from divergence toward integrative convergence.

3 CONCEPTUAL FRAMEWORK AND METHOD

3.1 Conceptual framework: the Multilayered Reconciliation Model

This study proposes the Multilayered Reconciliation Model to explain how multicultural teams transform culturally grounded divergence into integrative design outcomes. The model rests on three assumptions: cultural difference appears primarily as variation in problem framing rather than direct conflict; integration emerges through relationally mediated synthesis rather than compromise; and convergence is influenced not only by cultural dynamics but also by generational and experiential capital.

3.2 Research design

This study adopts a qualitative case study methodology to examine the processual dynamics of multicultural co-creation within a bounded educational setting. Case studies are appropriate for investigating complex, context-dependent phenomena. Global PBL environments exemplify such conditions. Rather than aiming for statistical generalisation, the study pursues analytical generalisation by refining theoretical propositions through in-depth empirical analysis. The case involves a six-month Global PBL programme (Figure 1).

Japanese and Estonian university students collaboratively designed interventions addressing social loneliness. The programme included six workshops: online collaboration through Miro and Discord, a four-day intensive face-to-face workshop, and a final presentation and reflection phase. Teams defined loneliness in both contexts, conducted research, generated concepts, and developed prototypes.

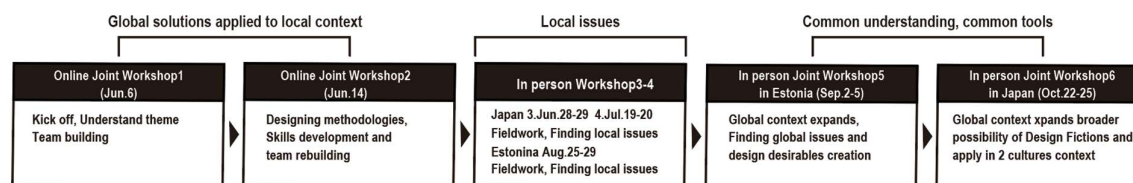


Figure 1. Global PBL programme

3.3 Data collection

Data for this study were collected from two primary sources: semi-structured interviews and a post-programme survey administered at the end of the Global PBL programme. The interviews explored participants' experiences with cross-cultural teamwork, perceived challenges, communication processes, and reflections on collaboration. All interviews were recorded and transcribed verbatim. Observational data (Figure 2) from the various workshops conducted during the programme were also collected and analysed.

The post-programme survey consisted of Likert scale items and open-ended questions designed to assess teamwork satisfaction, perceived cultural and generational challenges, and reflections on communication and collaborative processes. Although the wider programme included students from multiple cultural backgrounds, the present study includes only the survey and interview data from five Estonian students (E_A–E_E) and six Japanese students (J_A–J_F). Responses from other international participants were excluded to maintain analytical coherence and allow direct comparison between the two focal cultural groups.

All participants gave informed consent. Participation was voluntary, and identifiers were anonymised using coded labels to protect confidentiality while preserving analytical relevance.



Figure 2. Global PBL observational data: discussions, pitches, and whiteboards

3.4 Data analysis procedure

A thematic analysis was conducted in three iterative stages to examine the longitudinal dynamics of multicultural collaboration. First, open coding was applied to qualitative materials—including interview transcripts and open-ended survey responses—to identify expressions of cultural framing, perceived misunderstandings, negotiation strategies, mediation practices, and moments of convergence. Second, axial coding organised these codes according to the divergence–negotiation–convergence process described in the conceptual framework, enabling systematic comparison of meaning shifts across phases. Third, selective coding identified core reconciliation mechanisms, such as boundary object mediation, cultural brokerage, and trust formation, that accounted for movement from divergence toward integrative outcomes. Coding categories were refined iteratively to ensure alignment with the Multilayered Reconciliation Model.

The survey included 12 items divided into four domains: (1) participant background (Q1), (2) cross cultural and teamwork evaluations (Q2–Q3), (3) perceived difficulty related to cultural and generational differences (Q4–Q7), and (4) qualitative reflections on cultural, generational, and linguistic challenges (Q8–Q12).

For analytical purposes, survey items were grouped according to the process phases:

- **Divergence** (Q4, Q6)
- **Negotiation/Translations** (Q5, Q8, Q10, Q11)
- **Convergence** (Q2, Q3)
- **Generational comparison** (Q4 vs. Q6; Q5 vs Q7)

Descriptive statistics were used to examine patterns of perceived difficulty and satisfaction. Correlation analysis explored relationships between cross cultural functioning and convergence related outcomes. Quantitative patterns were interpreted alongside qualitative narratives to validate the identified process phases and underlying reconciliation mechanisms.

Credibility was enhanced through triangulation of interviews, surveys, and observational data. Member reflections were incorporated to support interpretive accuracy, and reflexive memoing documented researcher positionality. Analytical decisions were systematically recorded throughout the process.

4 RESULTS

4.1 Divergence: cultural and generational framing

The initial phase of collaboration was characterised by divergence in how loneliness was conceptualised. Survey responses to Q4 indicated moderate difficulty in identifying common loneliness issues across cultural backgrounds, suggesting early awareness of interpretive gaps. Interestingly, responses to Q6 showed comparable or slightly higher perceived difficulty in identifying issues across age and experience levels, indicating that divergence was not exclusively cultural but also generational. Qualitative evidence suggests that divergence manifested primarily in problem framing rather than interpersonal conflict. Japanese participants tended to situate loneliness within collective belonging and social withdrawal. One participant explained, “In Japan, loneliness is often hidden. People feel pressure to belong, and when they cannot, they isolate themselves.” (J_A). Another noted, “It is connected to social expectations and being part of a group. If you step outside, you feel alone.” (J_C).

By contrast, Estonian participants framed loneliness more as an individual, emotional disconnection. As one student described, “In Estonia, people are independent, but that independence can create emotional distance.” (E_B). Another reflected, “Loneliness is not about failing to belong, but about not feeling understood.” (E_C). These narratives reveal divergent relational logics: one centred on collective integration and obligation, the other on personal emotional recognition. Importantly, these differences were not reported as conflictual. Rather, they coexisted as parallel interpretive orientations that expanded the epistemic scope of the project. Generational divergence also emerged during this stage. Participants with more design education demonstrated urgency toward structuring and narrowing the problem, while less experienced members explored meanings more openly. As one participant stated, “Some of us wanted to move to solution mapping quickly, but others kept questioning what loneliness really meant.” (E_B). The divergence phase thus broadened conceptual space before convergence pressures intensified.

4.2 Negotiating and translation: mediating differences

The second phase involved active negotiation. Survey responses to Q5 indicated moderate difficulty in creating solutions across cultural backgrounds, and Q10 responses revealed that English communication posed additional challenges. Language limitations shaped collaborative interaction. An Estonian participant observed, “Sometimes we simplified ideas too much because explaining complex emotions in English was difficult.” (E_A). A Japanese participant similarly reflected, “I felt I could not express subtle cultural meaning. I worried that my explanation sounded too simple.” (J_D). However, linguistic constraints simultaneously catalysed reliance on visual and material artifacts. Shared storyboards, sketches, and prototypes functioned as mediating tools. As one participant described, “When we started drawing together on Miro, misunderstandings reduced.” (E_C). Another noted, “The storyboard helped us see that our ideas were not opposite but just focused on different aspects.” (J_B). These artifacts externalised implicit assumptions and shifted discussion from abstract debate to collaborative modification. Through iterative co-editing, culturally embedded meanings became visible and negotiable.

Within this negotiation phase, certain individuals emerged as cultural brokers. These participants translated not only language but also interpretive nuance. One respondent remarked, “She helped explain what ‘social obligation’ means in Japan in a way we could understand.” (E_B). Another commented, “He rephrased Estonian perspectives, so we did not misunderstand them as being cold.” (J_A). Broker roles were not formally assigned but organically assumed, often by individuals with greater international exposure or linguistic fluency. Yet brokerage entailed emotional labour. As one participant admitted, “I sometimes felt responsible for keeping the conversation smooth.” (E_A). This suggests that brokerage functioned as relational infrastructure, stabilising trust but unevenly distributed. Generational dynamics intensified during solution development. Comparison of Q5 and Q7 indicated that age-related differences were perceived as slightly more challenging during convergence stages. Participants reported tensions between experimentation and feasibility: “Senior members were cautious about feasibility, while younger members wanted bold ideas.” (E_D). Another reflected, “There was tension between experimenting and refining.” (J_C). Cultural divergence dominated early framing, whereas generational capital shaped decision thresholds during prioritisation.

4.3 Convergence: hybrid integration

Despite negotiation challenges, overall teamwork satisfaction (Q2) and perceived cross-cultural functioning (Q3) were high. Convergence was experienced positively rather than as forced compromise. Participants repeatedly described final outcomes as hybrid constructs integrating plural logics. One noted, “Our final concept combined community events with private reflection spaces.” (J_B). Another reflected, “It was neither Japanese collectivism nor Estonian individualism, it was something between.” (E_C). Rather than eliminating divergence, teams synthesised it into layered design solutions. For example, one concept combined small in-person gatherings (reflecting collective integration) with personalised digital journaling (reflecting individual introspection). Convergence thus embodied integrative reconciliation rather than assimilation. Face-to-face interaction during the intensive workshop played a decisive role in this transition. Participants emphasised the rapid strengthening of relational trust: “After meeting in person, trust increased quickly.” (J_A). Another stated, “Online we were careful, but in person we could read expressions and build confidence.” (E_B). Enhanced trust enabled more direct and constructive disagreement without escalation. Importantly, convergence did not erase underlying difference. As one participant acknowledged, “We still see loneliness differently, but we created something that respects both views.” (E_C). This suggests integration without homogenisation.

4.4 Cross-phase patterns

Across the six-month period, the collaboration unfolded iteratively rather than linearly. Cultural divergence was most visible in early framing stages, expanding its interpretive range. Generational divergence became more influential during solution prioritisation and convergence. Language functioned both as constraint and catalyst, limiting nuance but encouraging visualisation. Boundary objects and emergent brokers stabilised negotiation and enabled synthesis. Overall, the empirical pattern supports the conceptualisation of multicultural co-creation as a multilayered reconciliation process. Divergence expanded epistemic possibility; negotiation translated and externalised assumptions; convergence integrated plural logics into hybrid outcomes. Trust infrastructure and material mediation functioned as stabilising mechanisms, while generational capital shaped convergence dynamics.

5 DISCUSSIONS

This study examined how multicultural student teams transformed culturally grounded divergence into integrative design outcomes while addressing the socially embedded issue of loneliness. The findings suggest that cultural difference should not be conceptualised primarily as a source of interpersonal conflict, but as epistemic activation. During the divergence phase, Japanese and Estonian participants articulated distinct relational framings of loneliness—one emphasising belonging and social obligation, the other highlighting autonomy and emotional recognition. These differences expanded the interpretive space of the design problem rather than generating antagonism. Culture functioned as a situationally activated framing repertoire that shaped problem definition without rigidly determining collaborative trajectories.

The movement from divergence to convergence required structured mediation. Boundary objects, such as storyboards, visual maps, and rapid prototypes, played a critical role in externalising tacit assumptions. By shifting interaction from abstract linguistic negotiation to shared artifact modification, teams were able to reframe differences as complementary rather than oppositional. Language constraints, particularly operating in English as a second language, reduced expressive nuance but simultaneously encouraged visual communication. This paradoxical dynamic suggests that linguistic limitation can catalyse artifact-centred collaboration, strengthening material mediation within multicultural design processes.

The emergence of cultural brokers further stabilised negotiation. These individuals translated interpretive meanings and facilitated mutual recognition across cultural contexts. However, brokerage labour was unevenly distributed and occasionally experienced as emotionally demanding. This indicates that reconciliation is not purely cognitive but relationally sustained, requiring attention to invisible mediation work within teams. Integrative outcomes depended not only on tools but also on relational infrastructure.

Convergence did not occur through compromise or reduction to a lowest common denominator. Instead, hybrid solutions emerged that embedded plural cultural logics within shared design systems. Teams combined collective-oriented interventions with individualised reflective elements, demonstrating that

integrative synthesis can preserve differences while producing coherent outcomes. Trust was strengthened through face-to-face interaction and proved essential in enabling constructive disagreement and deeper integration. Convergence should therefore be theorised as hybridisation facilitated by relational trust, rather than mere agreement.

A notable contribution concerns the role of generational and experiential capital. Survey patterns indicated that age and experience differences posed greater challenges during solution development than cultural differences. Cultural divergence expanded problem framing, while generational gradients shaped convergence thresholds, particularly in prioritisation and feasibility evaluation. This suggests that multicultural collaboration operates across multiple axes of diversity simultaneously. Cultural plurality activates epistemic range, whereas generational capital structures decision-making dynamics. Together, these findings support the Multilayered Reconciliation Model, which conceptualises multicultural societal design collaboration as a recursive alignment of cognitive framing, relational trust, material mediation, and structural capital. Innovation emerges when these layers interact constructively. Rather than managing diversity as risk, educators and facilitators should design conditions that enable integrative reconciliation.

This study therefore reframes multicultural collaboration not primarily as communication management, but as a reconciliation process supported through relational trust, material mediation, and hybrid integration.

6 CONCLUSIONS

This research demonstrates that multicultural societal design collaboration progresses not from difference to sameness, but from divergence to reconciliation. Cultural framings activate plural epistemic perspectives that expand interpretive space. Through artifact-mediated negotiation, emergent brokerage, and trust-building conditions, these perspectives are integrated into hybrid design outcomes. Generational and experiential differences further shape convergence thresholds, underscoring the multilayered character of collaborative diversity.

The Multilayered Reconciliation Model reframes multicultural collaboration from conflict management to reconciliation design. Rather than minimising difference, effective co-creation structurally supports its integration. In addressing socially embedded issues such as loneliness—where ethical nuance and cultural sensitivity are paramount innovation emerges not from compromise but from creative reconciliation.

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PEDAGOGICAL INNOVATION: A LABORATORY FOR COLABORATIVE AND INCLUSIVE DESIGN

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ABSTRACT

This study describes the design and implementation of a Pedagogical Innovation Space (PIS) in a higher education institution. Designed to be dynamic and inclusive, the PIS fosters experimentation, collaboration and cultural diversity across disciplines such as engineering and design. It operates as an educational laboratory in which teachers, students and researchers collaborate to create and test solutions using user-centred and challenge-based methodologies. Inspired by Design Thinking and grounded in experiential and project-based learning principles, the PIS integrates multiple functional areas — creative, collaborative, research, interactive, development and presentation — to support transitions between ideation, experimentation, reflection and knowledge sharing. By linking physical and digital environments, the PIS fosters active, autonomous and collaborative learning, thereby enhancing technical, creative, social and empathetic skills. Design Thinking guides the transformation of traditional teaching models through its human-centred stages of empathy, definition, ideation, prototyping, testing and continuous evaluation, enabling innovative responses to complex and diverse educational contexts. The project adopts inclusive and participatory design practices that are in line with contemporary collaborative design education trends, making equality, diversity, and inclusion (EDI) core principles. Ultimately, the PIS aims to serve as a reference model integrating education, design, and diversity to prepare future professionals to develop more human-centred, collaborative, and inclusive solutions.

Keywords: Pedagogical innovation, design thinking, learning spaces, active learning, inclusion

1 INTRODUCTION

The rapid evolution of digital technologies has redefined technical education. The integration of these tools in the PIS is specifically designed to support the iterative prototyping and technical visualisation required in engineering and product design curricula. Unlike traditional classrooms, this space allows for a seamless transition between conceptual sketching and digital modelling, which is essential for modern design education [1]. The PIS operates as a dynamic laboratory where students and researchers collaborate to test solutions using user-centred methodologies. In this context, 'diversity' is addressed through two complementary dimensions to ensure a truly inclusive environment. First, it encompasses 'interdisciplinary diversity,' promoting active collaboration between students from distinct fields like engineering and design to solve complex problems. Second, it integrates 'functional and inclusive diversity' (EDI – equity, diversity, and inclusion), ensuring that physical layouts and digital tools are adaptable to different learning needs and physical abilities [2]. By defining diversity in this dual manner, the PIS moves from a generic concept to a structural principle that informs both spatial design and pedagogical practice. design thinking guides this transformation through its human-centred stages—empathy, definition, ideation, prototyping, and testing—enabling continuous evaluation of pedagogical effectiveness [3]. By linking physical and digital environments, the PIS fosters active learning and enhances the technical and empathetic skills necessary for future professionals. This study argues that the PIS serves as a critical pedagogical enabler by transitioning from lecture-based models to student-centred learning landscapes. The paper is organised as follows: Section 2 details the design thinking phases; Section 3 analyses the spatial diagnostics and conceptual design; and Section 4 presents the

expected outcomes and conclusions.

2 DESIGN THINKING METHODOLOGY FOR THE PIS

The development of the PIS is grounded in a hermeneutical application of Design Thinking (DT), serving as an interpretive bridge between educational needs and spatial solutions. DT is a highly effective active methodology for enhancing student engagement and developing the social and technical skills required in 21st-century education [4]. Rather than a linear sequence, this study adopts DT as a dynamic framework that informs decisions regarding interior design, technological integration, and collaborative practices [5] Following the human-centred principles established by Brown [6], the project was organised into iterative phases:

- **Empathy and Definition:** Qualitative data from focus groups and spatial diagnostics were interpreted to identify gaps in traditional lecture-based models, ensuring a deep understanding of diverse users—students, teachers, and researchers [7]
- **Ideation and Prototyping:** Drawing on Sawyer's (2012) [3], principles of creative innovation, insights were translated into tangible modular zones. This phase focused on the pedagogical benefit of seamless transitions between conceptual sketching and digital modelling.
- **Testing and Validation:** This stage ensured that the proposed solutions aligned with the institution's Equity, Diversity, and Inclusion (EDI) goals, promoting the continuous adaptation of spaces to a rapidly evolving global context [8].

By linking physical and digital environments through this methodology, the PIS fosters a culture of active and interdisciplinary learning, allowing stakeholders to collaboratively engage with real-world challenges (Costa & Barreto, 2024).

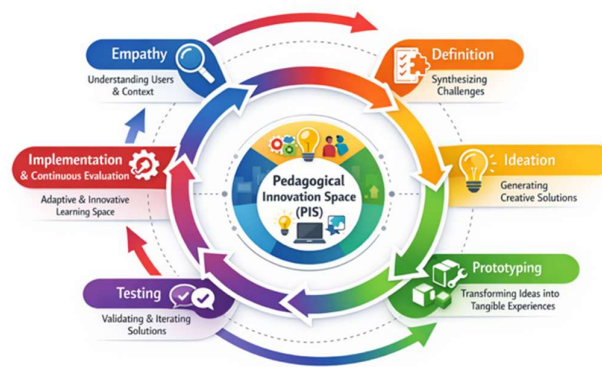


Figure 1. Design Thinking methodology applied to the Pedagogical Innovation Space

Figure 1 illustrates the structured and iterative Design Thinking process applied to the development of the PIS. Organised into six interconnected phases—Empathy, Definition, Ideation, Prototyping, Testing, and Implementation/Evaluation—the circular layout emphasises the non-linear nature of this methodology and its capacity for continuous refinement. In the Empathy and Definition stages, qualitative tools such as focus groups and spatial diagnostic panels were used to frame the pedagogical challenges of existing traditional layouts. The Ideation and Prototyping phases focused on generating spatial configurations that support active learning principles, such as 'Flipped Classroom' and 'Project-Based Learning' (PBL), ensuring the physical environment acts as a catalyst for creative problem-solving. Finally, the Testing and Validation stages involved stakeholder feedback to refine the modular zones, ensuring alignment with Equity, Diversity, and Inclusion (EDI) standards. This hermeneutical approach reinforces Design Thinking as a reflective framework for creating innovative, technology-enhanced learning environments

3 DESIGNING SPACES FOR ACTIVE LEARNING

The data collection methods and techniques are primarily applied to the case study classroom at the School of Education of the Polytechnic Institute of Viana do Castelo (IPVC), which is one of the six schools that constitute the Polytechnic Institute of Viana do Castelo. The remaining five schools are the School of Agriculture, the School of Technology and Management, the School of Health, the School of

Business Sciences, and the School of Sport and Leisure. This provides the empirical basis for defining parameters that can be transferred to the other spaces analysed. The classroom is predominantly used by undergraduate and master's students, faculty members who employ both lecture-based and collaborative teaching practices, and informal groups that occupy the space during free periods. Its use is intensive, characterised by frequent transitions between classes, prolonged group activities, and a recurring need to reorganise the furniture, which is rigid and poorly adaptable. Although the room dimensions (12.05 m × 6.54 m, with a total area of 78.81 m²) are suitable for medium-sized classes, they are insufficient for certain active learning dynamics without spatial reconfiguration. Photographic record of the analysed classroom, highlighting fixed furniture and limited flexibility (Figure 2).



Figure 2. Existing classroom conditions (Education School of IPVC)

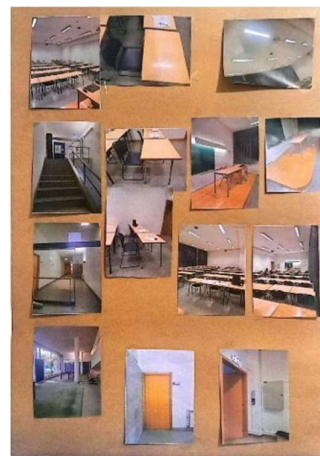


Figure 3. Spatial diagnostic panel

Natural lighting is provided by two large windows with opaque curtains for light control, while the artificial lighting, though uniform, lacks the comfort required for intensive reading and writing. The existing furniture is fixed, consisting of individual desks and rigid chairs without casters, which significantly limits mobility. This layout reinforces a traditional lecture-based model, contrasting with the needs for flexibility and ergonomics discussed previously. Photographic documentation was conducted systematically to record circulation flows and spatial conflicts, providing empirical data that complement the research (Figure 3). Based on these records, a spatial diagnostic panel was developed to synthesise identified problems and opportunities. This panel serves as an intermediate tool between empirical observation and the design phase, organising functional and behavioural information to inform the new layout. The PIS is conceived as a contemporary educational ecosystem designed to address challenges such as digital transformation and diverse learner profiles. Recent research highlights that both physical and digital environments significantly influence engagement and learning outcomes [8],[9]. The PIS is specifically architected to facilitate active learning strategies that, although established in theory, require specialised spatial affordances to be effective. By integrating modular layouts and high-tech infrastructures, the space provides the flexibility for Project-Based Learning (PBL) and Flipped Classroom models, which are frequently constrained by rigid, traditional settings. Current literature emphasises that flexible spaces are critical enablers of pedagogical innovation [10],[2]. Collaborative learning areas (Figure 4) feature modular furniture and interactive technologies that foster teamwork and knowledge co-construction [11]. These zones support both individual expression and co-creation through activities like brainstorming and prototyping, encouraging divergent thinking and innovation [3]. Equipped with tools such as 3D printers and interactive panels, students can translate theoretical knowledge into practical outputs, iterating and refining ideas in a low-risk, experiential setting.



Figure 4. Collaborative learning areas

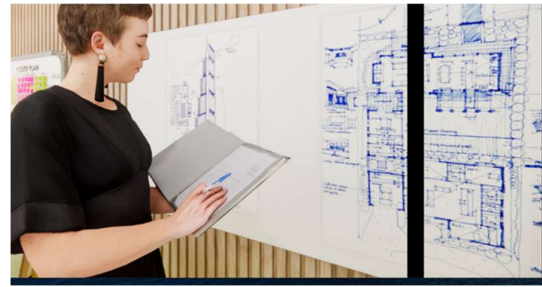


Figure 5. individual work and concentration

In parallel, the PIS incorporates zones dedicated to individual work and concentration (Figure 5), acknowledging the importance of self-regulated learning, critical reflection, and autonomous study in achieving deep and sustained learning. These spaces support individual research and inquiry-based activities, particularly within hybrid learning contexts that combine online and face-to-face components [11]. Designed for autonomous study, investigation, and reflection, this area provides a quieter and more controlled environment. It offers conditions conducive to focused activities such as reading, academic writing, and individual project development. Students are encouraged to explore independently, acting as active researchers who learn through practice rather than passive listening. Teachers can facilitate inquiry- and project-based learning, aiming to enhance students' analytical skills and critical thinking.



Figure 6. Pedagogical experimentation and prototyping areas



Figure 7. Technological and multimedia support areas

A distinctive feature of the PIS is the inclusion of pedagogical experimentation and prototyping areas (Figure 6), conceived as living laboratories for educational innovation. These spaces enable teachers and researchers to test new pedagogical approaches, digital resources, and emerging educational technologies—including artificial intelligence-enhanced tools and immersive learning environments—within a framework of action research and continuous improvement [12], [1]. Additionally, these areas can serve as flexible meeting spaces, supporting collaborative discussions, workshops, and planning sessions among educators and research teams. The PIS integrates technological and multimedia support areas (Figure 7) not merely as infrastructure for equipment, but as a dedicated environment for 'learning by design' and active knowledge construction. These areas enable students to transition from passive consumers to active creators of educational content, such as videos and podcasts. Also, the pedagogical value of multimedia production lies in the externalisation of thought; by restructuring complex information to communicate it through different media, students engage in deeper cognitive processing and synthesis [13]. Furthermore, this production-oriented approach fosters 'digital agency'—a critical competency in modern engineering and design education—ensuring that students develop the technical and reflective skills to solve real-world challenges through diverse representational formats.



Figure 8. Examples of informal meeting and socialisation spaces

Informal meeting and socialisation areas (Figure 8) are essential for promoting well-being and the development of 'communities of practice.' These environments facilitate spontaneous knowledge exchange and interdisciplinary collaboration, fostering a sense of belonging that is critical for sustainable pedagogical innovation and student success [14], [2]. In conclusion, the PIS represents a dynamic and flexible learning ecosystem aligned with international trends in educational transformation. By strategically integrating space, pedagogy, and technology, the PIS moves beyond traditional instruction toward active, learner-centred approaches. This model not only supports the immediate needs of Engineering and Design curricula but also contributes to the long-term quality, relevance, and sustainability of teaching and learning processes in higher education.

4 CONCLUSIONS AND FUTURE WORK

The development of the PIS marks a strategic shift from traditional, rigid educational settings to a dynamic, flexible and inclusive learning ecosystem. This research shows that shifting from conventional lecture-based models to active, collaborative learning environments requires a robust methodological framework based on Design Thinking principles. This approach ensures that spatial, pedagogical, and technological solutions remain genuinely user-centred and responsive to users' needs. An empirical analysis conducted in a classroom at the School of Education of the Polytechnic Institute of Viana do Castelo, used as a case study, highlighted that fixed furniture and limited spatial adaptability can restrict collaboration, experimentation, and the iterative processes, which are all essential in design and engineering education. In response, the PIS incorporates designated areas for collaboration, independent study, pedagogical experimentation and multimedia production. This configuration fosters co-creation, rapid prototyping and reflective learning, supporting the construction of both individual and collective knowledge. Equality, diversity and inclusion (EDI) are positioned as core principles of the project. The PIS was designed to ensure accessibility, participation and adaptability in response to the increasing diversity and complexity of contemporary higher education contexts, promoting inclusive learning experiences for all users. Although this study focused primarily on the conceptual design and initial implementation of the PIS, future work should place greater emphasis on the testing and validation phases of the design thinking methodology. Systematic testing of spatial layouts, pedagogical scenarios, and technological tools in real educational settings is essential for assessing usability, learning effectiveness, inclusivity, and user satisfaction. Longitudinal evaluation will enable strengths, limitations and necessary adjustments to be identified, supporting continuous improvement and long-term sustainability. Regarding the current stage of the project, it is important to acknowledge that as a conceptual and procedural proposal, this study does not yet include post-implementation empirical data. The primary focus remains on the methodological framework and the design of the PIS ecosystem. However, the transition from theory to practice involves inherent challenges that must be addressed to ensure long-term sustainability.

Implementation costs, particularly concerning modular furniture and high-end technological integration, represent a significant factor for institutional scalability. Furthermore, the effectiveness of these flexible spaces is deeply dependent on faculty training; without pedagogical support to transition away from traditional lecture-based models, the physical affordances of the PIS may remain underutilised. Finally, maintenance protocols for mobile equipment and specialised digital tools are essential to prevent technical obsolescence and physical wear. Future longitudinal studies will be fundamental to provide quantitative metrics on student engagement and usability, validating the scalability of this model to other

units within the institution. Several directions for future research are therefore proposed. Firstly, the scalability of the design will involve adapting the spatial and pedagogical guidelines developed in this study for an additional four classrooms in other PUVVC schools, while respecting the specific disciplinary and material conditions of each context. Secondly, the spatial impact of flexible and modular learning environments on student engagement, collaboration and the development of transversal skills compared to traditional classroom settings will be assessed through longitudinal studies. Thirdly, the integration of emerging technologies will involve incorporating artificial intelligence-enhanced tools and immersive learning environments (VR/AR) into prototyping and experimentation areas, thereby extending the boundaries of physical and digital educational practices. These developments are intended to enable the Pedagogical Innovation Space to evolve as a living laboratory for pedagogical innovation, thereby reinforcing its role as a reference model for inclusive, collaborative, and future-oriented design and engineering education.

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THE T-SHAPE OF FEMALE DESIGN ENGINEERS: STUDYING HOW THE DESIGN SKILLS OF FEMALE DESIGN ENGINEERS EVOLVE THROUGH THEIR CAREERS

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ABSTRACT

This study explores how female design engineers' skillsets evolve across career stages, how development pathways differ by gender and experience compared with previous data, and the implications for engineering education. Thirteen female design engineers were interviewed and grouped into Novice, Intermediate, and Expert categories to simulate a quasi-longitudinal view of how skills develop over time. Using an established skill-card method from two prior studies, participants identified and scored their skills before categorising them as Specialist or Multidisciplinary, and their profiles were analysed through T-shaped model theories. Findings showed both skill depth and the number of specialist skills typically increasing with experience, especially early in practitioners' careers. Many profiles did not fit predefined T-shapes. Compared with the previous results (that were almost entirely male), female participants selected fewer skills with larger gaps between their self-assessed and researcher-assessed scores confirming internalised gender bias. Overall, the study highlights the need for engineering education to counter stereotype-driven self-doubt, make technical achievements more visible to validate skills, ensuring that women are not unintentionally steered into 'soft-skill-heavy' roles at the expense of technical progression. Engineering education should support flexible, individually varied skill development rather than expecting students to conform to rigid models of expertise.

Keywords: Skill profiling, female design engineers, career progression, inclusive curriculum design

1 INTRODUCTION

This study explores how female design engineers' skillsets evolve across career stages and how development pathways differ by gender and experience compared with previous data, with implications for engineering education. Wider, and important, diversity issues associated with race, cultures, locations, ethnicity or age were not the focus of this study. In this paper, design engineers are defined as practitioners whose roles focus on the research and development of ideas for new products and systems, or the redesign of products and processes to improve their performance.

1.1 What is the T-shaped design engineer?

The 'T' represents desirable design-engineering capability: the vertical bar signifies deep expertise, while the horizontal bar indicates breadth across disciplines and the soft skills needed for collaboration. Companies such as IDEO, Google, Apple and Toyota endorse this structure [1]. Other variants of the model—including the I-shape, pi-shape, and X-shape—also feature in industry; for example, Airbus describes its ideal engineer as pi-shaped, showing *deep* technical experience and innovation competency and able to work *across* business functions [2].

1.2 How T-shaped theories have been discussed in education research

Design engineering relies on both technical and interpersonal skills, requiring curricula that balance technical proficiency with communication and open-ended problem-solving. Literature suggests engineering programmes often produce I-shaped graduates who broaden into T-shaped profiles over time [3],[4]. Developing T-shaped capability earlier requires educational experiences that simulate professional practice rather than traditional lectures. Industry places strong emphasis on soft skills such as communication, teamwork, leadership and creativity [5], yet higher education frequently undervalues

them. While most authors discuss skill-shape theories conceptually, only our previous studies [6],[7] have attempted to construct quantified individual skill profiles.

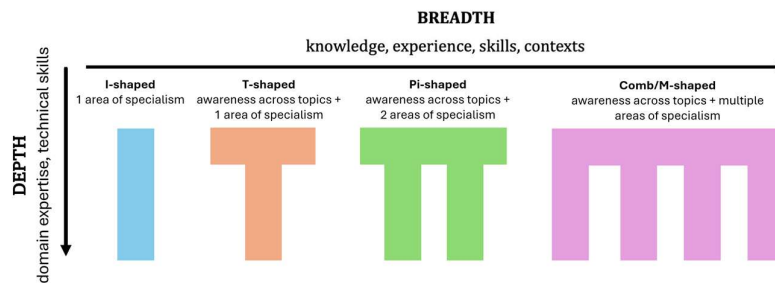


Figure 1. Basic visualisation of the 'T-Shape' model theory and the variations in the literature

1.3 Findings from previous studies using the method

Our previous studies (in 2019 and 2023) examined how design engineers' skills develop across a career and whether real-world profiles reflect T-, Pi- or M-shapes. Across 33 participants—11 novices, 11 intermediates and 11 experts—over 33 hours or 220,000 words of transcribed text were analysed, generating detailed profiles. Findings showed M-shaped profiles were most common, characterised by multiple specialist areas supported by broad multidisciplinary capability, with both skill depth and number of specialist skills increasing with experience. However, the data set was not gender-balanced: only one female participant was included. Figure 2 illustrates a sample of the dataset showing the profile shapes generated (labelled in red the 2019 participants, in black the 2023 participants).

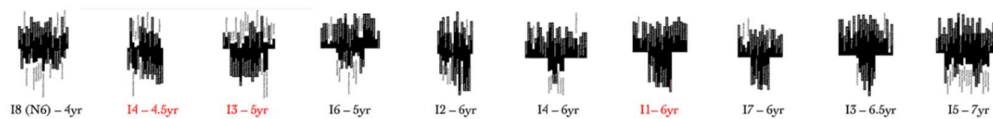


Figure 2. Sample of Intermediate skills profiles from the methodology [7]

1.4 What we know about female design engineers' skillsets across their career stages

Prior research identifies persistent gendered patterns: women often experience lower professional confidence and underestimate their technical abilities despite equal performance. Cech et al. [8] used longitudinal panel data to show that women's lower professional role confidence—rather than family plans or maths self-assessment—significantly reduces the likelihood of remaining in engineering, with women often underestimating their technical abilities despite equal performance. Naukkarinen and Bairoh [9], using cross-sectional survey data from over 4,000 early-career Finnish engineers, similarly found systematic gender differences in valued skills and professional identities, with women prioritising social and interpersonal skill development and facing identity-related pressures that may heighten attrition.

This study adopts a mixed qualitative–quantitative approach to construct skill profiles for female engineers for comparison with our previous studies where 32 out of 33 participants were male. Addressing the lack of gender diversity in engineering design education requires understanding the experiences of female design engineers. This study therefore examines how the skillsets evolve across career stages to inform recommendations for curricula and support.

2 METHODOLOGIES

Cederberg et al. [3] conducted before-and-after studies using questionnaires and interviews, showing that participants in Saab Aeronautics' Advanced Engineering Training Program (AAETP) expanded their T-shaped competencies effectively; one senior systems engineer, studied in detail, developed considerably greater breadth and depth. However, the methodology for the present study mirrored our own previous work [6],[7] as closely as possible, but this time thirteen female design engineers were recruited through academic networks, professional contacts, and social media. All participants were categorised into Novice, Intermediate, or Expert groups based on years of practice, using thresholds

aligned with job descriptions and the premise that professional expertise typically requires around ten years' experience [10]. This produced a sample of four Novices, five Intermediates, and four Experts.

2.1 Data collection process

Data was collected through semi-structured interviews conducted via Microsoft Teams. This provided a consistent framework aligned with the previous studies while allowing flexibility for participants to elaborate on their experiences. Interviews were recorded, anonymised and structured into four sections. The first gathered contextual background—educational history, job role, industry sector and career trajectory—to confirm each participant's experience classification and contextualise later analyses.

Table 1. Anonymised description of the UK-based research participants

Participant	Experience (years)	Education Level	Job Description
N1	1.5	5th Year IDE UG	Design experience with a global product design and technology company.
N2	1.2	5th Year Aero Eng UG	Design experience with a robotics company in the aerospace industry.
N3	1	4th Year IDE UG	Design experience with a design consultancy specialising in electrical power systems
N4	1	4th Year IDE UG	Design experience with a medical design company
I1	5	MEng	Design experience in the cosmetics industry
I2	9	MEng	Senior mechanical and project engineer for an engineering and design consulting
I3	7.5	MEng	Design experience in the medical device industry
I4	2	MEng	Design experience in the household appliances company
I5	3.5	MEng	Design experience in the automotive industry
E1	18	BEng	Design experience in the automotive industry
E2	16	BEng	Design experience in the building services industry
E3	14	PhD	Design experience for a design company
E4	11	MEng	Design experience in the structural design consultancy industry

The interview used a set of 47 design-engineering skills, grouped into 13 categories to help participants identify which skills they possessed. These categories included: Mathematics; Fundamental Engineering Design Skills; Specialist Engineering Skills; Dynamic and Static Analysis; Practical and Manufacturing Skills; Design Communication; Creative Skills; Software Skills; Interpersonal and Personal Skills; Management and Leadership; Business and Economic Skills; and any Additional Skills participants wished to add. Each category contained specific skills (e.g., CAD, FEA, Concept/Sketching, Report Writing, Rapid Prototyping, Leadership, etc), which participants sorted into 'Possessed' or 'Not Possessed' before rating proficiency. This produced a comprehensive inventory of each participant's perceived skillset and allowed comparison with the previous studies. In the third interview section, participants completed a structured assessment for every skill they identified as possessed. For each, they provided a self-rated proficiency score from 1 to 10, described how frequently they used the skill, and gave a brief workplace example illustrating its application. These three elements formed the core quantitative dataset: proficiency scores represented perceived capability, utilisation descriptions were later converted to numerical utilisation scores, and examples were used to allocate assessor-derived bias scores. Together, these captured both depth of skill and practical workplace use. In the fourth participants sorted their skills into specialist (skills they believed they had specialised in) and multi-disciplinary (more general skills used across engineering design disciplines or projects). This enabled construction of individual skill profiles, with multidisciplinary skills positioned at the top of the diagram and specialist skills at the bottom, and bar depth proportional to normalised proficiency. These visualisations supported interpretation of each participant's skill 'shape' (e.g. T-shaped, I-shaped, etc).

2.2 Data analysis method

Data analysis followed the procedures used in previous studies to ensure compatibility. Proficiency scores were normalised through a multi-step process addressing self-assessment bias and variation in skill-use frequency. First, a Weighted Proficiency Score was calculated by combining the self-assigned proficiency score with a numerical utilisation score derived from the participant's description of frequency of use. Second, a Bias Assessment Score was assigned by an assessor to moderate variance in self-reported skill levels. For this, four skills selected by all participants—Mechanical Design, CAD, Rapid Prototyping and Responsibility—were assessed using the participant's descriptive examples and predefined marking schemes based on Choulier and Weite's framework [11].

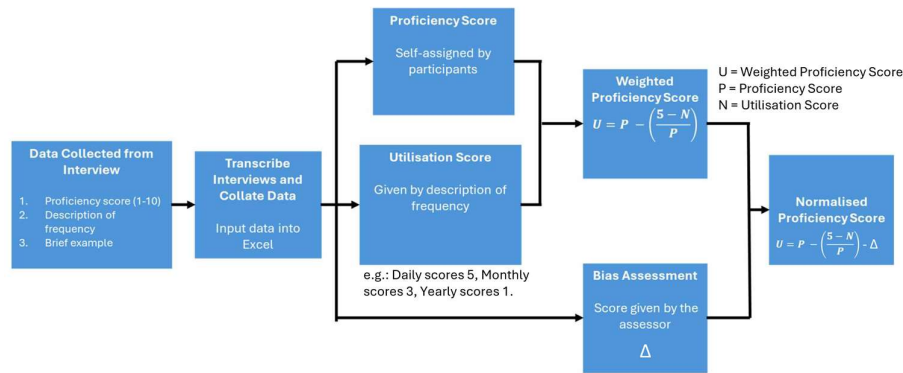


Figure 3. Data analysis and normalisation process

Third, the difference between each participant's weighted score and assessor's score was averaged, and this correction factor was applied across all skills to generate the final Normalised Proficiency Scores used for analysis. Individual skill profiles were then produced by plotting the normalised scores for each participant's specialist and multidisciplinary skills. These profiles visually represented the relative breadth and depth of skills within and across experience groups and enabled evaluation of whether each participant's pattern aligned with established skill profile 'shapes'.

3 RESULTS AND DISCUSSION

Figure 4 shows an example of the T-shaped profile produced by the method. The height or depth of each bar presents the score for the selected skill. Participants place their *specialist* design skills pointing downwards to form the vertical bar of the T, in line with the theory, while *multidisciplinary* skills are shown across the breadth at the top. The colours correspond to the 13 skill categories, although these are not analysed in this paper. Reviewing the full set of profiles visually supports a qualitative discussion of how the specialist skills of female design engineers change over time and what types of specialisations emerge across career stages.

However, analysing the differences in skill scores between this study and the previous studies allows exploration of how skill evolution differs between females and males across career stages. For example, Figure 5 shows that participants in the previous studies consistently selected *more* Multidisciplinary and Specialist skills than the female participants in the equivalent experience categories. However, the female participants averaged *higher scores for all skills* (except the Novice group's Multidisciplinary skills).

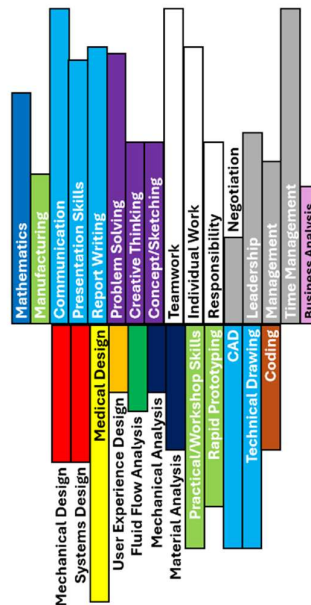


Figure 4. Example of one participant's T-shaped design skill profile

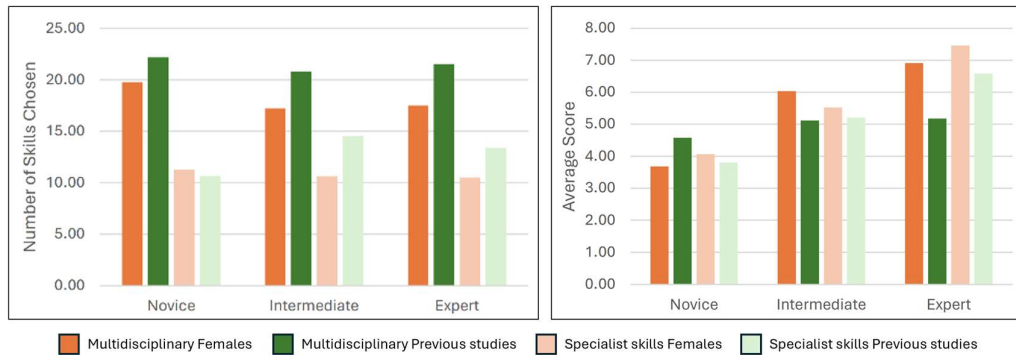


Figure 5. Comparing the average **number** of Multidisciplinary and Specialist skills selected (left) and their average **score** across career stages (right)

In terms of how skills develop across careers, we see in both the female participants and the previous cohorts that several skills increase through the different career stages as expected (for example, creativity, report writing, problem solving and communication skills), while many specific skills peak during the intermediate stage (such as workshop, prototyping and CAD skills). There are also notable patterns in management and leadership skills. Figure 6 shows that Expert female participants scored higher than their Expert counterparts in the previous studies in Leadership (8.04 vs 6.29), Conflict Management (7.64 vs 5.31) and Management (8.17 vs 6.57), whereas the previous cohorts consistently scored higher in Economic Analysis (2.88 vs 4.80) and Business Analysis (2.80 vs 4.60). This may indicate that female careers in engineering design place greater emphasis on managing people.

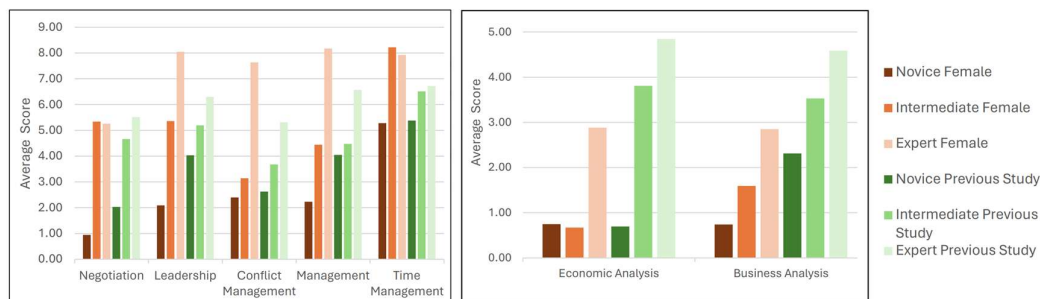


Figure 6. Average Management Skills/Leadership score (left) and Average Business Skills score (right)

The bias-assessment scoring also showed notable differences between the studies. Expert and Intermediate female participants *under-scored* their proficiency by an average of 0.66 and 0.65, whereas participants in the previous studies were more accurate in their self-assigned scores. Their Intermediate and Expert self-assessments *over-scored* their proficiency by only 0.16 and 0.01 respectively. In the novice cohorts there was no clear directionality in the data, some *over-scored* some *under-scored*.

4 DISCUSSION AND CONCLUSIONS

The results suggest a difference in the T-shapes of female design engineers compared with the mostly-male cohorts from previous studies. The findings echo Cech et al.'s work showing that women disproportionately underestimate their engineering competence despite equivalent performance [8],[12]. This indicates that women may benefit from educational environments that counter stereotype-driven self-doubt and make technical achievements more visible to validate skills.

In later career stages, female design engineers often showed stronger interpersonal and management skills, aligning with research suggesting women tend to value and develop social, collaborative and leadership capacities [9]. Educational programmes should recognise these strengths while ensuring they do not unintentionally steer women into 'soft-skill-heavy' roles at the expense of technical progression. Intentional changes to curricula, activities and faculty culture such as frequent low-stakes feedback,

iterative skill validation in technical tasks and technical specialisation pathways in later years, may help female engineers develop stronger professional engineering identities.

Engineering education may help broaden career outcomes for female engineering designers by embedding objective, multi-method skill assessment and clarifying their technical capability. However, as this research shows that real-world skill profiles rarely map neatly onto idealised shapes such as the T-profile, education should aim to support flexible, individually varied skill development rather than expecting students to fit rigid models of expertise, as also proposed by Tranquillo [1].

4.1 Limitations of the study and future work

Although this procedure produced rich data, interpretation was constrained by the small sample size. Given the time limitations of this research, a cohort-based method was selected to explore skill profiles across career stages. How closely it mimics longitudinal data can only be determined by conducting a longitudinal study and comparing results. Future work should therefore involve a larger and more diverse sample, ideally tracking design engineers through key career stages, to map skill evolution more accurately. Nevertheless, close adherence to the previous methodology and the structured interview format ensured that the results were robust enough to support meaningful comparisons.

Examining the T-shaped profiles across the studies showed they were useful for qualitative discussion, but they have not been effective in detecting patterns across career stages. A key issue is that allowing participants to define which of their skills they consider ‘specialist’ and which ‘multidisciplinary’, means the profiles have no common framework. Future work should establish which skills should be considered specialist (downward) and multidisciplinary (across the top) and reorganise the data accordingly. This may reveal clearer patterns in how skills evolve through career stages when using these cohort-based studies.

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HOW DID WE END UP HERE? MAKING DESIGN HISTORY RELEVANT FOR FUTURE INDUSTRIAL DESIGN ENGINEERS

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ABSTRACT

In the wake of the design thinking hype, the design discipline has expanded far beyond the boundaries of the physical product. Systemic design, public design, responsible design and more-than-human design -to name a few- are shifting design practice towards the intangible, the relational and the pluriversal. Although knowledge of the history of the design discipline can still be seen as foundational for the development of future design practitioners, the traditional focus on individual product designs and their individual (male) designers along the chasm of modernism-postmodernism, no longer seems to fit. In this paper I propose an alternative approach in teaching first year industrial design engineering students about design history, reframing design history education as a tool for disciplinary sense-making. Rather than following a canonical chronology, historical content is organised around themes relevant to contemporary Industrial Design Engineering practice, helping first-year students understand why the various topics of their programme matter. The approach thus aims at providing historically informed answers on contemporary design topics, in order to equip the students with a clear starting point for their task of shaping a desirable future.

Keywords: Design history, design education history, interaction design, human-technology relations, design culture

1 INTRODUCTION

Design history education has been approached from different perspectives. Each perspective resulting in a different view on design history and subsequently also with different outcomes and contributions to design education and design practice. For design history education at the Industrial Design Engineering schools in the Netherlands, the perspectives that have been used can be characterised by the keywords ‘historic’, ‘cultural’, and ‘methodical’ [1]. These approaches are mainly focussing on using the knowledge of design history for inspiration in contemporary design. When our programme management asked to incorporate design history as a subject in the very first module of the new Industrial Design Engineering (IDE) bachelor curriculum of the University of Twente, I took the chance to develop a new reason for teaching design histories; making sense of the discipline. Now that in the wake of the Design Thinking hype the discipline has broadened extensively [2,3], it can be hard for freshmen to understand what type of professional they will develop themselves towards. Especially with all the new topics that came with this shift from merely designing products to designing for transitions in a systemic way [4]. In this paper I will elaborate on how I used design histories to let the students make sense of their future discipline. The paper will start by discussing the theoretical backgrounds for the decision to adopt this new approach. Then, from the selection of relevant course contents and presenting some examples from the lectures the paper will conclude with a discussion on the feedback from the students.

2 HISTORY OF DESIGN HISTORY EDUCATION

When I studied IDE at the Delft University of Technology myself, design history was taught like general history in a classical way. The history of design was approached as a history of events, leading to a timeline or a canon of important artefacts, designers, and design ideas. The courses were also delivered from textbooks [5,6] that presented the history of design in chronological order. In order to better understand the emergence of certain design movements and their ideas this approach was later complemented by the emphasis on the cultural component in the history of design. This approach [7–9]

regarded design (also) as a cultural and social phenomenon, leading to an understanding of designs, related to their historical context. To make design history knowledge even more operational for design practice, these approaches were supplemented by a methodical perspective, that I developed and taught for the IDE programme at the University of Twente from 2012 onwards. Design history is herein regarded as a source of inspiration for contemporary design practice from a method point of view. This perspective is characterised by an emphasis on the process of designing and the methods which designers (historically) applied [10,11]. Different design movements, groups, and individuals are herein compared and analysed. Key of this approach has been, that the comparisons were not based on a similar timeframe (as in the classical historic approach) or on a similar context (as in the cultural approach) but on a similar design problem [12]. In this way, knowledge of design history could have a more practical contribution to the development of future designers.

3 CONTEMPORARY DESIGN DISCIPLINE

Valtonen [13] has convincingly shown that the industrial design engineering profession has become more complex over the decades. Expanding the designing of merely aesthetic objects in the 1950ies with manufacturing processes in the 1960ies, ergonomics in the 1970ies, branding in the 1980ies, Experience design in the 1990ies and interaction design and innovation in the 2000s (Figure 1).



Figure 1. Simple schematic of the historical development of the IDE discipline; from things to interactions to (product-service) systems: the complexity increases

Along the way, the topics that the future designer-to-be has to learn also expanded with new engineering subjects as electronics and programming. However, also with the integration of other disciplines like psychology, sociology, anthropology and communication science. In contemporary design, the emphasis has also shifted from products and solutions, to design for behaviour change and addressing societal issues [4,14,15]. For freshman, it therefore can be hard to grasp what they actually started studying, why they have to learn all these topics, and how they should apply and integrate them. This is where I started to think that design history could serve as an applicable lens to exemplify these developments and showcase them in both an explicit and appealing way.

4 CONTEMPORARY DESIGN HISTORY EDUCATION

When design has become so broad in topics, design history can be used to show how all these topics became relevant and why the students should know about all of them. Historical precedents can also make clear that it is important to integrate all these topics in the design process. Showing the first prototype of the famous cantilever chair by Mart Stam from the modernist period can make clear why knowledge about production technologies is important. This prototype is namely built from loose tubes and appendages as Stam did not have the machinery to bend the tubular steel like he had envisioned. This can be then directly connected to the *Endless chair*, developed by Dirk van der Kooij in 2012. He printed this chair with a converted robot arm from plastic waste. From there one can explain about 3d-printing and rapid prototyping, recycling of materials, whether this type of recycling is sustainable, and

even about the material characteristics of thermoplastics that make this type of recycling possible (Figure 2).



Figure 2. from left to right: the prototype for the cantilever chair by Mart Stam (1926), the Endless chair by Dirk van der Kooij (2012) and Dirk van der Kooij with his robot, producing a chair live at the Dutch Design Week in Eindhoven

Another example is streamlining. Through the advancements in airplane and automotive technology in the 1930ies, the teardrop shape became a real design icon. As a metaphor for progress it remained popular to promote innovations like the Philips dry shaver, nicknamed “the Egg”. From there one can discuss about the relations between form giving, meaning, metaphors and marketing. However, one can also explain about wind tunnel testing, the characteristics of drag and the factors that determine C_w -values. This can then be directly linked to contemporary cycling technology, like the streamlined helmets that caused a stir in the media when they first appeared in the Giro d’Italia in 2024 (Figure 3).



Figure 3. from left to right: promotional graphic for Tatra passenger cars (1937), advertisement for a Philips dry shaver with streamline styling (1951), and a member of the Visma-Lease-a-bike professional cycling team during time trials in the 2024 Giro d’Italia

5 TOPICS AND IMPLEMENTATION

Design histories were implemented in the very first quartile of our new IDE curriculum. Based on the overall teaching approach of our programme [16] the course is part of an integrated full-time module of 15 European Credits with the theme ‘Ideation’. In this module the students do several short design projects -called sprints- accompanied by theory courses and skills courses [17]. In the end there are nine sessions of two lecture hours for the design history part of the module, finalised with a written exam. Total study load available for the subject is therefore one EC. As this is ample time to dive deeply in the rich history of the discipline, the course design had to be selective in what topics to cover. Because the idea of the Ideation module is to frame the students for their future discipline (and in that way also for the rest of their study programme) this selection should balance carefully between the different aspects of the programme. Most important in that is the balance between ‘design’ topics and ‘engineering’ topics, represented by the vision of the module to make the students ‘bi-lingual’ [17]. Basis of this dual language idea is that future designers have to become profound in the ‘language of engineering’ (= mathematic) and the ‘language of design’ (= the visual) to be able to communicate with all future

stakeholders and across disciplines [18,19]. For their own design practice they should also understand how to integrate these. In order to specify IDE further from design engineering as such, we adopted a categorisation of topics across three domains (Figure 4), where “industrial” represents things like ergonomics, human-centred design, marketing, and design management.



Figure 4. Visualisation of the design history-informed answer to the question “What is IDE?”, covering the three domains with historic examples; Industrial – Design – Engineering (adapted from Mulder-Nijkamp [20])

So ideally there should be engaging design examples with engineering aspects, like in the comparison of the chairs in Figure 2, as well as examples about industrial and designerly aspects like aesthetics and marketing. Then all these subjects should also come together, like for instance in the streamlining example from Figure 3. The final selection of topics for each of the nine sessions is listed in Table 1.

Table 1. List of Topics in order of appearance in the course

What is Industrial Design Engineering (IDE)?	From styling products to systems design
The role of Aesthetics in IDE	From Art Nouveau to Biomimicry
The history of IDE Education	From Bauhaus to becoming bi-lingual
The role of Technology in IDE history	From mechanics to electronics
The concept of Functionality in IDE	From utility to significance
The development of Interaction	From the tangible to the intangible
Philosophy of Technology and IDE	From Utopia/Dystopia to responsible design
IDE as an <i>engineering</i> discipline	From woodworking to 3d printing and AI
The future in the history of IDE	‘Making technology available for people’

In this paper there is however not enough space to illustrate all the topics. For reference, an example from session two about aesthetics is presented (Figure 5). The ultra-short timeline aims to illustrate how the diversity in the contemporary styling of artefacts is inspired by design movements from the past.

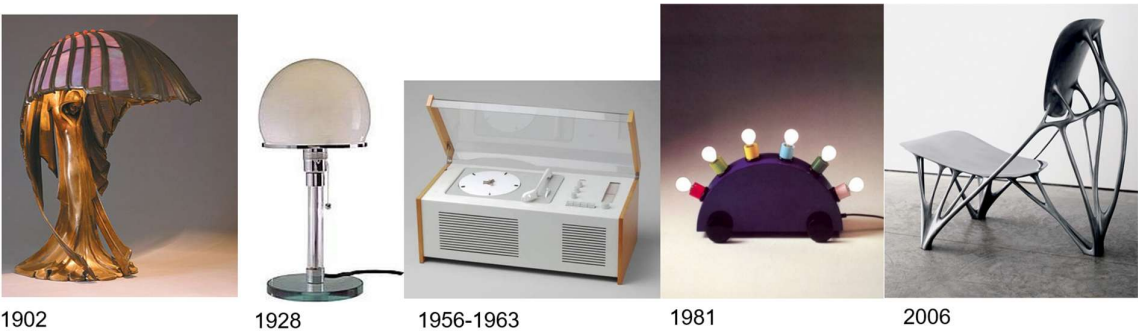


Figure 5. Example timeline for the topic “Aesthetics”: from nature inspired Art Nouveau (=figurative) to abstract functionalism (=geometric) and back (!)

6 EVALUATIONS

The course was relatively positive received. In the student evaluation 81% of the respondents reported that they were “satisfied with the overall experience” [21, p.16]. This was based on 52 students responding on a total of 168 participating in the course and a questionnaire with a 4-point scale from “strongly agree” to “strongly disagree”. Written feedback from the students also mentions “Historical examples and physical products presented in class helped make the material engaging and easier to remember.” [21, p.16]. Apparently, we also reached the goal of informing the students about the characteristics of the discipline. The report of the accreditation committee that visited our programme shortly after, mentions about the first module of the new curriculum that the students gained “a deep understanding of what designing entails”, and that it “helped lay the foundation for the rest of the modules” [22, p.8]. However, there was also critique. From the respondents, 45% disagreed on the statement “The instructor’s teaching methods for the Design Histories part were effective.” [21, p.15]. Although apparently, this did not refrain most of them from being satisfied with the overall experience of the course as mentioned earlier. Also, during a mid-term interview round the panel of students “felt that it might help to structure the lectures into more distinct time frames (e.g. 1900-1920 and 1920-1940 instead of 1900-2000 every lecture)” [23, p.1]. So, these students apparently were not yet convinced of the effectivity of the new teaching approach.

7 DISCUSSIONS

As said, only one EC to teach about design history is very little. However, with this new approach this short introduction can still be valuable as a foundation for connecting all the different topics within the remainder of the bachelor programme. By having concrete images of design examples that have linked together these topics in the past, the idea is that it will be easier to navigate the future complexities of the discipline. Whether this effect is really achieved will however only be visible when the first cohorts have finished their bachelor’s programme. The format of the exam with mostly multiple-choice questions did not so much allow to check whether the students indeed acquired this level of insight. Also, although the student evaluations showed a relatively positive image, they only represented a minority of the students participating. In the future it will be worthwhile to follow up on the development of the students, also because the selection of topics in the course could possibly be better aligned with the final result of the completed Bachelor curriculum redesign. Anyhow, to secure the link between design history education and contemporary design the list of topics should be closely monitored to keep it up to date with the prevailing topics in the current state of the discipline. Lastly, from the students’ remarks in the mid-term interview it can be concluded that some of them apparently had another idea by the subject name “design histories” and were possibly disappointed that they did not learn the history of design in a ‘proper’ way with a classical periodisation. However, to have such an overview in distinct timeframes of twenty years as mentioned is maybe easier for studying, it is also an oversimplification that is not really helpful in understanding the complexities of the present. Because, in the end it is about preparing our students to become competent industrial design engineers, not design historians.

8 CONCLUSIONS

In a diverse discipline like contemporary industrial design engineering, knowledge of the history of the discipline can provide stepping stones for positioning all the different topics of the programme. Instead of with a chronological overview, our bachelor curriculum started with presenting the history of design in close connection to these topics, which resulted in reported awareness of our students about their future as designers.

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A STUDY ON ENHANCING FEMALE HIGH SCHOOL STUDENTS' STEM CAREER AWARENESS THROUGH CAREER EDUCATION IN JAPAN

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ABSTRACT

The persistent underrepresentation of women in Science, Technology, Engineering, and Mathematics (STEM) fields remains a global concern despite sustained policy efforts to promote diversity and inclusion. Although female educational attainment has increased worldwide, participation in engineering and technical STEM pathways continues to lag. Japan presents a particularly instructive context: while female students perform strongly in mathematics and science, women remain underrepresented in engineering-related higher education and research careers. Despite national initiatives promoting women's participation in STEM and the institutionalisation of career education in secondary schooling, gender disparities persist.

This study examines how career education relates to female high school students' awareness of STEM careers in Japan. Using a mixed-method research design, a 5-point Likert-scale survey and open-ended questions were administered to 244 female students from three public high schools in the Kyushu region. Quantitative data were analysed descriptively, and qualitative responses were examined thematically.

The findings indicate that limited occupation-specific knowledge and concerns about workplace environments contribute to hesitation in considering STEM career pathways. Even in schools offering structured STEM programmes, students often lack concrete understanding of professional roles, required competencies, and career trajectories. The results suggest that STEM coursework alone does not necessarily facilitate career meaning formation. Rather, the alignment between disciplinary learning and structured career guidance appears critical in supporting informed career construction.

By highlighting how STEM education and career education may operate in parallel rather than integrative modes, this study contributes to international discussions on gender disparities in engineering and related fields. The findings underscore the importance of strengthening career education mechanisms during secondary schooling to support more diverse and inclusive participation in STEM over time.

Keywords: Stem education, career education, female high school students, career awareness, Japan

1 INTRODUCTION

Gender disparities in STEM participation remain a global concern despite increasing levels of female educational attainment [1][2]. Across Organisation for Economic Co-operation and Development (OECD) countries, women continue to be underrepresented in engineering, Information and Communication Technology (ICT), and other technical STEM fields. In response, governments and educational institutions worldwide have introduced initiatives aimed at broadening participation. These include expanding STEM-focused curricula, integrating engineering practices into science education frameworks, developing outreach programmes to encourage girls' engagement in science and technology, and strengthening career guidance systems to support informed educational and occupational decision-making [3][4][5].

Despite these policy efforts, gender imbalances in STEM pathways persist. Research suggests that participation in STEM coursework alone may be insufficient to foster long-term STEM career aspirations. Career development theories emphasise that occupational choices are shaped not only by academic performance, but also by self-concept, perceived belonging, social expectations, and culturally embedded images of particular professions [6][7]. Informational initiatives or curricular exposure alone

may therefore be insufficient if students do not perceive meaningful alignment between their educational experiences and future identities.

Within this broader international context, Japan presents a particularly instructive case. Japanese girls consistently demonstrate strong performance in mathematics and science assessments; however, women remain underrepresented in STEM higher education and research careers [8]. National responses have included policies promoting gender equality in science and technology, outreach initiatives encouraging girls' participation in STEM, and institutional programmes such as the Super Science High School (SSH) scheme to strengthen science and technology learning environments [9]. At the same time, career education is formally embedded within Japanese secondary schooling through structured guidance systems that emphasise self-understanding, career planning, and the development of transferable competencies rather than occupation-specific preparation [10][11].

Nevertheless, while STEM enhancement initiatives and career education policies coexist within the Japanese secondary system, their interaction has received limited empirical examination. Existing studies have tended to focus on policy implementation or general competency development, rather than investigating how high school career education may shape female students' awareness of STEM career pathways during the critical stage of academic tracking and decision-making. This gap underscores the need to examine how career education and STEM learning experiences intersect in influencing female students' career perceptions within the Japanese high school context. Against this backdrop, this study investigates the current state of STEM career awareness among Japanese female high school students and examines how career education relates to this awareness. Focusing on three public high schools in the Kyushu region with varying degrees of integrated STEM education, the study seeks to identify key factors shaping female students' understanding of STEM careers. By clarifying these factors, the study aims to contribute to discussions on how STEM coursework and career education may be more effectively aligned to support greater female participation and diversity within STEM fields.

2 LITERATURE REVIEW

Gender disparities in STEM participation remain a global concern despite increasing female educational attainment. Although overall educational attainment among women has improved, participation in engineering and ICT-related STEM fields remains comparatively low in many countries. In Japan, women represent a particularly small share of STEM researchers and technical professionals [12].

Research consistently identifies high school as a critical stage for career formation. Longitudinal studies demonstrate that interest in mathematics and science develops early and that career expectations often crystallise before university entry [13][14]. Gender differences in occupational aspirations are already visible during adolescence. In systems such as Japan's, where students select academic tracks during high school, limited awareness at this stage may narrow future STEM opportunities. In Japan, career education is formally embedded within secondary schooling and emphasises transferable competencies, self-reflection, and career planning rather than detailed occupational specialisation [15]. At the same time, initiatives such as the Super Science High School (SSH) scheme aim to strengthen STEM learning experiences through enhanced science and technology curricula [16]. However, the extent to which STEM coursework and structured career education are aligned in fostering STEM career awareness remains insufficiently examined. This gap underscores the need to examine how high school career education interacts with STEM learning experiences to influence female students' career perceptions within the Japanese context.

3 RESEARCH METHODOLOGY

3.1 Research questions and method of inquiry

This study aims to identify the key factors within high school career education that influence female students' awareness of STEM careers. To address this objective, the study investigates the following research questions: a) What is the current level of awareness of STEM careers among Japanese female high school students? b) What misconceptions or biases do Japanese female high school students hold regarding STEM careers? c) What aspects of high school career education shape female students' awareness and understanding of STEM careers?

This study adopts a mixed-method research design and focuses on three public high schools in the Kyushu region of Japan. Data were collected through an online questionnaire survey, which effectively gathered female students' perceptions, understandings, and attitudes toward STEM careers.

3.2 Research design and implementation

3.2.1 School Context

To examine whether female students' STEM career awareness varies across institutional contexts, three Japanese high schools (F, K, and M) representing different levels of STEM implementation were purposively selected. F High School is a general academic school without a formal STEM programme. K High School runs a STEM programme in which students study a shared topic at different levels depending on their interest. M High School, designated as a Super Science High School (SSH), integrates STEM across subjects throughout all three years. These schools represent low (F), moderate (K), and high (M) levels of STEM implementation.

3.2.2 Participants and Data Collection

Data were collected through an anonymous online questionnaire administered to female students in the three schools. A total of 244 valid responses were obtained (F: 43; K: 121; M: 80). Participation was voluntary, and institutional permission and informed consent were secured.

3.2.3 Measures

The quantitative scale employed 5-point Likert items (1 = Not at all familiar; 5 = Very familiar) to assess perceived familiarity with STEM-related careers. Questions for each of the four STEM fields were developed based on the framework provided by the U.S. Bureau of Labor Statistics (BLS), which introduces STEM careers across eight aspects: job types, work duties, required skills, required education, average income, job benefits, learning opportunities, and sources of career information. The same item structure was administered across four subject domains—science, technology, engineering, and mathematics. Table 1 presents the structure of the scale using science as an example.

Table 1. Example Structure of the STEM Career Awareness Scale (Science Domain)

Dimension	Example Item	Scale
Job Types	I have a good understanding of the types of jobs in science-related careers.	1-5
Work Duties	I have a good understanding of the work duties in science-related careers.	1-5
Required Skills	I understand the skills required in science-related careers.	1-5
Required Education	I understand the education required in science-related careers.	1-5
Income	I understand the average income in science-related careers.	1-5
Benefits	I understand the benefits in science-related careers.	1-5
Learning Opportunities	I have opportunities to learn about science careers.	1-5
Information Sources	I know where to find information about science careers.	1-5

Note. The same structure was applied to technology, engineering, and mathematics.

The second component consisted of open-ended questions designed to explore students' perspectives on gender and STEM careers. These questions are summarised in Table 2.

Table 2. Open-ended Questions

Theme	Question
Gender Perceptions	Do you think STEM jobs are more suitable for men or women? Why?
Career Interest	Would you like to work in a STEM-related job in the future? Why?
Challenges for Women	What challenges do women face in STEM careers?
Information Availability	Does your school provide enough information about STEM careers?
School Support	How should schools better support students' understanding of STEM-related jobs?

3.2.4 Data Analysis

Quantitative data were analysed using descriptive statistics (means and standard deviations) and between-school comparisons to examine differences in STEM career awareness across institutional contexts. Qualitative responses were analysed using inductive thematic analysis. Open coding was first conducted to identify recurring ideas, followed by category refinement and cross-school comparison to identify thematic patterns across participants.

4 RESEARCH FINDINGS AND DISCUSSION

4.1 Insufficient Career Information and STEM Career Intentions

As illustrated in Figure 1, female students across all three high schools demonstrate relatively low levels of STEM career awareness. Even in M High School, which offers a structured three-year STEM programme, awareness levels remain modest. This suggests that participation in STEM coursework alone does not necessarily translate into explicit career understanding. Figure 2 further indicates that low awareness is accompanied by limited career intention. A substantial proportion of students respond “No” or “I don’t know” when asked about pursuing STEM careers. Open-ended responses frequently cite insufficient knowledge of occupational roles, required competencies, and career pathways. Importantly, as shown in Figure 3, most respondents do not explicitly endorse the view that STEM careers are inherently gendered. This suggests that hesitation toward STEM pathways may not primarily stem from overt gender stereotyping, but rather from informational gaps and uncertainty regarding career trajectories. These findings align with Social Cognitive Career Theory [17], which emphasises the role of occupational information and outcome expectations in shaping career interest. Without explicit linkage between classroom learning and concrete career knowledge, disciplinary participation may not translate into sustained career intention.

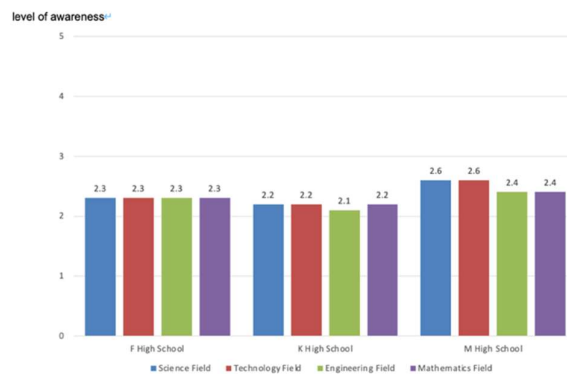


Figure 1. STEM career awareness across three high schools
Note: Scale ranges from 1 (Not at all familiar) to 5 (Very familiar)

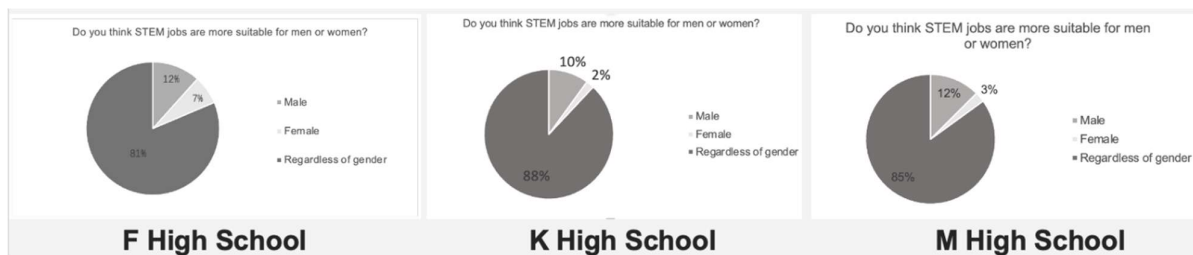


Figure 2. Female Students' Intention to Pursue STEM Careers

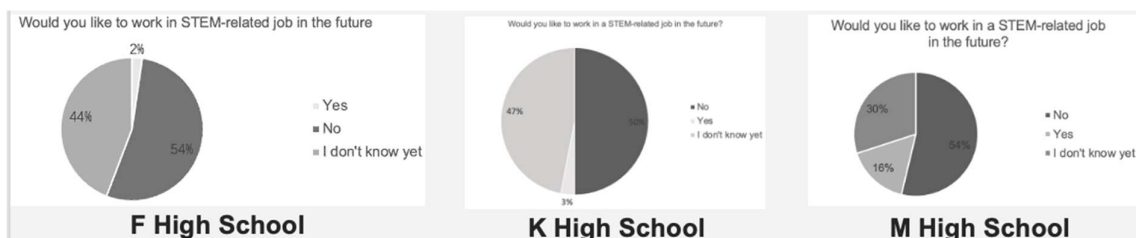


Figure 3. Female Students' Perceptions of Gender Stereotypes in STEM Careers

4.2 Perceptions of Workplace Environment as a Psychological Constraint

Beyond informational gaps, qualitative responses reveal a second dimension influencing STEM career awareness: perceptions of workplace environments. Many female students express concerns regarding potential social isolation and insufficient support for maternity or childcare in STEM-related professions. While this study does not measure psychological constructs directly, these perceptions may contribute to hesitation in considering STEM pathways. Correll [18] argues that occupational aspirations are shaped not only by performance but also by socially constructed expectations and identity compatibility. Even in the absence of explicit discrimination, students may adjust their aspirations if they anticipate limited belonging or support within a professional field. Interestingly, although Japan has implemented various gender equality initiatives and workplace reforms, student responses suggest that awareness of these developments remains limited at the high school level. This indicates a potential disconnect between macro-level institutional progress and students' micro-level career perceptions. Accordingly, career education may need to address not only occupational descriptions but also realistic representations of workplace structures and support systems. Providing evidence-based and balanced depictions of STEM work environments could help reduce uncertainty rooted in incomplete or stereotyped images.

4.3 Structural Alignment Between STEM Learning and Career Education

The findings must also be interpreted within the institutional framework of Japanese secondary education. Career education in Japan emphasises transferable competencies, self-reflection, and autonomous life planning rather than occupation-specific preparation. This competency-based orientation reflects broader reforms prioritising adaptability in a rapidly changing labour market. At the same time, STEM enhancement initiatives such as the Super Science High School (SSH) scheme aim to strengthen disciplinary learning environments. However, as suggested by the relatively low awareness levels observed in Figure 1, strengthened STEM coursework does not automatically produce explicit STEM career understanding. This observation is consistent with OECD, which emphasises that career guidance systems are most effective when educational experiences are intentionally connected to occupational pathways. Within a framework that prioritises general competencies and school autonomy, structured mechanisms linking STEM coursework to concrete career exploration may remain underdeveloped. The combined evidence from Figures 1–3 and institutional analysis suggests that female students' STEM career awareness is shaped by three interrelated dimensions: a) Access to concrete and structured STEM career information. b) Perceptions of workplace culture and anticipated belonging. c) The degree of alignment between STEM coursework and career education. These dimensions indicate that disciplinary exposure alone is insufficient. Instead, systematic integration of career guidance and STEM learning may be necessary to support more informed and confident career exploration among female students.

5 CONCLUSIONS

This study examined Japanese female high school students' STEM career awareness, intentions, and workplace perceptions across three secondary schools with varying levels of STEM provision. The findings indicate that overall STEM career awareness remains limited, even in schools offering structured STEM programmes. While explicit gender stereotyping appears relatively weak, many students report uncertainty regarding STEM career intentions, often citing limited knowledge of occupational roles, required competencies, and career pathways. Concerns about workplace culture and anticipated gender-related challenges further contribute to hesitation in considering STEM-related professions.

Importantly, these findings suggest that the central issue does not lie in the absence of STEM exposure or formal career education. Japan has implemented STEM enhancement initiatives and institutionalised career education frameworks within secondary schooling. However, the coexistence of these structures does not automatically ensure the formation of concrete career meaning. STEM education primarily cultivates disciplinary knowledge and technical competencies, whereas career education is designed to support reflection on occupational identity, workplace expectations, and long-term life planning. When these domains operate in parallel without intentional integration, students may acquire STEM knowledge without translating it into viable career consideration. The results therefore point to a structural alignment issue rather than a policy vacuum. Career education in Japan emphasises transferable competencies and self-reflection yet may not consistently provide occupation-specific

exploration of STEM pathways. Without explicit mechanisms linking STEM learning experiences to professional contexts, students may struggle to envision themselves within STEM-related communities. Within the broader context of persistent gender disparities in engineering and technical fields, this distinction is significant. Expanding access to STEM coursework alone may increase participation, but fostering diversity and inclusion requires supporting the processes through which students construct career meaning. Strengthening the alignment between STEM learning and structured career guidance at the secondary level may contribute to more informed career exploration among female students and, over time, to more inclusive participation in engineering and related STEM fields. This alignment may be operationalised through the integration of career-relevant contexts within STEM instruction, such as exposure to professional practices, interaction with role models, and structured reflection on career pathways. While situated in Japan, these findings may also be relevant to other educational systems where STEM learning and career guidance operate in parallel rather than as integrated processes.

6 FUTURE RESEARCH AND LIMITATIONS

This study has several limitations. First, it focuses on three public girls' high schools in the Kyushu region, which may limit generalisability. Second, the analysis relies primarily on descriptive statistics, and the findings should therefore be interpreted as indicative rather than statistically generalisable. Third, career awareness is measured through self-reported familiarity, which may not fully reflect students' actual understanding. Finally, although qualitative responses were analysed thematically, the analysis did not employ a fully systematic coding procedure, limiting transparency. Future research could adopt inferential statistical methods and more systematic qualitative approaches to better examine the development of STEM career awareness and explore how structured career-related activities (e.g., workplace exposure, role models, and reflective tasks) can be integrated into secondary STEM education.

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FROM BEATS TO BLUEPRINTS: RETHINKING CREATIVITY IN ENGINEERING EDUCATION

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ABSTRACT

Engineering education faces new challenges, including the rise of service-oriented products that integrate tangible and intangible features in their design. The traditional engineering design's preliminary phases, which centre on the artefact as the main object, are thus changing, calling for a more innovative and open approach. Intrigued by the clear behavioural difference observed between engineering and music students in how they approach open, openly defined educational tasks, this study contrasts music students' approaches with the early stages of engineering design to propose rethinking creativity training in engineering design education. The study draws on experience in teaching engineering design and music production, both of which share a common view of active pedagogy. As part of the Let's Create Music project, the ethnographic study has collected data through video recordings of online music camps featuring both non-professional and professional music producers. Observations in on-site camps also contributed to the study. The results illustrate differences and conclude with recommendations for rethinking engineering education, including integrating gender perspectives into assignments.

Keywords: Engineering design education, music production, design thinking, creativity, active pedagogy

1 INTRODUCTION

Sweden's music industry has achieved global success, thanks to producers such as ABBA, Dennis Z Pop, and Max Martin, as well as platforms like Spotify, and to a focus on popular music in elementary schools and Municipal Schools of Arts. Still, the engineer is regarded as a role model in Sweden's technical history, with acknowledgement of innovative solutions. Inventions such as the boat propeller, ball bearings, and the three-point seat belt are the result of creative engineering.

Both the engineer and the music producer share skills in innovation and creative product development, which, from a business perspective, have long been emphasised as critical to success [1]. From an engineering perspective, creative product development primarily involves the innovation of artefacts, i.e., products [2, 3]. Consequently, these processes are grounded in the designers' interaction with tangible objects [3]. In recent years, the vision of product-service systems has introduced the concept of product servitisation [4], highlighting the distinction between tangible products and intangible services and their combination [5]. Furthermore, combinations can be categorised as social and ill-defined, so-called wicked problems [6], for example, solutions to address climate change. However, even well-designed products can fail due to shortcomings in their digital interfaces. Contemporary engineering design calls for a more open approach, including the ability to identify and understand the problem from a user perspective. Such problems imply that teaching problem framing is as important as problem solving [7]. The issue of separating or defining the results of the development process is less evident in cultural creative industries, such as music production. Nevertheless, music and songs differ from material objects and manufactured goods. Despite this, music and songs play a role similar to that of engineering artefacts in driving creative and innovative processes. From an engineering perspective, it would be interesting to examine the behavioural differences between how engineering design and music students approach open problems.

This curiosity stems from 18 years of teaching creative development processes in engineering education and from participation in the research project called Let's Create Music. Meeting and interacting with professional music producers and students in the project's camps and masterclasses was an intriguing experience. As teachers, we were surprised that the music students, without hesitation, eagerly engaged

with abstract instructions such as “*go to the studio and make pop music, you have 2 hours at your disposal*”. Given our background in teaching engineering students, we found this behaviour astounding, whereas the music researcher considered it normal. In our classes with engineering students, instructions that, in our view, clearly describe a challenge, its context, users, and constraints elicit many questions and hesitation. For example, “*design a shelter solution for people affected by a natural disaster, using a 20-foot-long standard shipping container as a base*”. Sometimes, students conclude that they have been given an impossible, abstract task because the instructions are insufficiently defined, whereas their lack of interest in problem framing seems to be the main issue [8]. Therefore, this study contrasts approaches to the creative stages of music production education and practice to inform the rethinking of creativity training within engineering design education.

The study design is briefly outlined below. Subsequently, an active pedagogical view is presented, followed by examples and a discussion of the creative stages. The paper concludes with recommendations and lessons learned that could inform the rethinking of engineering design education.

2 STUDY DESIGN

The EU-funded project Let’s Create Music investigated the early creative stages of music production and proposed designs for innovative online support. The ambitious vision for this support was a virtual studio that, as realistically as possible, mirrored the co-creative process of a physical studio. The critical technical issue was assumed to be latency hindering online co-creation in music production, but technical researchers soon recognised that music production is often asynchronous. Instead, part of the project’s research focused on designing technical support for remote, wireless work and the creative stages more generally, for example, whether to use a mood board or AI to support alignment in group creativity. These technical supports are excluded from this study, which focuses on contemporary music production that uses only established tools. Music production studios are highly digitalised, for example, equipped with digital audio workstations that are central to online work. Online music production also requires tools for communication and documentation, such as Microsoft Teams, SharePoint, and similar platforms.

The research examined both in situ and online creative music production. Interactions with professionals (active in the music industry), non-professionals (local music entrepreneurs and start-ups), and students from higher music education institutions were held through masterclasses and camps. The professionals were known nationally and internationally as music producers and toplineers, meaning they created lyrics and melodies. A globally known American music producer also participated in the activities. In addition to engineering design and music education researchers, the project consortia included experts in digitalisation and communication. The masterclasses and camps were primarily held online via Zoom or Muse (a digital audio workstation) and recorded for further observations and analysis. Camps were also held in situ, where the project’s researchers observed and took field notes. Five professional music producers observed the camps and supported the participants during short breaks. In turn, the researchers observed and spoke with the producers about their observations of studio activities. The co-located camps concluded with a presentation of the music created during the full-day camps, and the five professionals offered formative feedback to the participants, including suggestions and recommendations. Qualitative data were collected over the three-year project and can be categorised as participatory action research [9]. This implies that we studied social interactions among participants, including creative teamwork, and that we could introduce changes based on our observations. It also includes a cyclical, iterative approach to planning, action, analysis, and reflective-in-the-way conclusions, in which we naturally compared our previous studies of engineering design and music education. Hence, in one of these partial conclusions, we identified an interest in examining lessons learned from comparing engineering design and music education, thereby motivating this study.

3 ACTIVE PEDAGOGY

Active pedagogy, or active learning, focuses on strengthening students’ learning. Quite some time ago, it was found particularly beneficial for STEM courses (Science, Technology, Engineering and Mathematics) as well as for all forms of learning [10], [11], [12]. Its opposite, so-called passive learning, can be useful when students must assimilate and translate subject-matter knowledge. However, that pedagogy falls short when personal development is central, as it is for both framing and solving complex problems; that is, learning should foster innovation and entrepreneurial abilities [13]. It is important to note that teachers’ values and beliefs about the purpose of ‘real’ education often sustain prevailing

passive pedagogy [14]. In earlier studies of engineering education, as well as in current ones, we encounter teachers expressing doubts, “*What should be removed?*” This doubt reflects an either-or attitude that impedes improvement. Barton [14] even calls it *traditionalist inertia*, because it resembles a not-invented-here tradition. In this view, one’s own courses are perceived as proven successful and excellent, at least within the context of one country, so why change? However, teachers who, for example, applied design thinking to support the implementation of active pedagogy found that it broadened their instructional repertoire. Commonalities between active pedagogy and design thinking were particularly useful, including playful learning, collaboration, productive failure/resilience, creative confidence, facilitation, mentoring, advising, and counselling [15] (p. 302). The teacher’s role shifts from instructor to facilitator in active pedagogy and learning, see Table 1.

Table 1. A changed role for teachers (Created by Authors)

Instructor (passive)	Facilitator (active)
Presents information	Designs learning experiences
Provides arguments	Supports dialogues
Shows a correct solution	Empowers plausible alternatives

The teaching and learning activities are suggested to be designed to enable investigations of realistic problems, promote self-development tasks, integrate pre-knowledge with new knowledge, and enhance task-based performance [16]. Furthermore, an inclusive atmosphere is required [16]. These dimensions constitute the grand challenges for teachers to address in course design, yet they are important for meeting the basic requirements of successful active pedagogy.

4 CONTRASTING APPROACHES

The study addresses approaches to the creative stages, implying that a deep dive into the term creativity constitutes a delimitation. Nevertheless, to operationalise creativity from an engineering perspective, it can be defined as “*a cognitive process culminating in the generation of an idea*” [17]. Within the design process, this idea should further develop into a product or process concept [17]. Additionally, in engineering design, creative work is applied in the early stages of the design or development process [17]. Creativity is both required and taught to understand the task and generate ideas, and it focuses on products, i.e., manufactured goods [18], [19]. Hence, the rationale is naturally centred on the product. Contemporary servitisation poses a cognitive challenge because it allows product replacement while the function remains unchanged. Such a change in the business model necessitates a corresponding shift in creative work [20]. That is, the creative process cannot begin with a product. This cognitive challenge lies in the contrast between the rationale for creativity in open-ended engineering design for servitisation (left in Figure 1) and the traditional design process (right in Figure 1).

In a previous study, an engineering student described the challenge of being assigned open-ended tasks. The student concluded: “*As an engineer, I like to take a thing, a product, look at it, twist and turn it, and then improve it or make it better*” [22]. Students’ frustration typically stems from the perception that they receive insufficient theoretical subject knowledge, even though they often receive more than in a technically oriented course.

The frustration may relate to the multidisciplinary nature of creative work. We interpreted this as a shortcoming in recognising, or perhaps acknowledging, it as a different kind of theory [7]. Yet, starting in an open-ended state led engineering students to realise that they were designing products for others rather than for themselves. The approach to creative, open-ended tasks has been tested in a study of engineering design teams, which examined their tendencies in problem framing and solving [8]. The students were divided into homogeneous teams based on their learning preferences to either master (develop a deeper understanding) or solve a task. It was found, of course, with some plausible deviation, that mastery-oriented students were more likely to engage in problem framing through exploration and to view users as people rather than objects in the design process.

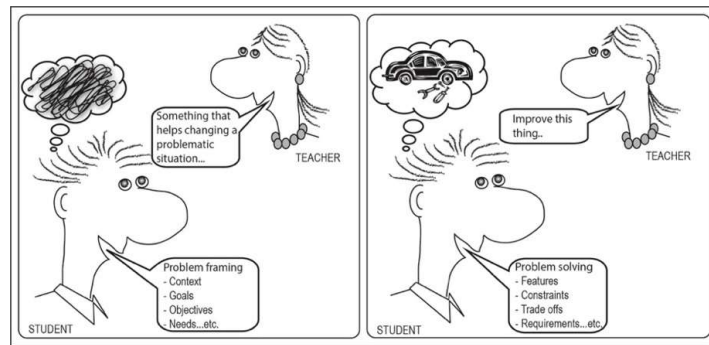


Figure 1. Problem-framing vs. problem solving. Source by authors (Revised from [21])

Understanding and treating users as people is considered essential for designing more sustainable or novel solutions to abstract problems [4], [8]. By contrast, music students and professional artists seem to adopt a more user-oriented approach as their natural way of working creatively, finding it normal to produce music with others and for listeners. To evaluate the result and progress of the music, they focus more on the actual musicking and the vibe the music and text can create, for example, a specific genre, a sunny day, driving a cabriolet through a scenic beach landscape with wind in the hair.

The intangible nature of music makes it easy to ‘prototype’ whenever and wherever a creative idea arises, for example, by humming a short melody into the voice recording app on a mobile phone and tapping the beat on the phone. Another observation is that in the early stages of music production, the team collaborates to develop a shared vision for the final product. This is done, for example, by nodding the head or stamping the foot to the beat, or by picking up an instrument and playing along. When engineering students learn about creativity as a cognitive process, music students and artists recognise emotional feedback from instruments and co-creators, as well as embodied and intuitive processes, as important inputs in the creative process. The creative process is a complex and holistic interplay of thoughts, feelings, sensations and shared experiences.

Creating a shared vision is a significant challenge in engineering design, particularly in open-ended contexts. Eifler and Myrup Andreassen [23] argue that embodiment design can better represent the physical artefact during the creative process than traditional conceptual design methods. Embodiment design, simplified as the materialisation of a conceptual idea, prevents design fixation and the common decision-making that leads to choosing between binary solutions, either one that delivers a certain function or not [23]. Such a selection disregards alternative, plausible solutions, thereby reducing innovation and the generation of more creative and better solutions. Embodied design, or cognition, emphasises that humans do not think only with the brain, as is the common approach in conceptual design, but also use facial expressions, gestures, body language, and so forth. Such visual representations are fundamental to the engineering design team’s creative work [24], yet despite being generally recognised, embodiment design is not influential in advancing ideas and solutions [23]. The extensive literature on product design and development processes commonly suggests stage-gated process models to guide activities in the process, for example, starting from a problem or task, going through stages of generation, selection, testing, setting final or detailed specifications, and deploying a production plan, e.g., [18], [19]. The stage-gate process may also separate work between the potential user and the product, a practice previously known as an over-the-wall approach. Whereas music production begins with a brief idea, such as a title, lyric, or motif, that serves as the basis for the entire song [25]. The development process appears to be built upon the integral parts of the song’s genre, such as the intro, verse, and bridge, and/or lead, drum, bass, etc. At a general level, the curricula for engineering design education and music production appear similar in their coverage of subject matter. One difference is that music production education, as an artistic discipline, explicitly addresses the development of students’ own profiles. The core focus of engineering education is subject matter [19]. Consequently, it overlooks personal development. We have met many students again after they finished their engineering education. One of them said, *“As a project leader, I now understand the relationship between my education and the profession. I could not see how user-orientation concerned engineering, or why I should develop any ‘people’ skills.”*

5 CONCLUDING DISCUSSIONS

It might seem like comparing apples and oranges, i.e., too different to be compared, when examining approaches to the creative stages with the aim of contrasting music production with engineering design. However, as our study progressed, we identified key approaches that can inform the rethinking of creativity training in engineering design education and ultimately help students become more comfortable with open-ended assignments.

One obvious approach is to view engineering design as artefact focused. In the same vein, engineering process models specify the team's *activities* required to design and develop a product. This creates a cognitive gap between designers' understanding of users' needs and the product's functional requirements. Music production is user-oriented, guided by holistic models that connect the idea to *all parts* of the song. Attempts to influence engineered products through a servitisation logic have long been proposed [26]. Such a model suggests that support for users' activities mediates the value of the solution rather than that of the physical product itself. Although servitisation is well-established as a model for sustainable development in industry, its impact on engineering education lags behind. A suggestion is to introduce open-ended, servitisation-like assignments gradually over the programme period, for example, as a complementary task in which students reflect on an alternative approach to servitising their proposed physical product. Appreciative inquiry [27] is grounded in exploratory dialogue, which aligns with design thinking. It could aid in designing servitisation-like assignments, for example, by guiding students to investigate a problem and who experiences it (What is the situation or problem?), envision a changed situation (What might be...?), generate creative ideas (What if...?), and select a solution by connecting 'what might be' with 'what is'. If so, engineering students would practise shifting the focus from a solution to its value for the client or user. Additionally, designing the assignment in iterations, with students providing feedback to peers, offers an opportunity to advance both ideas and the learning curve. Furthermore, teaching and learning activities would be more closely aligned with the complexity of the engineering profession, a central tenet of active pedagogy.

Another approach is that creative work in engineering design is typically confined to the early stages and is a cognitive analytical task of generating ideas [17]. Music production is a comprehensive creative process, from idea generation to the finished song. Music, simplified, is rhythm, sound, and harmonics that convey feelings and moods. Thus, producing music means that creators themselves will also be affected by it. Rhythm, sound, and tones embody the song's vision, for example, for the producer, the topliner, and the artist. Although considered beneficial to the creative process, embodiment design does not significantly influence engineering design [23]. However, servitisation designs, i.e., combinations of physical artefacts and immaterial services, may depend on the ability to empathise with others' perspectives and ideas to deliver value [26]. Empathy is cultivated through the practice of interpersonal skills, often referred to as soft skills, in engineering contexts. Emotional intelligence, behavioural traits, and the ability to build upon others' ideas are typical soft skills. Homogeneous teams can be beneficial because they influence one another in the same direction [8], but they are unfavourable when alternative solutions are desired. Engineering design, like other technical domains, is under-represented by women. In 2006, a study of 100 male and 3 female students suggested that interpersonal skills are needed in engineering education [28]. Such a gender imbalance persists 20 years later in engineering programmes; perhaps the comprehensive implementation of active pedagogy and a broader perspective on creativity could be the primary driver of a new paradigm in engineering.

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DIVERSITY AND DISCOMFORT

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ABSTRACT

Equality, diversity and inclusion work within engineering education often focuses on gender. Gender underrepresentation having long been established as an inequality within engineering education. Many interventions have been undertaken to address gender inequity yet the change is disproportionately small relative to the quantity of studies, and work on other EDI areas is less frequent and effective. To examine why this might be the case, research was conducted using queer ethnographic interviews with 11 EDI practitioners within engineering education. The key barrier to EDI work was identified as discomfort of academic staff. It is hypothesised that this relates to misalignment between engineering disciplinary identity and skills associated with EDI work. Literature on educational theory identifies discomfort as a necessity for learning and social transformation, and as such, the future of EDI success in engineering relies upon supporting and enabling those experiencing discomfort to utilise it as a driver for equity.

Keywords: Engineering identity, positivism, diversity, discomfort

1 INTRODUCTION

Anyone who has walked into an engineering lecture will be aware of the gender disparity in engineering education. Due to this visible underrepresentation, discussion of gender in engineering has been prevalent for decades, particularly within Higher Education (HE). However, gender is not the discipline's only area of marginalisation; just the one most oft published about. This focus on gender, or on equality, diversity and inclusion (EDI) in general is depicted in *Figure 1*, which shows the findings of a Royal Academy of Engineering systematic literature review on EDI in UK between 2013 and 2022. Here the yellow and turquoise segments, by far the majority of the bars, are gender and EDI respectively.

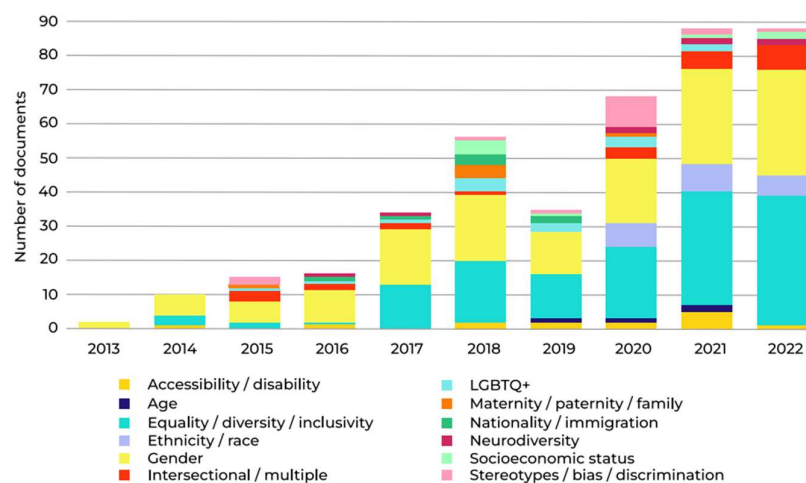


Figure 1. EDI in UK Engineering Documents over Time (Royal Academy of Engineering, 2023)

Furthermore, despite this focus on gender, the proportion of women in engineering in the UK has risen by only 6 percentage points in ten years (EngineeringUK, 2023), with similar findings globally. EDI though is more than just who is present in our classrooms, and whilst women may be severely underrepresented, racial equity remains a more divisive issue in terms of both degree awarding gaps (Codioli McMaster, 2021) and pay gaps (New Scientist Jobs, 2024). Beyond gender and race, EDI work

also encompasses disability, neurodiversity, sexuality, socio-economic status and many other elements, some of which are also visible in Figure 1. All are covered, to a greater or lesser extent, in this research. The research presented in this paper is part of a larger piece of work which examines the focus on gender, using this as a comparison point to explore why other areas of underrepresentation and inequity in engineering education have received less attention. The study interrogates whether the focus on gender relates to the prevalence of women carrying out EDI work in engineering education, with the research question “What is the nature of the relationship between EDI initiatives in Engineering Education, and the positionality of the EDI practitioner?”, looking at approaches to EDI work rather than at the structure of efficacy of the interventions themselves. The research is on-going, and too large for a conference paper, as such, this paper uses the wider body of research to ask, “What is the key barrier to EDI work being more widely and equitably adopted within engineering education?”

2 METHODS

Given this research is about underrepresented communities, and the demographics and characteristics of those conducting EDI work within engineering education, the research needed to use methods designed to amplify marginalised voices and examine identity. As such, Queer Methods were selected. Queer Methods grew from Queer Theory, which itself arose from lesbian, gay and gender studies in the 1990s (Brim & Ghaziani, 2016). They are recognised as being reflexive and dynamic and have been adopted within Social Sciences to move away from historic over-reliance on positivism (Browne & Nash, 2016), but are relatively new to engineering. This shift from positivistic to interpretivist approaches, through the use of Queer Methods, represents both a challenge and an opportunity for engineering education research. By using recognised methods and tools, i.e. Queer Methods, and the Wheel of Power and Privilege, within the research, a trusted framework enables new boundaries to be explored.

The research, approved by the Imperial College London Educational Research Ethics Panel, involved 11 participants from across the UK and US, all of whom were staff working within HE in engineering (or who have recently done so) and who self-identify as EDI practitioners. Participants were specifically selected to give a range of different demographics, backgrounds and institutions, mitigating the impact of small sample size. Each took part in a 1-1 queer ethnographic interview, including a set of 5 semi-structured discussion themes, and 2 activities which included critiquing and annotating images, one of which was the Wheel of Power and Positionality (Duckworth, 2022). An in-depth discussion of Queer Methods and the specific approaches used in this research is available in a prior paper (Agg, 2025). Annotation of the Wheel of Power and Positionality (henceforth WPP) also enabled nuanced collection of demographic data. A collective map of participant and researcher positionality, mapped onto the WPP is visible in *Figure 2*, with each line representing a participant with that characteristic. This shows our participants as being predominantly white, with post-secondary education, able-bodied, heterosexual, neurotypical, with mostly stable mental health, average body size, owning property, middle class, native English speakers with citizenship in the country they were living. Most characteristics had some representation outside the “norm,” and gender approached an even split:

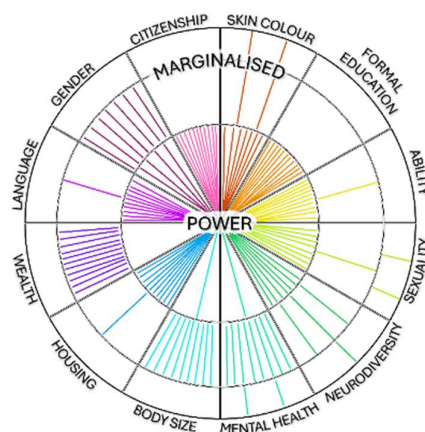


Figure 2. Wheel of Power and Positionality Mapping Participant Positionality

3 ANALYSES

The data included 14 images provided by participants, 11 annotated WPPs and almost 150,000 words from 11 interview transcripts. Only the data from transcripts were incorporated into the coding analysis, with the other data being present to support the reflective process of the interview as well as provide clarification of understanding for both participant and researcher. Transcripts were read several times, including reviewing the images and positionalities of participants, with notes being made throughout the process in order to arrive at a consistent and rigorous coding approach. An abductive approach was taken, using sensitising concepts to support the creation of codes. Sensitising concepts is a long-standing approach used in qualitative research (Blumer, 1954), particularly in ethnography (O'Reilly, 2009), to build upon existing theory whilst remaining open to the nuance of individual perspective. The sensitising concepts used came from the research's framing concepts including Freire (Pedagogy of the Oppressed, 1970), Merriam (Power and positionality: negotiating insider/outsider status within and across cultures, 2001) and De Zoysa (Motivation and the Role of Empathy in Engineering Work, 2024). Coding the transcript data resulted in 152 initial codes, which were then grouped into a set of themes and "regions", illustrated in **Error! Reference source not found.** and **Error! Reference source not found.**;

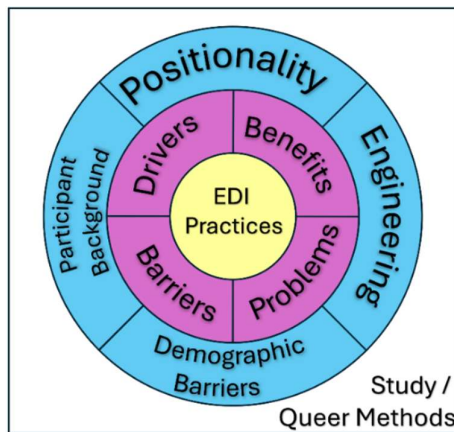


Figure 3. Coding Framework – Themes

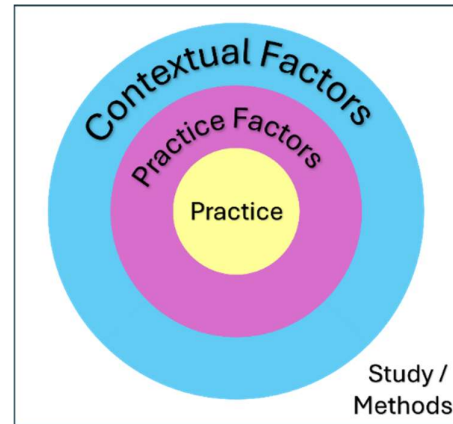


Figure 4. Coding Framework - Regions

Transcripts were coded manually using Nvivo, with segments often being assigned more than one code, for example in Figure 5, on the left Iretioluwa talks about why she started running a Headstart outreach and on program, with the coding stripes shown on the right, relating this to EDI Drivers/Own Background, Student Staff Barriers/Ethnicity, Student Staff Barriers/Class or Wealth, and Problems from EDI work/Lack of Belonging.

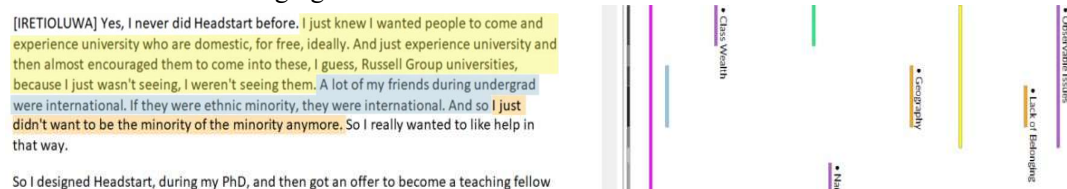


Figure 5. Example coding segment

4 RESULTS

As can be seen from the coding framework, barriers were a significant discussion topic, occurring both at a practice level and at a wider contextual level. Within EDI practice, barrier related codes occurred 486 times, as compared to 197 driver codes, 74 benefit codes and 34 problem codes. Within the practice related barriers, discomfort was the most prevalent code, occurring 31 times, with leadership/authority, resources/money, systems/rules and knowledge all having 25-27 occurrences. Codes relating to discomfort also featured, such as fear (20 occurrences), confidence (13 occurrences), tension (12 occurrences) and vulnerability (8 occurrences). Discomfort of participants colleagues in particular was a deeply discussed barrier to EDI progress as anonymised participants Chris and Iretioluwa illustrate;

“so some of that recalcitrance is that we can't call out because people are so uncomfortable with the idea of being called racist.” [Chris]

“Chloe: Why do you think there is that resistance from staff?

Iretioluwa: I think it's the embarrassment of the conversation.” [Iretioluwa]

Participants also raised concerns about the backlash of people in positions of privilege who have been made to feel uncomfortable:

“inherently there's going to be minority groups and resentment of minority groups if those that are uncomfortable to change are having to change and are identifying a small number of people as to why they need to change” [Toby]

EDI practitioners have also experienced the same discomfort as colleagues, but have either passed through it, or learnt to live within it and channel it to productive use. Below, Emily talks about her historic naivety, before her personal journey as a practitioner. In this quote the discomfort she has experienced on this journey is visible, perhaps enabling empathy for colleagues avoiding of EDI related discomfort:

“sometimes I wish I didn't do that reading and critical reflection because it opens your eyes up to all these things that were never an issue to you and now are. Obviously, I don't wish that.

But, you know, like you can see that sometimes life [was] simpler.” [Emily]

Some participants viewed colleagues' discomfort around EDI work, and to an extent their own personal barriers as well, as something stronger, pushing into being fear:

“before, you might get an email, but now they'll [students] find a forum, and they'll make sure it's like broadcasted widely as to why they're so upset with you. So if they could do that on like a mistake you made on a module, on a slide, right? What will they do if you've done something else wrong? You know, so it's that idea of, actually, let me not do anything, as opposed to trying to keep making a positive impact in all the spaces. Because I think there's a genuine fear on the NSS, student satisfaction, office students, students complaining, there is genuine fear of it.” [Iretioluwa]

Where this fear was being experienced by the participants, rather than by their colleagues, they also talked about having come through to the other side of fear, enabling them to take positive action:

“I think fear sometimes is probably the thing that hasn't gone as well. I'm less fearful now of getting things wrong because actually I'm now approaching it from a place of, well, I'm still learning. So, I want to ask questions because I want to learn and if I put my foot in it then I'll apologise profusely but I'll never do it out of malice and I don't intend to come across as being a nasty person so I'm probably okay. But I think, yeah, things that haven't gone well have usually not gone well because I've not felt comfortable asking the right question to find the information, I needed to make sure something was treated correctly.” [Elizabeth]

One hypothesis for the source of this discomfort associated with EDI work is that it arises from the clash between the traditional nature of engineering work, being a hard, quantitative subject, and the perceived nature of EDI work as being a soft, qualitative subject. This hypothesis builds upon discussion in engineering education research around the hyperfocus of engineering on quantitative data and reliance on existing hierarchies (Pawley, 2019), as well as the well-defined disciplinary identity of engineering as “hard” (Becher, 1989).

By contrast though, the participants generally have the same, or similar, academic background to their non-practitioner colleagues, and are compelled to create change rather than being prevented from doing so by their discomfort. The participants have all experienced discomfort through being marginalised and are therefore potentially more able to work within it, a skill which comes from their marginalisation and is something to celebrate. Participants have all reflected upon their own marginalised identities, and thus their discomfort has been transformative rather than preventative. This relates to Vygotsky's zones of proximal development (1978), which requires transformational crisis to move from one zone of development to another. Whilst originally focused on childhood development, this model has since been applied to learning in many settings so is likely applicable here. Certainly the participants exhibit the transformational crisis Vygotsky deems necessary for learning, as demonstrated in these quotes from Chris and Elizabeth:

“I think because, and we've talked about fighting all the battles. I think over the last, definitely three or four years, my positionality has changed. I think meeting, knowing, and understanding the lived experiences of different people has changed the way I see the world.” [Chris]

“I’m thinking timelines in my head of when I’ve had support and when that fear has then gone away. And they do link, actually, that having become a more confident, kind of calm person in myself, that journey of going to there has actually banished a lot of the fears. Because, partly because of who I am now, but also partly because there might be loads of other people who don’t know how to speak up about those things. And if you go in there and go, okay, yeah, nothing’s off the table, hopefully that will help. And I think it has helped.” [Elizabeth]

Building on Vygotsky’s zones of proximal development, Boler and Zembylas talk about “zones of discomfort” (Boler & Zembylas, 2003). These zones are part of the pedagogy of discomfort which is seated within social justice, focussing on changing of dominant practice and power hierarchies requiring both students and teachers to step outside of their comfort zone in order to enable a move towards equity. This pedagogical approach aligns closely the findings of this study, identifying that discomfort is a requisite component of change in the context of EDI and social justice, as well as crisis being essential for transformational learning. This conglomeration of crisis and discomfort for change and transformation also closely ties in with Queer Methods, which should be socially transformative, yet requiring destabilisation.

A notable caveat is that this research has thus far only interviewed EDI practitioners, so this interpretation of the barriers to other staff taking on EDI work is from the perspective of EDI practitioners, not from the perspective of staff who are being discussed. However, the recurrence of colleague’s discomfort, fear and disinterest through the interviews shows that this is a common theme experienced by EDI practitioners when working with other academics. Further research is needed, with non-EDI focussed engineering education colleagues as participants, to verify that this interpretation is correct. However, given the strong relationship to the well-established literature, and the expertise of the EDI practitioners it is a reasonable working assumption. Furthermore, staff who are not doing EDI work are less likely to engage in studies on the subject, and less likely to answer honestly if they did; admitting to fear, discomfort or a lack of skills being a challenge in itself. Therefore, EDI practitioners’ perspectives are a pertinent proxy in this case.

In terms of translating research findings into action, participants viewed their currently disengaged colleagues as an essential component to the future success of EDI in engineering. Here Dave identifies with civil rights movements, and the need of persuading the majority to change:

“you know as in all civil rights movements invariably it’s only when the minoritised have support of at least an element of the majority that change really ever happens. That’s how it got like that in the first place, because one group had power and one didn’t, it’s not until the group that have power are persuaded to change that it moves on” [Dave]

5 CONCLUSIONS

In asking “What is the key barrier to EDI work being more widely and equitably adopted within engineering education?” this paper finds that, engaging with EDI work induces discomfort in engineers. This appears to be caused by the prospect of moving away from traditional scientific comfort zones, which align with the “hard applied” territory of engineering disciplinary identity. This discomfort is amongst the greatest perceived barriers to successful and on-going EDI work. EDI practitioners are able, to some extent, to tackle these barriers by drawing upon their own positionality which is a source of strength, with marginalisation, empowering their empathy, authority and anger over inequity issues. Discomfort, it appears, can be both a barrier and a driver to action on EDI depending on a person’s access to reflective learning, and support to move outside of their comfort zone.

As it currently stands, EDI work is an act of rebellion. Not necessarily intentionally, nor radically, but inherently. EDI work looks to change systems away from the traditions of decades and centuries, it invites in people who have never been represented as holding power in engineering classrooms. When looked at on this scale, it is no wonder that it has the potential to cause discomfort. EDI practitioners however are fuelling this work through their difference from existing norms; they are already the outsiders and are thus well positioned to be the rebels. Though these acts of rebellion are initially intimidating or uncomfortable to undertake, EDI practitioners find them to be rewarding, and a source of pride. The challenge then is how to support others through their discomfort; to offer them opportunities to share the joy of EDI work through breaking a few rules or “norms” themselves, and to learn and reflect in the process. Historic methods have been ineffective and have relied upon data and focused on gender. As Audre Lorde says, “the master’s tools will never dismantle the master’s house”

(Lorde, 1984); if we want to dismantle an inequitable system we must use different tools such as queer methods, and be prepared to experience discomfort as we collectively transition from one zone to another.

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DIVERSE (DIGITAL) TEXTILE DESIGNING MODELS AND THE UN-/TOUCHABLE LEARNING EFFECTS

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ABSTRACT

Today the industry and the user are facing virtual spaces as parallel world to the physical experience. This scoping paper explores how digital and AI-driven simulations translate textile tactility into visual form, inviting users and designers within industrial creation processes to ‘feel’ through vision. Drawing on the concept of ‘Material Mind’ (by Wachs, M.E.) from 2008, with the statement ‘thinking of material, is touching material’, we are facing how this concept evolves in the context of digitalisation. As a diverse disciplinary and didactically diverse design project, this scoping paper focus on integrative interactive hybrid design and learning space for diverse users. These new forms of ‘co-ideating’ can be evaluated as embodied social knowledge spaces, where aesthetic meaning is co-created through diverse media, diverse senses and diverse didactically creation spaces and with respect to diverse culturally symbolic values. Bringing diverse perspectives of the user, the designer, and the industries into a discussion for resilient future, via ‘co-ideating’ as both designing and educational creation spaces, provides a deeper understanding of perceptual processes. Integrating Human-Centred Aesthetic Systems (Human-CAS by Rem, K.) enables a deeper understanding of aesthetic transitions grounded in embodied, cognitive, and diverse cultural competences in digital areas. New divers Co- designing and learning spaces and methods are describing the new significance of a ‘textile mind’.

Keywords: Embodied craft knowledge, haptic experiences in virtual spaces, diversity and participation in designing media, crafts designer & cultural diversity in industry, human-centred aesthetic systems

1 INTRODUCTION - THINKING MATERIAL IS TOUCHING MATERIAL?

This scoping paper envisions how digital and AI-driven simulations translate textile tactility into visual form - inviting consumers and industrial designers to ‘feel’ through vision. Drawing on the concept of Material Mind with the statement ‘thinking of material, is touching material’ from 2007 [1], we are facing 20 years later, how this concept evolves in the context of digitalisation. Today an inflationary perception of value is observable [2], in which raw materials are losing their significance. Through interdisciplinary designing systems, proclaimed through ‘tool driven’ case studies - denim upcycling methods, recovering textiles made of cotton grass (see chapter two) -, digitally mediated textile industrial usage and visions in industry (see chapter three), and a theoretical integration of virtual Human-Centred Aesthetic Systems (see chapter 4), new hybrid ‘co-ideating spaces’ (not co-working spaces) are triggered by the user and ‘crafts designer’. All three stakeholders work collaboratively: next-generation students and engineer experts from industry and user, this was just examined by interdisciplinary courses. That builds the base for integrated educative hybrid processes of learning and of perception. With the help of the defined model from 2008 ‘thinking material is touching material’, a further evolved system in imagining material through virtual representation gives room for remembering un-/ touchable material attributes through virtual experience of textile materials. Within the cultural and traditional contexts, textile technologies and resilient production processes are predominant factors [3] for products which are associated with higher quality and higher attraction by the consumer. This is based on embodied experiences and the frame of collective remembrance [4] of people, diverse spaces – analogue, digital and metaphorical – are creating in the post-digital era a new model of ‘textile mind’ [5]. As a diverse disciplinary and didactically diverse design project, this project-based course is showcasing an integrative interactive hybrid design learning model. Diverse perspectives - by the user, the designer, and the industries via co-ideating spaces as both designing and educational creation spaces - provide

opportunities for a deeper understanding of perceptual processes by diverse stakeholders. Starting with re-innovative, body-involved handmade designs as vision: Figure one (1) simultaneously demonstrates and evokes embodied knowledge [6] and the hand-brain coordination involved in sketching future visions, by using co-designing experiences and the development of ‘human body – machines driven – co-designing’ – this was shown at the Dialogwerkstatt at WDC – World Design Capital 2026 for example (see fig.1-3). It leads to crafts knowledge as trigger for innovative design and participative design.

2 DENIM UPCYCLING - INNOVATIVE CRAFT PRACTICES AS DRIVERS

The textile heritage of craftsmanship is the origin of the textile industry and thus an essential foundation for future-oriented design education [7]. The processes of craft practice involve implicit, embodied knowledge that is often intangible and challenging to articulate [8], yet crucial for learners to understand, evaluate, and navigate today's complex industrial practices [9]. The foundations of craftsmanship are embodied by experience-oriented and value-oriented learning in education, thereby enabling students to develop essential skills for managing values within industrial contexts [10]. The denim upcycling study is used to demonstrate how embodied textile craft knowledge can be applied in the field of design education. It examines hybrid methods that combine craft techniques, such as crocheting, with industrial processes, such as laser cutting, as educational tools [11]. As illustrated in Figure one (1) the digital file is translated into cuts by the laser cutter, with the resultant stripes then being crocheted together by hand with a crochet hook. The development of this technique is fully demonstrated in the outfit depicted on the right of Figure one (1). These processing techniques and methods enable students to translate their personal and cultural values into industrially relevant solutions by fostering slow design [12], co-design [13] and adaptive thinking [14]. This approach fosters reflective and diverse decision-making processes, which extends beyond the confines of purely digital modelling environments. In contrast, the process of hand-crafting exposes designers to uncertainty, resistance, and tactile feedback, whereas purely digital creation simulates pre-controlled material properties. These material negotiations require iterative adjustment and embodied judgement, generating tacit and relational knowledge that exceeds algorithmic prediction. By engaging directly with materials - by simultaneously reassessing the thesis from even 20 years ago ‘thinking material is touching material’, and processing through integrating craftsmanship in combination with industrial practices, a material-minded approach is cultivated. Therefore, designers are encouraged to become not only technically proficient, but also systemically relevant contributors capable of shaping resilient and meaningful industrial practices [15].

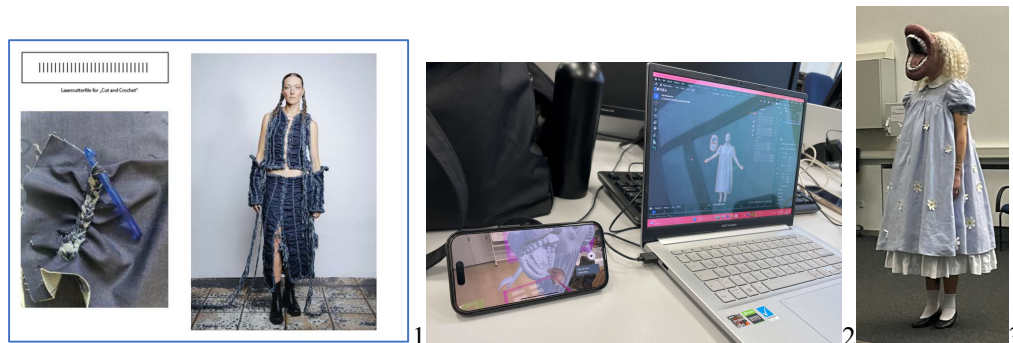


Figure 1. Digital laser cut file, prototype of hybrid ‘Cut and Crochet’-Technique; Outfit ‘Structear’ (c M. Lemper). Figure 2 & 3. digital – analogue x design experience; costume: the Cry, WS 2024/25

3 TACTILITY, CRAFT AND DIGITAL TRANSLATION IN DESIGN PRACTICE

At the beginning of the 20th century, products were primarily categorised and evaluated according to their visual appearance. Visual aesthetics like the shape or colour of a product played a decisive role in customers’ purchasing decisions. With the increasing diversification of product ranges, production methods and material options, however, additional sensory dimensions have become central to product perception and selection [16]. In the past, for example, a wooden table was typically made of solid wood, offering limited variation. Today, a table with a wooden appearance may assume almost any form or scale and can be produced from a wide range of materials, including plastics that visually simulate wood. As a consequence, tactile perception has gained importance as a key factor in purchasing decisions and

referencing to high quality in design and the atmospheric interpretation. Tactile sensation does not only refer to the immediate sensory experience of touching a material but is also closely linked to product functionality - such as ease of handling or comfort in use. While such functional tactile aspects can be comparatively well assessed and integrated into the design process through user research, sensory-affective tactile perceptions are far more complex. The evaluation of whether a material feels pleasant or meaningful is shaped by embodied, cognitive and cultural factors, including age, gender, social background and cultural identity. These dimensions of diverse triggered embodied perception are less predictable, yet they play a crucial role in aesthetic judgement and decision-making [17]. Material surfaces may be individually perceived as rough or smooth, warm or cold, sticky or slippery. In textiles in particular, production methods and internal material structures significantly influence surface qualities and tactile aesthetics [18]. As discussed earlier, textile heritage is deeply connected to craftsmanship and embodied cultural knowledge. Crafted materials - such as handwoven wool fabrics - are often perceived as carrying greater aesthetic and symbolic value than man-made fibres and industrially-produced textiles, even if identical raw materials are used. Visual and tactile indicators of craftsmanship thus contribute to the co-creation of aesthetic meaning and to the perception of higher product value [19].

Within contemporary design practice, AI-driven tools increasingly support design processes by accelerating workflows and aligning outcomes with user preferences [20]. However, translating virtual design simulations into meaningful physical products requires AI systems to be trained on deep material understanding [21]. In textile design education, this underscores the continued importance of teaching craftsmanship techniques and textile history. Such embodied knowledge [22] enables students to critically evaluate AI-generated design proposals and to actively shape Human-Centred Aesthetic Systems (see chapter 4). The loss of historical knowledge related to colours, patterns, and textile techniques would therefore not only weaken cultural heritage but also limit the development of resilient digital design practices and minimise a longevity of high quality of value-driven designed products and product languages [23]. In this respect, parallels can be drawn to inclusive design approaches, which shift from the task of adjusting individuals to fit in a system to adjusting the system so everyone can fit in [24]. Hybrid co-working and co-learning spaces should create accessibility to bring together academia, industry and craftsmanship to integrate embodied material knowledge with advanced digital technologies [25].

4 EMBODIMENT, PERCEPTION & SENSORY INTELLIGENCE

4.1 Embodied Perception and Aesthetic Meaning in Virtual Design Learning

This paper adopts theoretical and speculative research, aiming to establish a conceptual framework for diverse ideating spaces. The objective is to ensure that future generations of designers are well informed about cultural meanings and tactile feel and feedback while simultaneously working within contemporary design practices, which are increasingly inseparable from artificial intelligence [26].

When considering the increasing integration of digital media in design education over the past decade, indications emerge of a gradual transformation in the role and relevance of physical artefacts such as sketching tools, fabrics, books, and other material media. Rather than a complete disappearance, these artefacts may become recontextualised within hybrid educational environments that combine innovative physical (see chapter 2) and digital modes of learning. How can embodied sensory intelligence and culturally embedded craft traditions - historically shaped through prolonged physical interaction with materials - be meaningfully supported in learning environments where sensory input is reorganised through virtual mediation? While contemporary VR interaction systems increasingly incorporate multisensory and sensorimotor feedback, they differ fundamentally from direct material engagement, particularly regarding resistance, texture, and material agency. In this context, the question is not whether embodiment disappears, but how forms of embodiment are transformed within virtual learning systems [27].

Regarding the acquisition of aesthetic competence during comprehensive design education, students undergo multiple stages of learning how aesthetics are constructed and how they are perceived by users of designed artefacts. These competencies are subsequently applied when entering professional industrial contexts. Designing products within corporate environments requires the creation of artefacts that are user-friendly, aesthetically coherent, and intuitively understandable for a company's specific target group [28]. For this purpose, the term 'Human-Centred Aesthetic Systems' (the author) is proposed as a conceptual framework rather than a prescriptive model. It is intended to support analytical

reflection on how aesthetic meaning emerges from the interaction of embodied perception, cultural background, emotional response, and contextual use, rather than to define a universal or measurable system. The following definition is proposed: Human-Centred Aesthetic Systems (Human-CAS) are systems applied during the design and creation of products, services, or experiences. They describe the holistic integration of human well-being, needs, perceptions, emotions, and cultural values that are meaningful to the individual during the process of selecting, purchasing, interacting with, and using a product, service, or experience. A key characteristic of Human-CAS is the diversity and inclusivity of potential outcomes, which depend on the individual engaging with the designed artefact. Diverse cultural backgrounds and personal preferences therefore fundamentally influence aesthetic perception [29]. Consequently, Human-CAS are grounded in individual embodied perception and cognition. In conclusion, this definition postulates that human perception, emotion, movement, and cultural background co-construct aesthetic meaning. This here developed Human-CAS can be evaluated as valuable embodied social knowledge place, where aesthetic meaning is co-created through tactile experience visual-cognitive, and culturally symbolic processes and turning diversity into a strength.

At this point, a central question emerges: how can design education within VR-based learning environments enable students to embody aesthetic meaning without direct material contact? Donald Hoffman, a cognitive scientist and author of 'The Case Against Reality', refers to Darwin's theory of natural selection and argues that all living organisms, including humans, perceive reality through perceptual systems optimised for survival rather than for objective truth. He illustrates this by comparing different species' perceptual capabilities [30]. For example, bats perceive their environment primarily through echolocation, which enables efficient navigation and hunting in nocturnal conditions [31]. Dogs possess approximately between 125 and 300 million olfactory receptors, whereas humans have approximately five to six million, resulting in vastly different sensory priorities [32]. These examples illustrate that non-human species possess sensory capabilities that exceed human perception in specific domains. Consequently, humans are constrained in their sensory access to reality. This supports the assumption that humans do not perceive reality as it objectively is, but rather as it is functionally useful for survival in the individual's culture and environment.

4.2 Mental and Sensory Intelligence in Co-Ideating Spaces

Donald Hoffman's theory of perception, while contested within cognitive science, offers a speculative lens for rethinking material and tactile perception: as an adaptive interface rather than a direct representation of reality. Within the scope of this paper, the theory is not treated as empirical evidence, but as a conceptual provocation that allows reflection on how perceptual interfaces - such as virtual learning environments - might be intentionally designed to communicate cultural, traditional and tactile perception and meaning without replicating physical reality. One example of such an approach proposes virtual craft learning - in textile business areas, such as learning to crochet, knit or sew through simulated exercises rather than through direct manipulation of physical tools, like proven (see chapter 2). Research on exergaming and mental rehearsal demonstrates that motor skills and cognitive performance can improve through movement-based virtual interaction and mental simulation [33]. While these findings cannot be directly equated with material-based craftsmanship, they provide indicative evidence that embodied learning processes can occur in the absence of traditional tools, thereby grounding in a base of information, mental preparation, and motivating further investigation into how aspects of craft learning might be supported through virtual environments.

Motivation and mental preparation, like it is proposed by Marina-Elena Wachs in her theory of 'Touching Material is Thinking About Material' [34], leads us to comparable improvements in physical and mental performances, that have been documented in individuals who engage in mental rehearsal of sports movements or musical performance. Neuroimaging studies demonstrate measurable neural adaptations and skill improvements resulting from purely mental practice and visualisation [35]. Motion-based and gesture-controlled applications thus provide precedents for learning through rhythm, movement, and virtual feedback [36]. This supports the assumption that craftsmanship skills in textile and tactile spaces can also be acquired through embodied interaction, even in the absence of physical tools and materials. That was shown by the sustainable analogue-virtual designed costume 'The Cry' (presented 12. Of June 2026, F. a M.) – see figures 2, 3. Another case study of cotton grass and the textile mind (see EPDE Conference September 2026) shows the didactically capability of envision sustainable design solutions by the combination of embodied experiences and digital diverse tool for a

textile change management and usage of textile diverse archives – through the ‘untouchable textile learning spaces’.

In the development of such virtual learning environments for future design education, artificial intelligence can function as a key component of augmented tactile learning systems and lead to embodiment. Artificial intelligence, when critically designed and carefully implemented, has the potential to support adaptive learning environments that respond to individual sensory, cognitive, and cultural differences. In this sense, AI can function as an enabling technology for inclusive Human-Centred Aesthetic Systems and educational scenarios, rather than as an autonomous replacement for traditional craft knowledge or pedagogical expertise.

5 THE UN-TOUCHABLE DIVERSE DESIGNING MODEL

The scoping concept formulates ‘how digital and AI-driven simulations translate textile tactility into visual form to ‘feel’ through vision’. Our just in time applied courses draw a hybrid-disciplinary and diverse didactically design environment. Diverse case studies integrate the concept of an expanded material mind (2008) as an expanded ‘textile mind (2026) – for an integrative, interactive hybrid design field that emphasises experiential learning, spatial exploration, and collaborative co-ideation rather than direct instruction; this is and will be integrated into current courses of XR-learning design spaces. The didactic model integrates generative parameters such as motivation, information systems, and interdisciplinary mediators - both physical and AI-based avatars. The concept frames the effect of ‘untouchable’ tactility:

1. The ‘feeling-through-vision’ creative element stimulates industrial innovation;
 2. New hybrid ‘co-ideation spaces’ are simultaneously activated by users and craft designers;
 3. Craft designers are educated beyond traditional pedagogical models;
 4. The traditional ‘material mind’ takes an active role in co-designing digital textile knowledge;
 5. Connected educational spaces represent future diverse material-creation system, the ‘textile mind’ as an important tool included.
 6. Industry-user interactions establish virtual creation by co-ideation & diverse-creation scenarios.
- Diversity through participation by education with diverse media results in creating new products which are considered as significant sustainable - as valuable in the user’s sense. Within this conceptual vision, design students may increasingly be positioned as mediators between physical spaces and virtual material domains, assuming reflective roles in translating embodied, cultural, and Human-CAS across hybrid design contexts and diverse tactile designing and co-ideating spaces.

DECLARATION

AI – Usage only for evaluating our style of writings - not for developing content.

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CO-CREATING A PROGRAMME OF BELONGING FOR UNDERGRADUATE WIDENING PARTICIPATION ENGINEERING STUDENTS

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ABSTRACT

Students from low socio-economic backgrounds face significant barriers to progression. Isolation, lack of belonging, and imposter syndrome are genuine concerns for widening participation (WP) students and can undermine attainment and experience. In partnership with students, we co-created a support programme for first-year undergraduates to foster belonging and improve progression and retention. Each element of the programme was carefully curated to build cohorts, develop interpersonal skills, and provide academic and social support, while challenging negative preconceptions about engineering research. Initial evaluation highlighted the residential's impact in easing transition and strengthening belonging. This paper examines longitudinal outcomes, alongside staff and student perspectives on sustaining success. Key challenges, such as low female participation and clashes between religious obligations and study demands, are analysed through an intersectional lens. Student voice was embedded throughout design and evaluation, with staff and student collaboration valued equally to mitigate bias and amplify marginalised voices. By reflecting on successes and flaws, we propose a framework for other universities to enhance WP student transition and outcomes.

Keywords: Widening participation, co-creation, belonging

1 INTRODUCTION

While initiatives to widen participation have expanded opportunities for underrepresented groups, there is growing recognition that access alone is not enough. Students from low socio-economic backgrounds continue to face significant barriers to progression. Feelings of isolation, lack of belonging, and imposter syndrome are genuine concerns for widening participation (WP) students and can negatively impact their academic attainment and overall student experience. Fostering a strong sense of belonging is increasingly recognised as a critical factor for success, both in terms of academic achievement and overall wellbeing [1], [2], [3]. Departmental belonging is not always achievable or desired by students [4], so the creation of an additional cohort to connect with is essential.

Working in partnership with student representatives from Imperial's working-class network and funded by the Royal Academy of Engineering's Diversity Impact Programme, we designed a pre-arrival residential programme for first-year WP students that aimed to instil a greater sense of belonging and address lower levels of progression and retention at Imperial College London. The New Starters' Residential Programme was developed to help students build early connections, develop confidence, and feel comfortable within the university environment before the start of term. Between September 2022 and October 2024, the programme successfully supported 185 engineering students in their transition from school to university. The programme has continued, but this study focuses on the first three years to enable longitudinal data to be examined.

2 PARTICIPANTS

First-year undergraduate engineering offer holders who met the published criteria for contextual admissions were invited to take part: 120 students were invited (52 attendees) during August 2022, a further 133 (60 attendees) during August 2023, and 190 (73 attendees) during August 2024, from across ten engineering departments. The pre-arrival residential was an opt-in programme with a consistent uptake rate of ~40%. Students were categorised as WP based on published criteria, including: low socio-economic background, first in family to attend university, or experience of care or caring

responsibilities. Only Home (UK-based) students were eligible, due to greater data availability to identify WP markers.

This demographic remains underrepresented in academia; HEFCE data shows 14% fewer WP students at UK universities than would be expected based on A-Level grade benchmarking [5], with intersectionality increasing this gap. For example, the ethnicity profile of attendees did not mirror that of the broader student body: 15% of participants identified as Black African, compared with just 4.98% of Imperial's total undergraduate population [6]. Disability was another key intersection identified, with the residential serving as an opportunity for early identification and provision of support.

While most students were aware that they met one or more WP criteria, we did not assume they would feel comfortable being identified as WP among peers. For this reason, participation was opt-in rather than opt-out, and great care was taken to ensure that invitations, and the design of the New Starters' Residential Programme, adopted an asset-based rather than deficit-based approach.

3 PROGRAMME DESIGN

Analysis of institutional data, progression trends, and consultations with students identified four key areas as priorities for widening participation (WP) students: academic progression, retention, enrichment, and belonging. The working group designing the programme included educators, wellbeing advisers, and support staff from all ten engineering departments, and WP student partners from Imperial's working-class network. Students were involved from the outset in co-creating the programme, supporting delivery (including society-led sessions), and contributing to evaluation design, with student union welfare officers facilitating focus groups.

Our design was guided by three principles: belonging-focused pedagogy, asset-based framing, and equitable access. To avoid positioning students at a disadvantage before starting their degree, the programme emphasised pastoral and social activities, and all costs including travel were covered to ensure minimal or zero financial burden.

The New Starters' pre-arrival residential included carefully curated academic and social activities that supported cohort building, developed interpersonal skills, and enabled early engagement with lecturers and student ambassadors. Survey data, student feedback and staff-student collaboration guided initial decisions about session content and activity balance. Activities ranged from sports and library treasure hunts to team-building exercises and workshops on imposter syndrome, as well as academic poster sessions and lab practice, with a deliberately busy timetable to provide multiple networking opportunities and most accurately represent a typical week at university.

The programme was refined iteratively across all three years of delivery, with adjustments to recruitment, timetabling, and activity selection. Notably, arts and humanities-based sessions were introduced in later cohorts following participant feedback. Student ambassadors - many of whom had previously taken part in the residential themselves - provided ongoing insights into both the participant and delivery perspectives, further strengthening the programme design year on year. Overwhelmingly positive feedback from students and staff (100% of participants reported they would recommend the programme to a friend) led to continued delivery within Engineering and, in 2025, adoption of the residential university-wide.

3.1 Designing for Academic Confidence and Belonging

Feedback both via a belonging survey and directly from student collaborators identified a need to instil confidence in academic ability and belonging within departments and wider faculty. Data highlighted the importance of student societies, lack of community within departments and the prevalence of imposter syndrome. Students reported that the size of departments can feel overwhelming, and at times they feel less welcome as a result.

This informed the key theme of networking with a variety of staff in the department and faculty. At a faculty level, there was a welcome lecture from the Faculty Senior Tutor, Associate Dean for Education and an Engineering academic, to inspire students and demonstrate that the faculty cares at multiple levels. Departmental networking events introduced key staff that students interact with in the first year, e.g. heads of department, teaching staff, administrators, wellbeing advisers etc. This humanised these staff members, removing barriers for students to approach staff when they first start. We wanted to ensure students felt comfortable and knew where to seek help if they were struggling during their study before the campus filled with thousands of students.

Other activities included general orientation, including departmental tours featuring offices of key

contacts, exhibitions, lab visits etc., granting independence and familiarity within department buildings. One example of attending the Undergraduate Research Opportunity Programme (UROP) poster exhibition in the Mechanical Engineering department, became an impactful way to introduce students to research programmes and see how their curriculum is applied in real-time. Incoming students networked with older year students, inspiring several students to pursue UROPs in the summer after 1st year. Due to the popularity of the exhibition with the residential cohort, the UROP organiser now schedules the exhibition to coincide with the residential.

3.2 Designing for Social Connection and Community

The residential programme also included opportunities for social connection and community. This included bowling, boardgames, and spending time in the common room with fellow students and ambassadors. Peer-to-peer networking was highly valued, and students later reported relying on the social networks they established during the residential week when later facing challenges.

We encouraged students to try a wide range of activities and remain open-minded. Even less enjoyable tasks, such as being tied together for the welcome scavenger hunt, helped build group cohesion. To balance the packed schedule, we included mindful activities, like gardening and drawing. We embraced spontaneity, for instance an impromptu walk in Hyde Park on a sunny day led by the student ambassadors, which received excellent feedback. Students especially appreciated having space for honest discussions with peers and older students without staff present.

4 STUDENT PERSPECTIVE

Evidence gathered through evaluative student focus groups, surveys, and reflective feedback indicates that the pre-arrival residential achieved its primary objective of enhancing students' sense of belonging and readiness for university. Students attributed the programme's effectiveness to its co-design with student partners [7], its welcoming, asset-based ethos, its visibility of diverse staff who shared backgrounds similar to their own, and the balance of academic and social activities that made the transition feel manageable and meaningful. Anecdotally, participants have a different and less isolating first-year experience to those who have not attended the residential, though there is still research to be done with non-participants to fully understand the impact of the residential, both in the short- and long-term.

4.1 Co-design and an Asset-Based Ethos

Students perceived the programme as relevant and respectful because it was shaped by people with lived experience and delivered with them, not to them [7]. As one student noted, it *"had been made by people who knew what it was like to be in my position, which hasn't been the same for other activities I've participated with other organisations"*. In contrast, students critiqued deficit-framed approaches elsewhere that made them feel they needed to *"catch up"*, reporting that such framing can undermine confidence, leading to students feeling uncertain about their capabilities and whether they will be behind the rest of their cohort even before university starts. By contrast, activities that invited students to voice concerns and shape the space made them feel *"more confident for the next stage"* [7], [8].

Students highlighted how the residential empowered them to voice their perspectives, questions, and concerns about the norms of university life. These conversations encouraged students to articulate their needs confidently and created space for meaningful institutional reflection and improvement. For example, students highlighted the need to re-evaluate prayer facilities and ensure the residential timetable allowed participants to attend prayers without missing activities. This responsiveness to student feedback illustrates how an asset-based approach can surface structural barriers that might otherwise remain hidden and can guide more inclusive programme design and institutional practice.

4.2 Easing the School-University Transition and Clarifying Expectations

Students repeatedly emphasised the challenge of transition: *"The jump from College to University is immense, and it can be a very unfamiliar period for a student"*. The programme addressed this by offering structured exposure to academic and social elements of university life. Early encounters with staff and student ambassadors helped students form a holistic picture of expectations and how to engage proactively in their department. Importantly, the residential reduced barriers to experiences that might otherwise be inaccessible for students from low-socioeconomic backgrounds. For instance, taking part in societies and the chance to sample 'dorm life'. This was particularly valued by commuting students:

“There are some people that live in London and go to accommodation. I would never be able to do that”. By having these experiences, students who commute could feel more included when engaging with peers who lived in student accommodation during term time.

4.3 Building Social Capital and Cross-Cohort Community

Students described the residential as a *“shared experience”* that helped them *“ease into the huge community that is, Imperial.”* They reported that new friendships and networks made their wider experience more sustainable and fulfilling: *“The people I met on the program, having time with them is very like, it makes the other stuff worth it.”* Cross-disciplinary connections were a specific gain - *“I’m meeting lots of students from different departments and I probably wouldn’t have the opportunity otherwise”* - broadening academic horizons and informal guidance networks beyond the programme. Students repeatedly linked belonging with identity affirmation and psychological safety: *“The programme has allowed me to make friends with people in similar situations to myself and has assured me that I won’t be attending here with people overly unlike myself.”* Peer support reduced isolation and supported help-seeking: *“It has been great to have someone to go to when I am experiencing problems, for example when I was stressing about exams and didn’t know how to approach revision.”* The role of ongoing social contact in sustaining motivation was explicit: *“I think the social element is massively important. [...] But just by hanging out with them, you feel happier... that’s what you need to give you the extra boost...”* Experiencing residential-type activities with peers from *“a variety of lived experiences and disciplines”* fostered a *“willingness to communicate,”* which students identified as foundational for future collaboration and confidence in university spaces.

5 LIMITATIONS AND BARRIERS TO SUCCESS

The success of the first New Starters’ Residential in September 2022, and of the subsequent programmes, was underpinned by strong cross-departmental collaboration, a significant degree of goodwill from staff, and sustained partnership working with student ambassadors, officer trustees (Imperial Student Union), and liberation and community networks (Imperial Working-Class Network). Achieving this could be difficult if replicated in larger or less resourced institutions. These collective efforts shaped both the design and delivery of the residential and contributed to its positive reception among participants. In this section, we examine the key insights gained through implementation, outlining the programme’s limitations and challenges encountered across the three years of delivery.

While this model was effective in a pilot context, long-term sustainability requires more formalised resourcing, staff training, and institutional structures to avoid over-reliance on volunteer labour. It is also important to acknowledge that programmes of this nature often draw disproportionately on the time, emotional labour, and expertise of staff and students from underrepresented or minoritised backgrounds. This “minority tax” [9] can place an additional burden on individuals who already carry significant informal responsibilities in supporting inclusion and belonging within the institution. To ensure equity and sustainability, dedicated workload allocation and institutional support that does not depend on the unpaid or under-rewarded labour of those who share similar lived experiences with the participants is required.

The programme operated on an opt-in basis, which attracted students who were already motivated to seek additional support or who felt comfortable engaging in pre-arrival activities. More work needs to be done to better understand the motivations of students who chose not to engage with the programme, and how this has affected their sense of belonging and academic progression at Imperial. Student perspectives gathered on this show that more needs to be done to explain the benefits of the programme, as well as fully subsidising travel costs for students attending the residential. Furthermore, the wraparound element of the programme offers an opportunity for students who initially “opted out” to join the programme once term has commenced. The open invitation nature of this aspect must be greater emphasised to encourage non-attendees to participate.

Capacity constraints linked to accommodation availability, staffing, and funding also limited the number of students who could participate each year. Fortunately, we never met this participation limit, as we always budgeted for a 50% uptake rate, but it is a limitation that other institutions should consider when attempting to replicate the programme.

6 KEY FINDINGS AND RECOMMENDATIONS

Findings from the initial three years of delivery show that the New Starters' Residential Programme was highly successful in strengthening students' sense of belonging, confidence, and readiness for the transition to university. Student feedback consistently emphasised the value of being welcomed into a peer community of others with similar experiences: *"The programme has allowed me to make friends with people in similar situations to myself and has assured me that I won't be attending here with people overly unlike myself."* Across all three cohorts, 100% of participants reported that they would recommend the programme to a friend, reflecting the overwhelmingly positive reception of the residential.

To evaluate the programme's effectiveness, we collected mixed-method data (pre- and post-participation survey responses, focus groups, interviews, and quantitative data provided by university central services to map student progression and retention) with full ethical approval. Four key groups contributed evidence: WP students who participated in the residential; the project team and student advisory panel involved in co-creation; academic staff and student ambassadors who supported delivery; and external partners who contributed to key aspects of the programme. This multi-stakeholder dataset provided a robust foundation for identifying the programme's impact, limitations, and areas for development.

One of the strongest findings concerned the importance of transparency. Students responded positively to the clear and upfront communication about why they had been invited, and staff engagement improved markedly when departments understood the programme's purpose and their own role within it. Regular communication within the working group, and the use of a single departmental contact ensured alignment, and reduced duplication across the ten engineering departments involved.

The involvement of student ambassadors was a significant strength. Participants valued opportunities to ask senior students questions about university life that they might not have felt comfortable posing to staff; the ambassadors lived experience made their guidance particularly meaningful. The co-design approach was central to identifying student needs - such as prayer facilities, concerns about financial support, and clarity around bursary eligibility - which shaped both programme content and institutional improvements.

Equitable access also emerged as a key driver of engagement. Making all activities free of charge, coupled with travel bursaries and lunch vouchers, enabled students to participate fully without financial worry. Staying in student accommodation was especially impactful for students who would not otherwise have experienced halls, helping them to understand what to expect and feel more prepared for the start of term.

Cross-departmental collaboration enhanced both student and staff experience. Participants appreciated meeting peers from other engineering departments - *"I'm meeting lots of students from different departments and I probably wouldn't have the opportunity otherwise"* - and staff who delivered sessions reported that small-group interactions allowed them to better understand students' needs. This helped surface undisclosed or undiagnosed disabilities, financial challenges, and other concerns early, enabling timely referrals and support.

The timing and duration of the residential were viewed as appropriate by staff and students. A week-long schedule provided sufficient time for friendships and networks to develop, and the residential aspect was considered essential for establishing peer belonging. A strong variety of social activities supported this process, with students describing long-lasting friendships and ongoing support networks across cohorts.

Students frequently commented on the "genuineness" of the programme and the comfort of being surrounded by peers with different accents, characteristics, and personalities, noting that *"[the programme] had been made by people who knew what it was like to be in my position"*. The sense of shared experience helped students *"ease into the huge community that is Imperial"* and many continue to draw on these relationships as sources of academic, social, and emotional support.

Overall, the residential had a significant positive effect on participating students and staff and has contributed to a broader shift in Imperial's approach to supporting widening participation students during transition. As evidenced by the overwhelmingly positive feedback and strong engagement, the residential model offers a powerful mechanism for improving belonging, transition, and equity for widening participation students in Engineering. This feedback directly informed the decision to continue delivery within Engineering and, in 2025, adopt the residential model across the university.

7 CONCLUSIONS

Unlike many broad, institution-wide widening participation (WP) initiatives, this work is rooted in the specific disciplinary context of engineering, where challenges around retention, progression, and diversity remain particularly acute. The New Starters' Residential Programme was co-designed with students and delivered collaboratively across ten engineering departments and included engineering specific activities. Evaluation across three cohorts demonstrates measurable improvements in students' sense of belonging, academic confidence, and transition preparedness. Intersectional analysis of barriers offers educators a practical, inclusive framework for supporting WP students.

Our aim was to create a positive learning environment in which belonging could enhance students' persistence, academic development, and engagement. Although ambitious, the qualitative findings show that meaningful progress has been achieved. The programme provides evidence of the value of early, community-focused transitional support and serves as a replicable model for practitioners seeking to embed similar approaches within their own institutions. Learning gained across multiple iterations highlights the importance of asset-based design, student partnership, and equitable access for supporting underrepresented students.

A strong sense of belonging is known to improve academic persistence, wellbeing, and identity development [1]. We anticipate that this programme will continue to contribute to reducing attainment gaps, such as higher rates of re-sits and deferrals among WP students, by instilling this sense of belonging and fostering ownership over learning [7], [8]. Beyond strengthening belonging, the residential has enhanced cross-departmental collaboration and partnership with university services. These findings, alongside overwhelmingly positive student feedback, provide strong justification for the continued investment in and scaling of pre-arrival support for WP students within Engineering and across wider university networks using a co-creation approach [10].

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INCLUSIVE SOCIAL DESIGN IN PRODUCT DESIGN EDUCATION DEVELOPING THERAPEUTIC SOLUTIONS FOR SPASTICITY IN THE MEXICAN PUBLIC HEALTH CONTEXT

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ABSTRACT

This proposal describes the design process and results obtained through an academic and social collaboration between Product Design students from a Mexican University and the Physical Medicine and Rehabilitation Unit of the Mexican Social Security Institute (IMSS). The project focused on developing products for patients with upper limb spasticity, a condition requiring constant therapy, which is often demotivating and involves limited accessibility to affordable equipment. The implemented methodology is an example of inclusive design and diversity in educational practice, as it compelled designers to look beyond technical specifications. Extensive ethnographic research and constant validation were carried out with various stakeholders: patients (adults and youth), family members/carers (who often provided information due to patients' language complications), therapists, and psychologists. This empathetic approach revealed that the main obstacles to recovery were the lack of motivation and psychological needs (anxiety/depression), in addition to the lack of tools for home therapy. The resulting solutions (such as ARMS, MindFit, Fonbu, Mino, MelodiX, and Kinisi) integrated elements of gamification and cognitive stimulation with occupational therapy to encourage constancy and social interaction. This work demonstrates how user diversity (physiological, psychological, and social) becomes the driver for innovation in design education, equipping future designers to address public health problems with empathy and more holistic solutions.

Keywords: Inclusive design, higher education, physical motor rehabilitation, User-Centred Design, innovative education

1 INTRODUCTION

Product design education stands at a critical intersection, where technical excellence alone is no longer sufficient to address the complex problems, designers face as professionals. There is currently a pressing need to cultivate critical, creative, and strategic thinking to engage with complex social, technological, and environmental transformations [1]. The call to explore diversity and social inclusion compels us to look beyond university settings and to confront systemic disparities in access to healthcare services. This article examines an academic initiative developed in Mexico, in which design education shifts towards 'Inclusive Social Design', focusing on the creation of therapeutic solutions for patients with spasticity within the complex ecosystem of the Mexican public healthcare system.

1.1 The Challenge of Spasticity in a Context of Inequality

The project addresses spasticity, a motor disorder characterised by muscle stiffness, rigidity and pain, resulting in significant limitations in patients' mobility and autonomy. It is a common sequela of neurological conditions such as cerebral palsy, stroke, multiple sclerosis and traumatic brain injury. Globally, it is estimated that over 12 million people live with spasticity associated with cerebral palsy and stroke alone [2], [3]. However, in developing countries such as Mexico, the challenge is exacerbated by socio-economic barriers that limit timely diagnosis, continuous treatment and access to rehabilitation services.

Mexico's public healthcare system is primarily represented by the Instituto Mexicano del Seguro Social (IMSS), which provides treatment, rehabilitation and therapy services to patients with physical disabilities through facilities such as Clinic No. 1, the Physical Medicine and Rehabilitation Unit. This

unit faces significant patient overcrowding, which limits the frequency of in-person rehabilitation sessions [4], [5]. Consequently, shifts responsibility for ongoing care, monitoring and therapeutic continuity to patients and their families.

1.2 Educational approach of design

The pedagogical approach underpinning this project prioritises empathy, ethics and ethnographic research, enabling students to design solutions that not only enhance fine and gross motor skills but also consider the psychological factors and socio-economic contexts shaping patients' everyday experiences. From a design perspective, spasticity presents a high degree of complexity, as each patient exhibits different levels of mobility and strength. Impairments most commonly affect the upper limbs the hand, wrist, elbow and shoulder compromising performance in activities of daily living (ADLs) [6], such as eating, dressing and personal hygiene. The management of spasticity requires a multidisciplinary approach [7].

Field research conducted by the students revealed that many of the devices currently used in rehabilitation could be described as 'DIY' (Do It Yourself), consisting of improvised objects such as containers, recycled plastic lids or even children's toys. This precariousness not only affects the effectiveness of treatment but also impacts patients' morale; therapists report that adults frequently complain that the materials resemble 'nursery objects', which diminishes their motivation to engage actively in their recovery.

This reality points to an urgent need: the design of low-cost rehabilitation devices suitable for home use and adaptable to the anatomical and functional diversity of a population that often cannot afford specialised medical equipment for personal use [8], [5]. Moreover, the high cost and limited availability of specialised assistive technologies further exacerbate disparities, particularly for low-income households [9], [5], [10]. From a rights-based perspective, access to rehabilitation services and appropriate assistive devices constitutes a fundamental component of independent living and full participation in society [11]. It is precisely at this intersection of systemic constraint, social inequality and therapeutic necessity that Inclusive Social Design can intervene meaningfully, contributing not only to improved motor function but also to enhanced dignity, autonomy and quality of life [12].

'Social Design' is not merely a category of product development but a philosophy of practice that prioritises human wellbeing and equity over commercial gain [13], [14], [15]. Within design education, the integration of this perspective enables students to recognise their responsibility as agents of social change rather than solely as service providers to industry [16].

2 METHODOLOGIES

The projects were developed by fifteen students coursing the sixth semester of the bachelor's in design from Tecnológico de Monterrey during 2024. The implemented methodology is an example of Social Design for inclusion in educational practice, as it compelled designers to look beyond technical specifications. Extensive ethnographic research and constant validation were carried out with various stakeholders: patients (adults and youth), family members/carers (who often provided information due to patients' language complications), therapists, and psychologists [17], [18]. Students approached 'field research' not as a theoretical exercise, but as an immersion into the reality of public hospitals where time and resources are scarce. These learnings were documented in each student's field journal, wherein all activities undertaken were systematically recorded, together with their individual reflections. Within this environment, user diversity manifests across multiple dimensions, including age, gender, degree of motor impairment, and socio-economic and family context. The Social Design for inclusion process can be divided into four major stages.

Ethnographic and Field Research: Students conducted visits to IMSS facilities to interview physicians, therapists and patients, gaining first-hand understanding of mobility limitations and the challenges associated with maintaining existing equipment.

Identification of Specific Needs: It was identified that a lack of motivation, time and external assistance prevents patients from carrying out their exercises at home.

Iterative Prototyping and Validation: Alpha and Beta prototypes were developed, validated by medical experts and directly tested by patients to refine ergonomics, durability and ease of use.

Life Cycle and Business Analysis: Assessment of the feasibility of local production as a strategy to reduce costs.

3 RESULTS

The results of this study demonstrate a clear relationship between the insights obtained through ethnographic research and the design decisions implemented across the five projects. Table 1 analyses the key characteristics of the projects developed in collaboration with the IMSS, highlighting their therapeutic approach, user, value proposition and design innovation within the public healthcare context.

Table 1. Key characteristics of Inclusive Social Design Projects

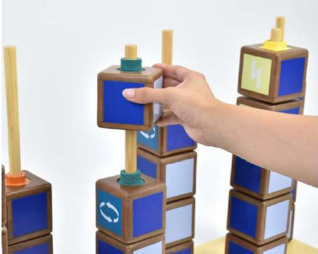
Feature	MINO	KINISI	FONBU	ARMS	MINDFIT
Therapeutic Approach	Fine motor skills and manual dexterity	Autonomy and muscle strength	Holistic neurological rehabilitation	Occupational therapy for severe spasticity	Physical-cognitive rehabilitation and well-being
User	Adults with neurological sequelae in their hands	Patients in intermediate stages of recovery	Patients with barriers to accessing the clinic	Patients with high limited mobility	Elderly people
Value proposition	Multifunctionality, portability, and accessibility for home therapy	Regaining a sense of independence	Makes it easy to perform complete therapy at home	System adaptable to varying degrees of spasticity	Connection between mental health, habits, and physical exercise
Design Innovation	Simplify fine motor skills exercises in a single multifunctional and compact object	Design based on natural (kinetic) movement with adjustable resistance	Self-directed therapy system, no therapist required	Adaptability to different degrees of spasticity	Holistic approach, combining physical and cognitive stimulation

One of the most significant findings was the low level of motivation and adherence to therapy, particularly due to repetitive and discouraging rehabilitation routines. In response, several projects incorporated gamification and interactive elements to foster engagement and continuity. For instance, MINDFIT integrates cognitive challenges and habit-forming dynamics, while ARMS and FONBU introduce playful interactions that transform therapeutic exercises into more engaging experiences.

A second key insight relates to the psychological barriers associated with spasticity, including anxiety, depression, and loss of autonomy. These factors were not initially evident as primary design drivers but emerged strongly through stakeholder interviews. Consequently, projects such as KINISI and MINDFIT adopted a more holistic design approach, integrating cognitive stimulation and emotional engagement alongside physical rehabilitation, thus addressing both mental well-being and motor recovery. The research also highlighted the high variability in motor impairment, as spasticity manifests differently across patients in terms of strength, range of motion, and coordination. In response, students prioritised adaptability and flexibility, developing systems with adjustable resistance, modular configurations, or scalable interactions. This is particularly evident in ARMS and KINISI, which allow the therapy to be tailored to different levels of ability and stages of recovery. Another critical finding was the limited access to rehabilitation services, caused by economic constraints, transportation difficulties, and the saturation of public healthcare facilities. This insight directly informed the development of portable, home-based solutions such as FONBU and MINO, which enable patients to continue therapy independently outside clinical environments.

Additionally, the need to support fine motor skill development for activities of daily living led to the creation of targeted solutions such as MINO, which focuses on hand dexterity through a compact and multifunctional design, adopting a more dignified and user-appropriate design language, enhancing user acceptance across several projects. This analysis demonstrates that design education, when addressing public health, must generate an ecosystem of products rather than a single universal solution. Table 2 shows the five products.

Table 2. Inclusive Social Design Projects

	Design iteration and user validation	Final prototype
MINO		
KINISI		
FONBU		
ARMS		
MINDFIT		

Regarding the educational value, the key processes that shaped the students' learning trajectories are compared below, illustrating how they navigated the tension between the technical rigour of the solution and the sensitivity required to enhance patient motivation in occupational therapy.

MINO & ARMS: Students experienced a 'reality shock' upon witnessing the saturation of the public healthcare system. Their research focused on trauma ergonomics, learning to translate complex medical diagnoses into concrete design requirements.

FONBU: The research approach adopted a socio-logistical perspective. Students identified that the primary barrier was not solely physical impairment, but also distance and transportation costs. This shifted their learning towards service design and tele-rehabilitation strategies.

KINISI & MINDFIT: Students learned to integrate mental health considerations into the design brief, recognising that patient motivation is as critical as the mechanical resistance and functional performance of the device itself.

4 DISCUSSION AND CONCLUSIONS

The methodology applied in these projects followed an iterative prototyping cycle grounded in clinical validation. The need to ergonomically validate each device with real patients compelled students to confront their assumptions about the ‘average user’. Clinical literature underscores that spasticity presents different degrees of impairment [2],[7]. In the context of Mexican public healthcare design, the ‘average user’ does not exist; rather, there is a diversity of bodies with complex medical histories that demand flexible solutions. Beyond motor limitations, spasticity is frequently accompanied by psychological factors such as depression and anxiety linked to loss of independence and reduced social participation [7], reinforcing the need for holistic, patient-centred design approaches aligned with global calls for integrated rehabilitation strategies [4].

The most significant educational achievement was the deconstruction of the ‘average user’. A single problem: patient spasticity generated five distinct pathways of learning and technical innovation.

Functional Diversity: Students recognised that spasticity manifests uniquely in every individual, as widely documented in neurological research [2]. Consequently, they developed modular and adjustable systems instead of rigid, standardised artefacts.

Socio-economic Diversity: Designing ‘for IMSS’ required consideration of product life cycle, maintenance and affordability. In a context where people with disabilities face structural barriers and limited access to assistive technologies [4],[8],[9], students learned that a solution beyond the patient’s financial reach ultimately constitutes a design failure.

Cognitive Inclusion: Particularly in the MINDFIT project, neurodiversity and ageing were integrated into the brief, positioning older adults as active users deserving of high-quality and dignified design, a stance consistent with rights-based frameworks advocating independent living and inclusive participation [11].

This article presents a disability-centred, real-world design education model developed through five full-scale student projects in direct collaboration with a public rehabilitation institution in Mexico. By focusing on spasticity within an overburdened public health system [4], [5], the initiative offers a replicable framework for integrating social responsibility into design curricula [18]. Unlike traditional studio-based or simulated projects, this approach situates students within contexts shaped by disability, socio-economic inequality and institutional constraints, requiring them to adapt and critically reassess standard design methodologies. The findings provide practical, field-tested strategies for embedding equality, diversity and inclusion (EDI) into design education [13], [14], [15].

Ultimately, the study argues that design education must evolve to embrace the complexity of human diversity. Anchoring learning in real societal challenges not only strengthens students’ technical and strategic capabilities but also fosters ethical awareness and civic responsibility [1]. By engaging directly with issues of access, dignity and systemic inequity, future designers develop a deeper understanding of their role as agents of social change, enriching both the design process and the broader pursuit of global equity.

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EXPLORING THE ROLE OF INDUSTRIAL DESIGNERS IN ENTERPRISE INNOVATION STRATEGIES FROM THE PERSPECTIVE OF TALENT CULTIVATION

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ABSTRACT

Although, the literature indicates that Industrial Designers play a significant role in supporting companies' implementation of innovation strategies. The literature is not specific enough in to define what specific roles the Industrial Designers undertake in supporting the enterprise innovation strategies. Therefore, based on the five factors and four levels mentioned in Koostra's (2009) Design Management Staircase, this paper proposes a capability requirement map for the evolution of the role of Industrial Designers (Table 1). The research results show that the different roles played by Industrial Designers at various levels in supporting enterprises' innovation strategies are hierarchical and superimposed, which also requires Industrial Designers to possess more comprehensive capabilities. The research results aim to provide educators with more diversified ideas for talent cultivation from the perspective of innovative strategies and to rethink the potential abilities that novice Industrial Designers need to possess in the training process.

Keywords: Design talent, design management, innovation strategy, design process

1 INTRODUCTION

Design Management Staircase [1] assessment tool was developed to ascertain at what level organisations incorporate a design management function to support its innovation processes. It evaluates the organisational approach to design within an enterprise with a focus on the internal hierarchy of design activities.

First, we introduce the Design Management Staircase model (DMS) and its specific four levels: (i-dms) no design, (ii-dms) design as product, (iii-dms) design as function, and (iv-dms) design as culture and the five factors that contribute to assess at what specific Staircase level an organisation operates. Then we will propose four designers' roles (dr): (i-dr) Silent Design, (ii-dr) Product Optimiser, (iii-dr) Design Manager, and (iv-dr) Design Leader; each of these corresponding to one of the four Design Management Staircase model's levels.

The research aims to establish connections between the four Design Management Staircase model levels and the roles of Industrial Designers. We envisage that this information can be used to customise courses in order to cultivate design talents needed by enterprises operating at different levels. Recruiters can also use this knowledge to better match the role of designers with the specific needs of enterprises, thereby responding to the diversity of design talent education and development paths at different levels.

2 FIVE FACTORS IN DESIGN MANAGEMENT STAIRCASE

Buchanan [2] proposed that integrating design into complex organisations has long been one of the significant challenges faced by managers. By adopting a design perspective and applying design methods to address strategic and organisational issues has a potential to significantly transform the connections between enterprises and its stakeholders, such as their customers, and suppliers [3]. The following section introduces each of the five factors that are used to measure the Design Management Staircase model four levels. These are: Factor 1: Awareness of Benefits; Factor 2: Process; Factor 3: Planning; Factor 4: Resources and Factor 5: Expertise.

2.1 Factor 1: Awareness of Benefits

The key factors of awareness of benefits lie in clarifying for the company the "why" and "what" of potential value design, including Industrial Designers [1]. The scope of work of Industrial Designers by the management of an enterprise will directly affect the extent to which design can drive the enterprise to achieve organisational innovation strategies. This is related to the cultural background and strategic vision of the enterprise senior managers. As whether an enterprise wants to establish core competitiveness or gain competitive advantage is closely related to the skills of senior management personnel and their understanding of the expansion and modification of the enterprise's resource base [4]. In addition, the process of an enterprise reconfiguring its existing resources or capabilities needs to be undertaken in a series of specific and identifiable procedures. The affirmation of the value of dynamic capabilities (in combination with existing knowledge in other fields) and the construction in advance are the consensus for further understanding and promoting the competitive advantage of innovation. For different team members involved in the new product development process, it is important to have the awareness of achieving benefits in aspects such as design innovation and competitive advantage, because when an idea is accepted by the group, the group will review the feasibility of this idea in a collective form [5]. The degree to which employees within an enterprise recognise the value of design is also an important factor that affects the support of design for enterprise innovation. When the majority of participants within an organisation reach a consensus on the value of design, this represents the highest degree to which Industrial Designers support an enterprise's innovation strategy. Designers need to integrate the multiple roles of managers and leaders, managing and leading relevant participants to achieve and build a strong and effective team.

2.2 Factor 2: Process

The coordinated unity of strategy, talent, structure, rewards and processes constitutes an important evaluation system for enterprises to achieve the success of organisational innovation strategies, which effectively shapes decisions and behaviours at different levels of the organisation [6]. Among the process factors, as an enterprise manager, it is necessary to consider whether the design management process is incorporated into the core business and strategic planning processes of the enterprise's development. The design process in which Industrial Designers participate is not only reflected in the research and development of new products but also includes effective management collaboration and knowledge sharing among different departments to avoid unnecessary conflicts [7]. Actively guide stakeholders to put forward different ideas and feedback during the design process and aim to avoid potential risks and misunderstandings that may arise in the design process. The Industrial Designer will need to be able to coordinate and promote views of different participants in the design process and making reasonable design decisions at key stages.

2.3 Factor 3: Planning

Among the planning factor, as mentioned in the process factor, enterprise managers need to further clarify the scope of the subjects that Industrial Designers are concerned about, that is, the extent to which the enterprise plan supports the design and construction of the enterprise's strategic development. Scholars have indicated that the scope involved by Industrial Designers is constantly expanding, from the product itself, the product development process, user experience, to the construction of the enterprise's strategic planning vision [8]. When achieving different task goals, Industrial Designers need to have clear planning and management capabilities for future actions, clearly define the main scope of design goals, and thereby further break down complex design problems, plan design processes, and build strategic design visions, etc. In addition, prioritising the goals at different stages is also an important factor in further promoting the realisation of an organisation's innovation strategy.

2.4 Factor 4: Resources

Buchanan believed that design not only needs to fully recognise external service activities (relationships with customers, suppliers and the government), but also needs to plan and manage internal resources, emphasising the importance of organisational structure in analysing and managing resources and design activities [2]. Koostra regards resources as the total sum of all design investments made by the company in design projects, such as the number of designers, financial budget support, training budget, and production technical support [1]. Helfat [9] pointed out that enterprise managers need to be clear about the significance of internal resources, management processes, and the competitive dynamics within the

organisation. In addition, the informal connection content (cultural connotation, organisational culture) in the collaborative relationship between people has gradually become a part of the internal resources of enterprise organisations [10]. Therefore, the organisational structure determines the level of resources available for design. The Industrial Designers should be familiar with and understand the organisational structure of the enterprise and the design resources available to different departments. This includes the integration of explicit resources (such as design knowledge) and implicit resources that are difficult to replicate or imitate (such as experience, design cognition, membership relationships, and culture).

2.5 Factor 5: Expertise

Among the expert factor, the explicit emphasis is placed on the ability requirements for Industrial Designers. As a key figure in discovering, defining and solving design problems, the capabilities that Industrial Designers possess form the basis for determining the extent to which they support the innovation strategies of enterprises. The capabilities that Industrial Designers possess form the basis for determining the extent to which they support enterprises' innovation strategies. As the fields involved in Industrial Designers continue to expand, the capabilities they are also constantly increasing. This is not only reflected in the improvement of professional skills but also includes the requirements for non-professional skills. For instance, in cross-departmental team collaboration, one needs to possess communication, management and leadership skills, sensitivity to the product market, as well as the ability to plan enterprise strategies and many other capabilities [11].

3 REVIEW THE CAPABILITIES AND THE ROLES OF THE INDUSTRIAL DESIGNERS

Design Management Staircase model clarified that design management not only focuses on the visual presentation of companies and brand products, but it also involves non-visual aspects related to the design process itself, product development, production, distribution, sales, delivery and services [1]. Based on the five factors and four levels of the Design Management Staircase, this section will explore potential roles of Industrial Designers in relation to the level design management supports enterprise innovation, technology, knowledge, culture to drive organisations to achieve their innovation strategies (see Table 1).

Table 1. The capability requirements map for character evolution

The level of DM	DR	The function of Industrial Designer					Organizational innovation strategy
		Awareness of benefits	Process	Planning	Expertise	Resources	
No DM (i-dms)	N/A (i-dr)	N/A	N/A	N/A	N/A	N/A	N/A
DM as Project (ii-dms)	Product Optimiser (ii-dr)	Design value in R&D (User experience)	Separate design in NPD	Design group cooperation	Knowledge /Experience /Skill generation	People/Technology /Environment	Technology /Knowledge/Culture -oriented
DM as Function (iii-dms)	Design Manager (iii-dr)	Design value in R&D/ Market competition	Design incorporated in NPD	Cross-departmental cooperation and management	Knowledge /Experience /Skill utilisation	People/Technology/ Environment/ Organization/ Structure/Finance	Technology /Knowledge/Culture -oriented
DM as Culture (iv-dms)	Design Leader (iv-dr)	Design value in R&D/ Market competition/ Corporate culture	System design for NPD	Cross-departmental cooperation and strategic management	Solving social and environmental challenges	People/Technology/ Environment/ Organization/ Structure/Finance/ Policy	Technology/Knowledge/ Culture/Strategy -oriented

DM: Design Management DMS: Design Management Staircase DR: Designer roles R&D: Research & Development NPD: New Product Development

At the first level (i-dms, see Table 1), when enterprises do not use design management function to support their organisational innovation strategies, the Industrial Designers either do not participate, or their roles are taken over by others, or their efforts are "hidden".

3.1 Product optimiser at the project level

At the project level (ii-dms, see Table 1), Industrial Designer act as "Product Optimiser" to support enterprises in achieving organisational innovation. The design function is used as a marketing tool to add value to products during the new product development process through aspects such as appearance, design style, packaging, and marketing. For instance, it stimulates the formation of product-related memories or creates unique products to deepen their irreplaceability. Mugge pointed out that emotional design needs to focus on the emotional connection and dependence between the product and its usage, such as capturing users' memories and endowing the product with emotional value [12]. In the awareness of benefits, the design value is more reflected in the improvement of the visual presentation of the product based on user experience. By further proposing creative ideas through market data,

product optimisation, cost control, technological transformation and other contents, the user experience can be optimised. As a product optimiser, the design did not generate any additional value during the new product development process and rarely established close ties with other departments to support the organisation's internal innovation strategies. To be able to plan and cooperate with members of the new product development team members require Industrial Designers to possess basic communication, collaboration, project and team management skills. At the expertise stage, Industrial Designers need to possess professional knowledge, experience and proficient skills in operating design software (such as CAD/Rhino/UI, etc.) to generate the domain knowledge required for product development. In the resources, communication with different personnel, the degree of technical support, and the environment of cooperation will directly affect the quality of design work and the efficiency of design projects. When design management is used to support the innovative development of enterprises at the project level, technology and knowledge are important indicators that directly affect the realisation of innovation strategies.

3.2 Design manager at the function level

At the function level, Industrial Designers act as “Design Manager” to support an organisation in achieving innovative strategies. Based on the concept of ‘Managing as Designing’ proposed by Boland [13]. As a manager, the goal is to provide creative changes in the management methods, technologies, manufacturing and other aspects of the internal systems of the enterprise, thereby building a communication bridge for cross-departmental integration and product development, and transforming ill-structure problems into well-structured problems that can be solved [13]. At the high awareness of design benefits in the organisation, the value of design is not only reflected in the product development itself but also covers the innovation process. This also means that design function requires collaboration among different departments within the organisation. At this level, the Industrial Designers need to reconsider the key factors of design in achieving product innovation strategies from multiple dimensions, including individuals (Industrial Designers), groups (Design Departments), and organisations (cross functional collaboration across engineering, marketing, sales, and other departments during the new product development stage). This requires managers to have the ability to optimise the design process and improve and adjust the organisational structure. Managers need to seek opportunities for cross-departmental collaboration at the appropriate stage; In the process, as design experts taking responsibility for the organisation's management of the innovation process requires the ability to strategically and systematically manage the design process. If the design function is well managed within the enterprise, management knowledge is imparted to Industrial Designers, and the design thinking and the ability to use design methods and tools of non-Industrial Designers are cultivated to help the enterprise achieve growth goals. The design thinking methodology of “people-oriented, prototype iteration, and empathetic insight” is introduced into the enterprise’s innovation process, promoting the integration and practice of design thinking throughout the entire innovation process of the enterprise. In the planning, Industrial Designers need to collaborate with personnel from different departments of new product development around product services, brand design strategies, and user experience to complete the product delivery and build an innovative team that crosses departments and disciplines. In the expertise, more emphasis is placed on the rational application of knowledge, skills and experience to shape corporate culture. This includes a comprehensive understanding of changes in the existing market, social and cultural background, enterprise architecture model and political background, etc., to achieve technological and cultural transformation of the enterprise design model. In the resources, as a manager, when helping an enterprise achieve its strategic goals, one needs to take into account communication and cooperation among personnel, technological changes, the culture atmosphere of the enterprise, organisational structure, and financial support, etc., so as to realise the different functions of the enterprise at each level. In conclusion, to support enterprises in achieving organisational innovation strategies at the functional level, a model oriented towards technology, culture and knowledge will be more likely to realise the organisational innovation strategies of enterprises.

3.3 Design leader at the cultural level

At the cultural level, Industrial Designer undertake the role of leaders. This means that design function changes the original environment, organisational strategies, and future plans of the enterprise. The management supports the strategic vision of the enterprise through design, which not only includes the formulation of strategies within the enterprise organisation It also involves the construction of forward-

looking scenarios with the organisation's external environment. This is consistent with Hsieh, who pointed that design leaders need to possess a strategic vision, professional skills, and design leadership [14]. In the awareness of benefits, the value of design is not only reflected in the development of new products, system coordination and management design, and process innovation in other departments, but also in addressing the challenges faced by today's world and society based on cultural and knowledge backgrounds and designing for the future. In the process, when Industrial Designers are confronted with the ill-structure problem of the social system, they not only need to consider the user experience and the optimisation of the service system, but also need to consider whether the strategic decisions of the enterprise have a positive impact on social culture and whether they have forward-looking significance. In the planning, Industrial Designers need to take into account multiple aspects such as user needs, user service experience, market research on competing products, internal and external coordination of the organisation, clarifying the planning and design process, building an innovative atmosphere in line with the corporate culture, identifying and bridging the gaps in the innovation strategy and execution process, and influencing brand positioning, market share and business model through design. In the resource, Industrial Designers need to rationally allocate the key resources that directly affect the implementation of innovation strategies based on the priority of the strategies, break down the innovation goals, and form a feedback mechanism for factors such as knowledge, talent, technology, and culture to further optimise the deficiencies in the enterprise's innovation process. They should also put forward feedback suggestions through visual data reports. In terms of expertise factors, Industrial Designers need to be proficient in applying and imparting design tools and methods to non-participants. During the process of actively participating in the formulation, support and optimisation of corporate strategies, they also need to apply design thinking to develop innovative processes for the enterprise and promote consensus on corporate culture both within and outside the organisation. In the process of multi-disciplinary and cross-departmental collaboration, perceive and predict future market development trends, the potential feasibility of technologies and products, and changes in user pain points. In summary, the role of Industrial Designers is to spread the seeds of design thinking throughout the entire organisation, not just limited to systematising design thinking throughout the entire product production cycle process. At the same time, guide cross-departmental use of design methods and tools to complete process-oriented work content, and the design value guides enterprises to achieve organisational innovation strategies in the form of cultural display.

4 CONCLUSIONS

We suggest that the integration level of design in the organisation and the degree of support from enterprises for design management directly affect and restrict the role boundaries of designers. The success of design function depends on the full support of the enterprise for the corresponding five factors and by dynamic matching of designers' capabilities. Among the factors of "Expertise" and "Resources", the issue to be addressed is "How to do it", while among the factors of "Planning" and "Process", the problem to be solved is "How to manage". Among the factors of "Awareness of Benefits", what needs to be addressed are the essential issues of "Why to do it" and "What needs to be done". Compared with the degree of the five factors from low to high, the ability requirements for Industrial Designers have gradually shifted from "What to do" to "What to plan", and the role they undertake has also evolved from "Silent design" to "Team leader". This is consistent with the different roles that Industrial Designers undertake at four levels. From the perspective of talent cultivation, different roles have different independent value of existence, corresponding to the hierarchical progression from "i-dms" to "iv-dms". The role of Industrial Designers at different levels is not to replace but to continuously complement, which also means that designers need to possess more comprehensive capabilities.

For educators, it is necessary to rethink the goal of cultivating design talents. The ultimate goal should not be to become a single all-round designer, but to cultivate differentiated talents for different design management levels to achieve the creation of corresponding value at corresponding levels. Design talents need more diversified training paths. "Diversity" should be based on the theoretical framework of the design management staircase as its logical foundation, and the cultivation of different ability levels of design talents should be classified through systematic knowledge reconstruction. According to the dynamic matching and integration levels among organisations, designers need to undertake different roles and possess different capabilities. The success of design depends on the full support of the enterprise organisation for the corresponding five factors and the two-way dynamic matching of the designer's capabilities. Through systematic knowledge reconstruction, the cultivation of different ability

levels of design talents is classified. This is not only reflected in the imparting of design knowledge, but also in the cultivation of more tacit knowledge (e. g. experience) and abilities during the design process, corresponding to the dynamic matching and integration level among organisations. At the top level, designers need to possess more comprehensive capabilities such as coordination, management and leadership.

For the development of an enterprise, the role framework that Industrial Designers undertake at different levels can serve as a toolkit to help the management of the enterprise clarify the level of support for Industrial Designers to achieve the organisational innovation strategy and refine the ability requirements for design talents to avoid value mismatch.

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TOWARDS A TOOL FOR SCAFFOLDING DESIGN SYNTHESIS

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ABSTRACT

Many design tools support ideation and other divergent design activities. Design synthesis is a core design activity that is often under-supported. Students find it particularly challenging to integrate disparate design insights into coherent design concepts. This paper presents the ongoing development and testing of a guided synthesis tool that intends to support this type of thinking. The tool aims to help students make explicit connections among different kinds of design knowledge and to structure their reasoning in the early stages of concept generation, laying the groundwork for later phases of detailed design and design justification.

The paper discusses several versions of the tools and their evaluation with students from diverse disciplinary backgrounds. Although the prototypes received positive feedback, we are still improving our understanding of how teachers can support students in coherently developing design synthesis, design argumentation, and design rationale. Early feedback suggests that our approach of combining different types of knowledge and design reasoning is promising, but supporting the actual moment of synthesis remains a challenge.

Keywords: Design synthesis, design reasoning, concept generation

1 INTRODUCTION

The study reported in this paper is part of a larger project to develop several design tools for converging phases of design. This paper reports on a tool that focuses on the phase in which initial insights, ideas, and requirements are combined into an initial concept. We see design tools as a way to scaffold certain types of design reasoning. The idea is that the tool supports students in organising information in a certain way or taking certain steps in their reasoning process. The tools are designed to guide design students and non-design students who work on designing new solutions through a synthesis process. The tool is meant to encourage students to make their motivation explicit and to provide a structure for them to act in a particular way towards a design challenge. Over time, it is expected that students will internalise these thinking patterns and adapt this way of thinking flexibly to novel situations [1,2].

Synthesis is a vital design reasoning skill that is challenging, in particular for students with little design experience [3,4]. While divergent thinking is well supported by a wide range of brainstorming and ideation tools, synthetic (or convergent) thinking is hardly supported. Students find it hard to formulate ideas that elegantly address a wide range of demands. This plays out at different stages of the design: formulating a problem statement based on divergent needs, formulating a concept from bits and pieces collected at the beginning of a project, or creating a detailed design that meets all the implicit promises embedded in the concept. Strangely enough, there seem to be few concrete tools and techniques available to support these synthesis steps. To give an impression: [5] feature 27 diverging techniques and only 6 converging techniques. Furthermore, most convergent techniques are decision-making tools, such as multi-criteria decision-making, rather than tools for combining ideas into novel ones. An exception is [6], which offers methods such as ‘double down’, in which designers are challenged to add ‘one’ element of an alternative design to their solution; or ‘hidden gem’, in which designers are invited to combine elements of existing solutions into novel ones.

In this paper, we report on the development of a guided synthesis tool for concept development. Our quest has been to investigate how we could scaffold integrative thinking in the concept generation step. We wanted students to do this in a way that would make integrative thinking a stepping stone towards articulating a design rationale in subsequent stages of the design process. The first step toward achieving this was to review materials on design argumentation and use them as the basis for a concept-creation tool. In this paper, we discuss the iterative development of the tool across several versions, report on student and expert evaluations, and reflect on the potential and limitations of our approach so far.

2 RELATED WORKS

We consider design synthesis to be the creative process of integrating research insights, constraints, ideas, and other information into coherent design directions or solutions. In contrast to analysis, synthesis brings elements together rather than breaking them apart. Different authors emphasise different elements of design synthesis, such as abductive reasoning [7], reframing problems [8], combining disparate inputs [9], and generating structured concepts that guide design decisions [7]. Most writers agree that synthesis is hard to teach [3,4,7]. Therefore, a core question is how to scaffold it. Several suggestions have been made in the literature, such as using concrete scenarios [11] or supporting students in structuring information to benefit synthesis [7,9,10]. Our approach aligns with these writings. We can encourage synthetic thinking by helping students to organise information in ways that lower the threshold for synthesis and by combining this with an explicit invitation to piece things together (like in [6]).

To answer the question of what type of generic structure might help, we examined work on articulating design decisions [12], design rationale [13], and design knowledge [14,15]. The idea was that the type of arguments one uses to convince stakeholders of a design might also form a good basis for design synthesis. The side effect, apart from supporting synthesis, could be that the tool would prepare students to argue for their designs. In the end, a taxonomy of theory functions in design appeared to be the most promising venture point [14,15]. Bringing together many sources on design reasoning and knowledge, such as [16][17], the authors suggest that there are three types of knowledge involved in design, each involving its own type of reasoning: a) an analysis of the current situation in terms of cause and effects, *|is|*, b) an examination of the desired situation defined in terms of ends and means, *|could|*, and c) an examination of the desired situation defined in terms of mechanisms, effects and outcomes, *|will|*. All three types of knowledge are generated or mobilised during the design process and used for developing the final solution. Table 1 provides an overview of the three types of knowledge, their corresponding argumentation patterns, and their knowledge functions.

Table 1. Three types of design knowledge and corresponding questions, adapted from [14]

Type of knowledge, knowledge functions	Goal within the design process and argumentation patterns	Questions to gain this type of knowledge
<i> is </i> > Diagnostic knowledge (description, explanation)	Analyse the current situation, causes, and effects	What is happening? What are its causes? What are the effects now and later?
<i> could </i> > goal-oriented knowledge (generation, aspiration)	Explore and generate goals, design criteria, and solution concepts. Formulate means-ends propositions.	What are the main design aspirations for the solution, according to relevant stakeholders or external aesthetic or ethical frameworks? What are possible and desirable solution concepts?
<i> will </i> > result-oriented knowledge (prediction, prescription)	Enhancing and improving the solution concept into a final design	How can we improve our design? What works, and why?

Not all types of knowledge are equally important in each phase of the design process, but in the concept development phase, designers typically iterate quickly across all types of design knowledge. An innovative solution concept includes knowledge of a) what is the case now, and why; b) what kind of solution concepts could be desirable in terms of contributing to design goals and criteria of all stakeholders; and c) what effective social and technical mechanisms and design patterns could help realise the proposed solution. We consider these types of knowledge and argumentation as intrinsically complementary. Our idea was that if we used the taxonomy of knowledge functions in design [14,15] as the basis for a new design tool, it could provide both a structure for synthesis and preparation for design argumentation. The guiding questions in Table 1 can serve both ends.

3 TOWARDS A SYNTHESIS TOOL

The tool was developed in a series of seven design iterations. In each iteration, the tool was a) refined based on the feedback on the last version, b) tested in a class of students or by a panel of experts in design education, and c) evaluated in a standardised manner. Four iterations followed tests with students; three were done based on teacher and expert feedback. Students in the test group were typically from different backgrounds, such as economics or the humanities, and used the tool in their design thinking class. We used convenience sampling, meaning the tool was tested in classes that we happened to teach at the time of the test. In both expert and student evaluation the respondents were asked to fill out a form with five questions based on the E2R evaluation approach [18]: a) what worked for you in using this tool?, b) what would you want more from the tool?, c) what can be improved?, d) if you could choose why would you use this tool rather than a different one?, e) if you would grade this tool on a scale from 1-10, what would it be?. The researcher who administered the test summarised the answers to these questions, leading to changes in the next version.

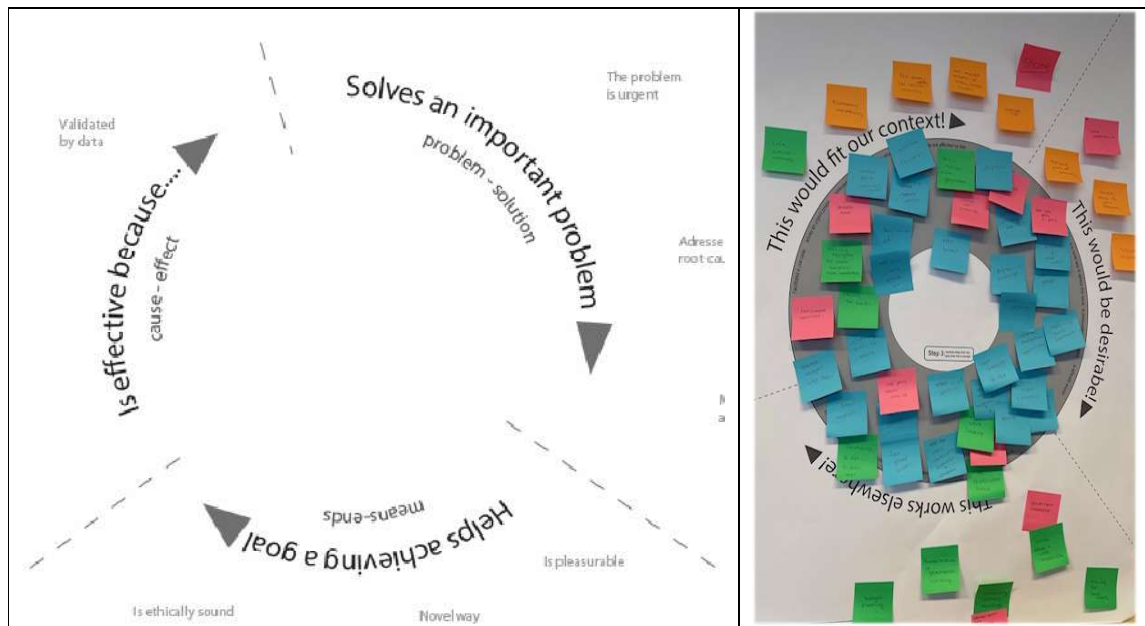


Figure 1. Depiction of the first version of the tool (left) and the 7th version in use (right)

Figure 1 depicts the first version of our tool. It consists of an idea circle with three segments corresponding to the three types of knowledge: |is|, |could|, and |will|, and the main reasoning styles corresponding to that: problem – solutions, means-ends, and problem-solutions. We also put prompts taken from [12] for each segment to further aid the brainstorm of the students: (a) the design facilitates a use case, (b) the problem the design solves is urgent, (c) the problem addresses a ‘root cause’, (d) many people may be affected by this, (e) the design is pleasurable, (f) the design addresses the problem in a novel way, (g) the design has positive side-effects, (h) the design is ethically sound, (i) the design addresses a real need, (j) the design is elegant, (k) the design meets a standard, (l) the design is validated by data, (m) the design uses tried and tested means, (n) the design ideas are supported by research. After an open brainstorm, students were invited to (a) organise their ideas on sticky notes into the three

segments on the outer circle, (b) synthesise them by picking one from each segment, and (c) combine them into a concept. The idea behind this was that every good idea has a hook in the real world (i.e. solves an important problem), meets aspirations of its users (i.e. helps people to achieve a goal), and uses effective means to do so. Figure 2 depicts the development of the tool so far and students' feedback on different versions. Each line depicts a key feedback point (i.e. organising ideas in the top line). The thickness of the dot suggests how many students gave this feedback (i.e. also in later iterations).

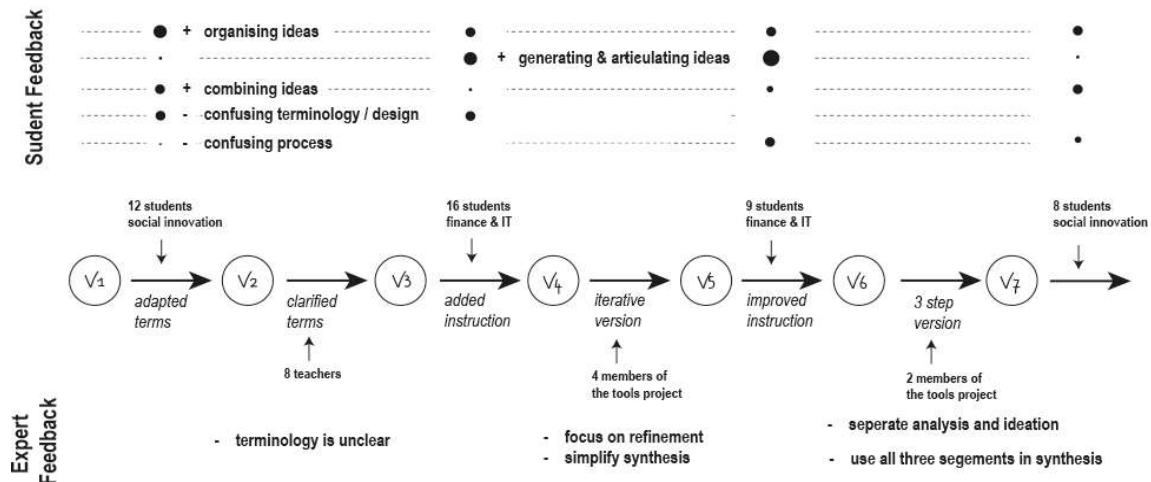


Figure 2. Depiction of the iterative design process and the feedback of experts and students

The *first* version was tested with 12 3rd-year bachelor's students in a social innovation course. The students appreciated the tool for helping them organise, combine, and articulate their ideas. However, they found the terminology confusing and the distinction between the segments unclear. For example, many ideas would solve users' problems by helping them achieve a goal, so they would not necessarily see these segments as different.

In the *second iteration*, we therefore adapted the segment terminology to be more engaging and distinctive: 'this helps', 'we want this', and 'this works elsewhere'. The other prompts remained the same. This was evaluated by an expert panel of 8 teachers, who were positive about the tool but suggested adding more instructions and a box outlining boundary conditions or requirements for the design.

In the *third iteration*, the tool was tested with minor adjustments to terminology and improved instructions with 20 3rd-year bachelor students in a design minor in finance and IT. As in the first test, students praised the tool for helping them organise their ideas and for its collaborative nature. They specifically praised the tool's collaborative use and the encouragement to combine best practices with their own ideas. Apparently, the clarification of terminology had put them on this track.

In the *fourth iteration*, a panel of design education experts suggested the tool could be adapted to invite design iterations. The idea was that, rather than a static worksheet, the sheet could be used multiple times, with each version refining the design idea. The 'we want this' section was simplified by asking students to write down their main design challenge in this segment. Next, they could write down existing products and practices in the 'this works elsewhere' section and ideas for their particular challenge in 'this helps here' section. The following step was to synthesise ideas for a new design from an existing product or practice and one of their own ideas. The prompts were replaced with instructions to clarify this new procedure.

Based on this, the *fifth version* was tested among 10 students a design minor in finance and IT. The feedback was similar to that in the first and third iterations. Also, the students suggested that the separate steps needed clarification.

In the *sixth iteration*, two experts evaluated the tool and noted that versions 4 and 5 had taken a slightly different direction from the original tool. In particular, the simplifications to support an iterative mode had the side effect of reducing the different needs, wishes, and aspirations that may guide a design to a single, refined design, thus narrowing the design's aspirational space. Put differently, the [could] information was fixed to a specific design goal rather than mapped as an open space for exploration. The experts felt this fixation might be inappropriate in this stage of the design. Therefore, we created a

new version of the tool. This version was the same as the tool that was used in the first 3 iterations, but with clarified terminology and a 3-step process: a) analysis according to the 3 segments of the tool, b) a synthetic brainstorm by combining elements from 2 segments, and c) concept creation by combining multiple ideas from the synthetic brainstorm. These steps were visually depicted as 3 concentric circles (Figure 1, right side).

For this *seventh version*, students praised the structured way of working and the geometrical support for that (working from the outer fringes to the centre). However, they needed guiding questions for the analysis phase, asked us to clarify the terminology further, and they requested guidance in the last open synthesis step.

Across these iterations, students consistently suggested that the tool helped them organise, generate, and combine ideas. They felt particularly encouraged to combine existing ideas with their own. In general, students' feedback was consistent but not very specific about how the tool helped combine ideas. Additional work will be needed to determine more precisely how different versions support synthesis. Over iterations, the terminology became less of an issue, suggesting that our clarifications worked, but occasionally students continued to report overlap between the segments. Versions 3-5, in which we simplified the tool into a synthesis of existing ideas, were conceived more as brainstorming tools, whereas versions 1 and 7 were perceived more as organisers. Many of the changes we made were based on the expert feedback, since they focused more specifically on our rationale for supporting synthesis.

4 CONCLUSION AND DISCUSSION

In this paper, we have reported on the ongoing development of a guided synthesis tool. The core idea has been that design synthesis is challenging for students, and concrete tools that support synthesis in design may scaffold the development of synthetic design skills. Our venture point in designing such support has been that students could be helped by deliberately combining elements from different types of design knowledge: (a) relating to the current situation is one is designing for, *|is|*, (b) the imagined possibilities and aspirations for the design, *|could|* - or (c) knowledge about what works and why, *|will|*. The reasoning for this choice was two-fold. First, we believed that synthesis would be easier if the elements being combined were inherently complementary. Second, we believed this structure could be reused in later phases when students need to articulate a rationale for their decisions. Across the four student evaluations and the three experts' evaluations, there was support for this basic venture point of the design. Students claimed that the tool helped them to combine ideas and encouraged them to look at the design from different angles. This was probably reinforced by the tool's geometry: working from the outside towards the middle of the circle signalled that students needed to piece things together. Although we are positive about using *|is|*, *|could|*, and *|will|* as starting points for design synthesis, students did not always immediately grasp the differences among these sections. Simplifying the terminology has helped a lot, but we are still exploring other ways to make this more natural for students.

A second consideration is that the tool places equal emphasis on the three types of knowledge, whereas one could argue that, in different phases of design, these types may not play equally dominant roles. Tools that support synthesis in the detailed design phase might need a structure in which *|will|* knowledge plays a greater role. Our versions 4, 5, and 6 had such a bias, although we returned to a more even treatment of all three knowledge types in later versions. We are still exploring how the different tools we are developing in our project can be linked to help students place the right emphasis at the right time. During the seven iterations, the tool's focus has shifted back and forth between a concept-creation tool, in which students dream up concepts from the materials they collected, and a concept-development tool, in which students iteratively refine concepts they already have. We see opportunities to split these versions into separate tools with these dedicated goals. In that case, using the same underlying structure might help students who use them in sequence.

So far, the project has delivered valuable insights into how design synthesis can be supported in practice. However, it is worth acknowledging that the actual moment of synthesis remains somewhat elusive. It is an open question whether the different versions of our tool really scaffold synthetic thinking more effectively than existing tools. Such claims would require us to refine our evaluation methodology quite drastically [20]. In the student evaluations in our setup, most information was provided on the tool's usability, but less on its effectiveness. That is a lot to ask from a beginning designer: to learn about synthesis and reflect on a tool's contribution to this activity at the same time. Moreover, the evaluation is quite global. Other methods, like think-aloud protocols, could be more informative. These limitations do not degrade the value of our work. As teachers, we are confident in saying that using our tools in

class creates a context in which students feel encouraged and safe to *try* synthesis. For our educational context, this is already quite a leap. To gain more insight into how a synthesis tool can help converge after ideation and make design choices explicit, we plan to conduct additional research. To this end, we will observe students across the various phases of a design project.

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RESEQUENCING CAD IN DESIGN EDUCATION: A CURRICULAR CRITIQUE OF 3D MODELLING METHODS IN PRODUCT DESIGN LEARNING

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ABSTRACT

The integration of Computer Aided Design (CAD) tools in product design education, where learning begins with parametric software such as SOLIDWORKS, often prioritises technical precision at the expense of creative and aesthetic sensibilities. Students who are developing proficiency with complex software frequently simplify their physical prototypes that meet technical criteria but compromise their original design intent.

This study explored how curricular sequencing can influence creative and cognitive outcomes. A digital modelling structure was developed to encourage early engagement with freeform modelling in a Product Design and Technology programme. Second-year students used Blender, a non-parametric digital sculpting tool, to explore and develop expressive CAD concepts before learning parametric CAD techniques in third year to support seamless cognitive progression from creative form exploration to design refinements and manufacturability, allowing students to build technical fluency on a foundation of creative expression.

Comparative analysis focused on the extent to which students' final parametric models reflect their original design intent. Evaluation criteria included aesthetic surface fidelity and accuracy of human factors proportions, supported by student reflections.

Findings suggest that beginning with Blender fosters greater creative confidence and improved representational accuracy. Students demonstrated a stronger ability to retain complex form characteristics when transitioning to parametric modelling.

By introducing freeform modelling for early-stage digital exploration, followed by parametric refinement, educators can better align CAD tool use with stages of creative visualisation and analytical thinking. The revised sequence offers a transferable model for design educators seeking to balance creativity, cognition, and manufacturability within a coherent and progressive design curriculum.

Keywords: CAD education, design cognition, freeform modelling, parametric modelling, curriculum sequencing, product design pedagogy

1 INTRODUCTION

Computer-Aided Design (CAD) is firmly established as a central component of engineering and product design education as a core digital competency aligned with contemporary industrial practice [1-3]. The increasing reliance on digital modelling environments in professional workflows has reinforced the emphasis on parametric CAD education within undergraduate curricula [4]. Parametric modelling history-linked features and constraint logic influence how students generate, refine and rationalise three-dimensional form, applying design thinking [5]. Hybrid digital toolkits have been found to enhance designer-tool interaction and support more holistic design thinking in integrated studio settings [6].

While CAD is often preferred for its technical capabilities, students sometimes encounter increased cognitive load getting acquainted to parametric digital modelmaking, resulting in design simplification and reduced exploratory refinements during conceptual stage [7]. Research indicates that although digital tools can enhance technical accuracy and visualisation, creative freedom is not evenly explored, with some students reporting constraints imposed by interface logic and early commitment to parametric workflows [8, 9]. Reviews of CAD in education tend to focus on competency and skill acquisition, with less emphasis on creative impact, cognition and design intent retention [10].

Studies suggest that CAD modelling processes can improve spatial understanding and creative expression and support functional creativity when integrated thoughtfully [11, 12]. Design cognition research shows that digitally mediated environments can impose cognitive load affecting varied ideas and strategy selection in early design phases [7, 13].

Strengthening CAD education requires integrating non-CAD thinking approaches that develop spatial reasoning, perceptual skills, and form-making sensitivity in students. Studies show that iterative, hands-on modelling, whether physical or digital, enhances spatial understanding, conceptual clarity, and problem-solving in design learning. Physical modelmaking such as clay sculpting or paper prototyping remain valuable for building an embodied sense of volume and surfaces, supporting learners' transition into advanced digital surface modelling environments [14, 15]. Similarly, observational sketching, contour studies, and photographic analysis sharpen students' ability to decode form, curvature, and proportion, skills that underpin competent use of NURBS-based curve networks and continuity control in CAD workflows. Aesthetic design research further highlights that linking natural visual references to digital abstraction strengthens students' judgement and intentionality when engaging with parametric and surface-driven tools [16, 17]. When combined with reflective documentation that supports modelling strategy development and conceptual understanding, these non-CAD practices create a more holistic learning environment that enhances students' digital modelling and design capabilities [20].

Design learning theory identifies reflection as key to develop deeper design understanding, enabling articulation of rationale and iterative refinement [18-20]. Reflective interventions have shown enhanced design performance, including idea generation, problem framing, and meaningfully engaging with ambiguity during design development [21, 22]. However, rational to link CAD tool sequencing with reflective practice remain limited. This study examines whether sequencing freeform digital modelling prior to parametric CAD better supports creative exploration while bridging toward industrial and manufacturable competencies. It proposes that establishing aesthetic coherence, proportional logic and conceptual intent in a freeform environment may reduce premature simplification while later engaging constraint-driven parametric modelling. This study focuses on how CAD tool sequencing impacts creative outcomes, aesthetic fidelity and translation of user-centred, manufacturable intent under increasing technical constraint. By foregrounding structured artefact comparison with student narration, it contributes evidence toward a cognition-led CAD pedagogy for product design education. This research was approved by the Science & Engineering Research Ethics Committee (2026_01_05_S&E).

2 METHODOLOGIES

2.1 Context and Participants

The study examines two sequential 2nd and 3rd year modules designed to scaffold creative digital fluency toward industrial manufacturability. The first module, Digital Modelling & Prototyping, centres on expressive freeform development through a design-led lens. Students deconstruct an established brand to identify and articulate its signature aesthetic language, before applying those characteristics to the design of a computer peripheral (e.g., mouse, keyboard, headset, speaker) using Blender (Figure 1 - left). The project outputs prioritise surface exploration, proportion, brand coherence, and digital representation. Blender was selected as the initial modelling platform due to its mesh-based, non-parametric workflow supporting expressive form generation and iterative experimentation [23]. However, freeform modelling can result in geometry that is problematic for manufacturing or rapid prototyping [24]. Outputs are twofold: a suite of high-fidelity renders that present the product in a brand/aesthetically accurate context, and a 3D printed prototype to demonstrate geometric integrity, watertight modelling, and physical viability. The second module, Design Studio (Industry), shifts emphasis toward technical refinement and Design for Manufacturing. Students reproduce their previous concept in SOLIDWORKS using complex surface modelling, and integrate industrial constraints including wall thickness, ribs, bosses, webs, assembly logic, and injection mould optimisation. SOLIDWORKS was selected for subsequent refinement due to its parametric, constraint-based environment, widely used in industry and design education, enabling structured design for manufacture and assembly refinement [1, 25]. Along with in-class demonstrations and direct tutor support, a suite of video resources was also created to promote asynchronous learning and to ensure clarity when approaching technically complex surface modelling tasks. The final output is a suite of industry-standard engineering drawings representing a manufacturable product (Figure 1 - right). Both modules require a process book documenting development, decision-making, and structured reflection throughout.

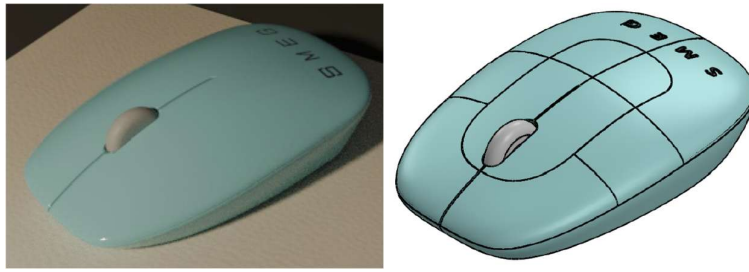


Figure 1. Computer peripheral created using freeform modelling (left) and then reproduced through parametric modelling (right)

2.2 Research Approach

This study uses a qualitative, reflective case study approach examining student artefacts, design brief adherence and narratives across two sequential modules. Early freeform outputs were compared with subsequent parametric reconstructions to assess retention of design intent under increasing technical constraints. Evaluation focused on surface fidelity, proportional accuracy, human factors resolution and integration of Design for Manufacture, Assembly and Disassembly DFMAD principles (Table 1). Artefacts, engineering drawings and prototypes were triangulated with annotated Process Books and structured reflections using a predefined assessment matrix. The matrix systematically assessed form fidelity, cognitive progression, reflective awareness and creative confidence, enabling analysis of both design outcomes and evolving decision-making processes under industrial constraint.

Table 1. Evaluation Matrix for Comparative Analysis Across CAD Modules

No.	Criterion	Module 1 output (freeform)	Module 2 output (parametric)	Submitted sources	Evaluation metric
1	Form & Aesthetic Fidelity	Surface complexity, brand coherence	Retention of curvature, dimensional accuracy	Renders, CAD models, drawings	Degree of form preservation
2	Cognitive Progression	Iterative conceptual exploration	Design refinement, constraint balance, DFMAD integration	Process books, annotated development	Creative intent and DFMAD alignment
3	Reflective Awareness	Articulation of design rationale	Explicit discussion of compromises, and technical decisions	Reflective entries, evaluations	Depth of metacognition
4	Reported Creative Confidence	Comfort with freeform modelling	Confidence in managing DFMAD constraints	Reflection excerpts, feedback	Perceived growth across modules

2.3 Data Collection

Data collection comprised two primary sources. First, designed artefacts from both modules (2 x 47 project submissions) were examined, including sketches, drawings, low-fidelity models, 3D printed prototypes, and final digital outputs. Central to each project's deliverables were students' Design Process Books, which curated project development, annotated decision-making, documented final outcomes, and embedded structured reflections throughout the design journey. Second, module evaluations were reviewed, in which students reflected on module delivery, teaching quality, learning supports, and overall sequencing, providing insight into perceived pedagogical effectiveness alongside artefact-based evidence.

3 RESULTS

3.1 Form and Aesthetic Fidelity

Students established form, proportion and surface intent in freeform modelling before translating designs into parametric environments, reducing the risk of early constraint-driven simplification (Figure 2). While not all students produced geometrically complex initial forms, several augmented their designs or selected more complex artefacts from parallel modules before transitioning to SOLIDWORKS. The requirement to produce a watertight model for 3D printing introduced geometric and topological

challenges within mesh-based workflows, yet manufacturable outputs were achieved by all students. Outputs retained complex surface qualities, demonstrated stronger alignment between early concepts and final outcomes, and showed improved handling of organic and ergonomic geometries.

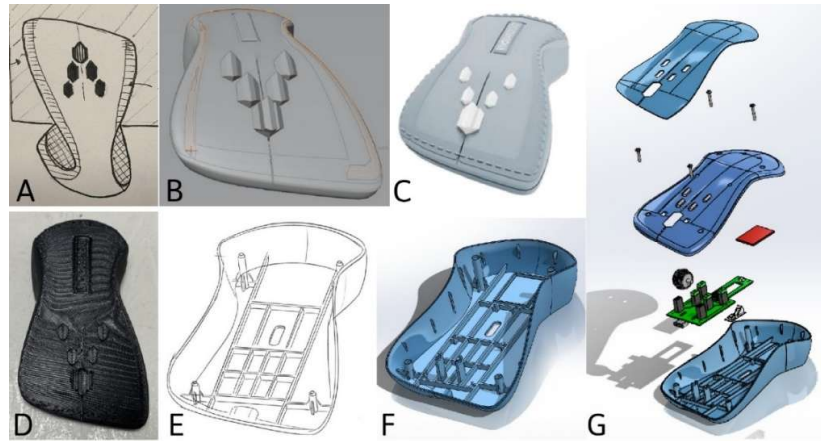


Figure 2. Workflow demonstrating how form and aesthetic fidelity were retained throughout A) initial sketch explorations, B) freeform modelling, C) digital renderings, D) 3D printing of freeform model, E) DFMA optimisation, F) parametric modelling, and G) full assembly

3.2 Cognitive Progression

Students demonstrated clear cognitive progression from exploratory form generation to structured refinement. Reflections described a shift from divergent experimentation to deliberate constraint balancing, particularly when addressing wall thickness, draft angles and assembly logic (Figure 3). Although parametric CAD was sometimes perceived as restrictive, students recognised its value in translating concepts into manufacturable outcomes. Design decisions showed stronger justification of proportion, human factor and production strategy. Final outputs aligned more closely with original intent while integrating DFMA requirements without compromising core design identity.

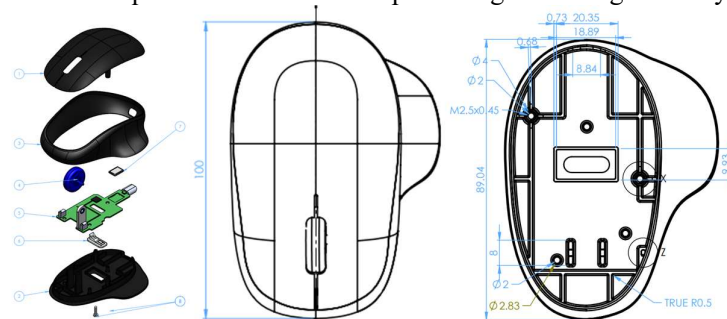


Figure 3. Students engaged with complicated surface modelling in SOLIDWORKS, implementing DFMA principles, and produced industry-aligned design documentation

3.3 Reflective Awareness and Creative Confidence

Student reflections reveal marked gains in reflective awareness and creative confidence across the sequenced modules. Students reported that Blender enabled risk-free experimentation, and how the "process of a sketch becoming a 3D product I could hold and examine... showed [them] how quick it is to learn very useful skills like Blender". One student also noted that "this is the project that [they] enjoyed the most since starting product design." Students could articulate when simplifications occurred and why, typically due to manufacturability constraints, time management pressure, linking those decisions to explicit trade-offs in their Process Books (Figure 4). Several reflections emphasised that internal geometry matters as much as external form; students reported newly appreciating wall thickness, ribs, bosses, fastening features and minimum radii as design decisions that affect both ergonomics and manufacturability, with one student noting they "learned that it's important to regularly check the minimum radius of curvature rather than waiting until the end". Accounts showed authentic learning through repeated iteration. Repeated, frustrating attempts to reconcile surface topology were reframed

as essential practice that improved technique and judgement. Parametric surface modelling was often described as more restrictive, but students also recognised its role in resolving technical detail and assembly logic, as one student stated how DFMA considerations were “*new considerations for [them] but learning them made [the student] realise how important manufacturability is in real product design*”. Time constraints limited some parametric refinements, with a few students modifying models due to deadlines. However, lecture expertise and asynchronous video resources supported technically challenging surface modelling in SOLIDWORKS. By project end, most students showed improved iteration, planning and metacognitive awareness, with greater confidence balancing creativity and manufacturable, user-centred outcomes.

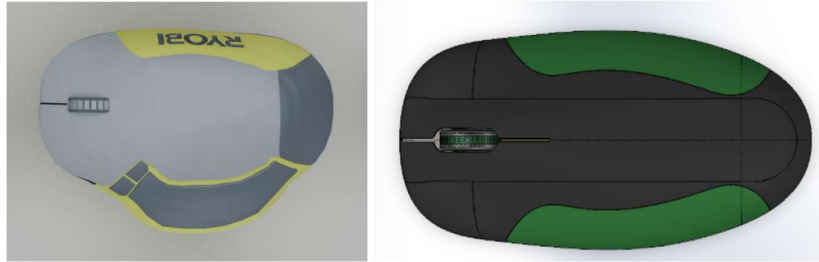


Figure 4. Example of model simplification when transitioning from freeform (left) to parametric modelling (right). Note that one half was faithfully recreated in SOLIDWORKS and then mirrored, allowing for a greater level of DFMA detailing as a result

4 DISCUSSIONS

These findings support the argument that intentional CAD sequencing strengthens industry-aligned design outcomes. Early freeform modelling enhanced divergent thinking and preserved aesthetic and proportional intent before technical constraints were applied. When parametric CAD was positioned as refinement rather than origin, students demonstrated stronger form retention and clearer articulation of design rationale. Consistent with experiential and reflective learning theory, exploratory making followed by structured constraint negotiation supported deeper cognitive development. Reflection functioned as a safeguard against software-determined decisions, reinforcing user-centred, sustainable and manufacturable intent. Pedagogically, the results advocate a shift from software-first to cognition-first sequencing. Early modules should prioritise creative exploration and surface literacy, with later modules introducing industry constraints such as manufacturability, assembly logic and sustainable DFMA. This staged progression offers a transferable framework that aligns creative integrity with industrial relevance and sustainable best practice.

5 LIMITATIONS AND FUTURE WORK

This study is the first evaluation of the revised module sequence, so there is limited longitudinal comparison. Future work will situate this sequencing model in a programme-level context to evaluate broader pedagogical impact, while also considering how it impacts traditional sketching capabilities.

6 CONCLUSIONS

This study shows that introducing freeform digital modelling early supports creative exploration and representational accuracy. Establishing form, proportion and intent before applying parametric constraints enabled stronger retention of design intent during technical development. Creativity was not reduced by later industrial requirements, though targeted refinements were needed for manufacture. Structured reflection improved articulation of rationale, awareness of compromise and avoidance of tool-driven limitation, strengthening communication of user-centred and manufacturable outcomes. The findings emphasise selecting CAD tools based on pedagogical alignment as well as industry relevance. The proposed sequencing model offers a transferable framework for balancing creative integrity with DFMA implementation in product design curricula.

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UNCOVERING NEUTRALITY: A CRITICAL PEDAGOGICAL ANALYSIS OF BIAS IN DESIGN THINKING FRAMEWORKS

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ABSTRACT

Modern engineering and product design education uses design thinking frameworks like the Double Diamond and Human-Centred Design (HCD) as the most common teaching methods. These frameworks seem unbiased, universal, and transportable for student approaches to consumers, difficulties, and innovation. These frameworks are classroom-based. They are utilised worldwide in education. Design thinking is being applied to tackle more socio-technical problems in India, including urban informality, public health, sustainability, and social innovation. However, these frameworks' impartiality hides its cultural, social, and epistemological biases. This research uses critical design pedagogy to examine how mainstream design thinking frameworks affect Indian design students' understanding of users and design problems. The study examines student design challenge understanding. A qualitative comparative case study of three Indian design institutions with 126 students examines students' curriculum materials, studio critiques, and reflective diaries. Educational tools like empathy maps, personas, and stakeholder matrices adopt a normative "universal user" paradigm. A middle-class, metropolitan, able-bodied, Western paradigm is assumed. Thus, these mechanisms restrict culturally appropriate and inclusive innovation. This study proposes a culturally appropriate design pedagogy paradigm that blends reflexivity, situational ethics, co-creation, and design processes. This research seeks a solution. The research found that design thinking's neutrality must be questioned to properly teach engineers and designers to handle a variety of social situations. This is because design thinking is considered neutral.

Keywords: Critical design pedagogy, design thinking, Double Diamond, human-centred design, inclusive education, decolonial design, India

1 INTRODUCTION

In recent years, design thinking has become a more important teaching tool in engineering and product design education worldwide. The visual clarity, process orientation, and focus on empathy and creativity of frameworks like the Double Diamond and Human-Centered Design (HCD) have made them popular. Technical and commercial design colleges in India have seen these frameworks growing in popularity. They are often promoted as solutions to "wicked problems" in urbanisation, healthcare, sustainability, and social innovation. Despite their widespread dissemination, design thinking frameworks are typically advertised as useless and relevant in many contexts [1]. When applied to informality, structural inequality, caste systems, gendered work, and economic precarity, this premise is problematic. These variables characterise many Indian societal situations. This makes the assumption difficult. Teaching methods that simplify complicated realities into user personas or linear issue statements may ignore important parts of lived experience.

This main objectives of this study are:

To examine micro-level instructional methods used to operationalise bias in studio practice.

To focus on micro-level design tools, even if design thinking frameworks like the Double Diamond and HCD guide the higher-level design process.

2 LITERATURE REVIEW

Over the past two decades, design thinking has dominated engineering and product design education [1, 2]. This fosters creativity, innovation, and user-centred problem-solving. Most recommend it to enhance these skills. Double Diamond and Human-Centered Design (HCD) frameworks have had a large

influence because they are structured but adaptable, feature a clear visual depiction of the design process, and promote empathy-driven, iterative development [3][4]. HCD uses empathy, ideation, prototyping, and testing to understand user needs [5]. Design alternates divergence and convergence in the Double Diamond model [6]. Its use in university courses represents a change from technical training to multidisciplinary, process-oriented methodologies that promote iterative discovery, teamwork, and experience learning [7][8]. Design toolkits, curricular modules, and transdisciplinary innovation institutionalise these frameworks. Design schools, engineering, management, and policy schools use it [6]. Indian public technical institutes and commercial design schools use design thinking to solve "wicked problems" such as urban informality, healthcare access, sustainability, and social innovation. Design thinking solves these issues methodically. Design thinking is adaptable and can solve large socio-technical issues.

Many experts doubt design thinking concepts are neutral, universal, and culturally transportable. Perhaps these concepts are becoming more prevalent in education. Critics contend these frameworks assume epistemology and culture [9] [10]. Scalable, market-oriented solutions are assumed [11]. Also assumed are linear issue framing and individualist agency [12]. These assumptions are linked to Western modernist and management epistemologies that emphasise abstraction, efficiency, and optimisation. Personas, empathy maps, and stakeholder matrices use simplified user representations to aid learning, according to a study [12]. Divided into simpler groupings helps depict complex social realities [13] [14]. This abstraction may marginalise informal, precarious, and communal social connections. In India, where caste hierarchy, gendered employment, language variety, and informal government institutions affect daily life, universal design thinking may hide key parts of the lived experience [15] [16].

Critical design studies emphasise more that design processes provide knowledge, authority, and representation. Study focuses on this. Design thinking may increase instructional power [17]. A framework for issue definition and legitimising affected voices does this. Personas and empathy exercises may make designers interpret user experience instead of co-learners, creating unbalanced designer-community relationships [18]. Assessment standards, critiquing cultures, and institutional expectations that prioritise practicality, scalability, and formal innovation over social justice and ethical reflexivity amplify these dynamics in educational studios [19] [20]. Students may internalise normative beliefs about "good design" that coincide with dominant socio-economic norms, restricting their ability to critically reflect on marginalised contexts [21].

Critical design pedagogy challenges society's view of design education. This method emphasises power, positionality, and ethics in design learning environments using Freirean critical pedagogy, feminist epistemologies, and decolonial theory [22] [23] [24]. Critical design pedagogy questions how instructional techniques generate certain knowledge while ignoring others [2]. According to scholars, critical pedagogy helps students acknowledge their privilege, interact responsibly with communities, and question prevailing narratives of innovation and progress [25] [26]. This paradigm supports multiple epistemologies and culturally situated design practises that challenge universalist assumptions in non-Western countries like India [27]. Critical design pedagogy makes engineering and design education more inclusive, reflexive, and socially relevant by redefining design education as ethical and political [20].

3 DESIGN THINKING AND CRITICAL DESIGN PEDAGOGY

The Double Diamond model structures design into divergent and convergent phases, while HCD emphasises empathy, ideation, and prototyping. These frameworks have been adopted globally through standardised toolkits and curricular models (Figure 1).

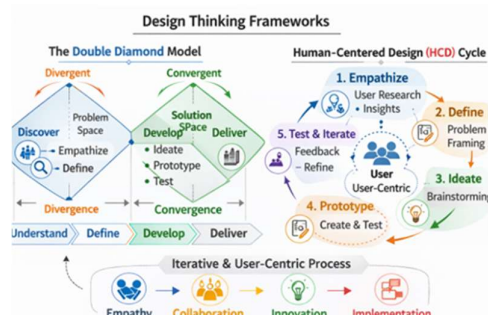


Figure 1. A synthesised model of the Double Diamond process and Human-Centred Design (HCD) principles. Source: Author

The thesis that is put up by critical academics is that design thinking provides precedence to individualist agency, market-oriented innovation, and simplified representations of users via the application of design thinking. On the other hand, the fact that such assumptions are made is a reflection of Western epistemologies, which put a focus on abstraction, efficiency, and scalability. The Indian context, which is characterised by design difficulties that are deeply based in social interactions, informal government, and collective activities, often reveals that these assumptions are inadequate when applied to the setting of India. Critical design pedagogy draws from a variety of sources in order to study power relations within the field of design education like decolonial research, feminist theory, and critical design pedagogy. In contrast to the traditional view of design methods as neutral tools, this approach analyses the ways in which pedagogies develop knowledge, authority, and representation inside the studio. It recasts design education as a process that is both ethical and political in character, rather than only concentrating on the technical elements of design.

4 METHODOLOGIES

This research uses a qualitative-dominant mixed-methods comparative case study strategy. This design relies on qualitative data, while quantitative content analysis uncovers patterns rather than performing statistical analysis. The research was done in a public technical university in North India, a private interdisciplinary design institute in South India, and a private design university in Western India. These institutions are all in India.

Nine academic members and 126 undergraduates from product design, interaction design, and engineering design studios participated in this project. To make interpretation clear, student work was interpreted across three studio project categories. Social innovation, including public health and sanitation, urban service design, mobility, and informal settlements, and consumer product design, including home products, were considered. Since the project context may affect user representation, classifying this information is crucial. If this possibility is ignored, bias may be misinterpreted.

4.1 Participant and Institutional Breakdown

The study was conducted across three Indian design institutions representing diverse academic and regional contexts:

- (1) a public technical university in North India,
- (2) a private interdisciplinary design institute in South India, and
- (3) a private design university in Western India.

A total of 126 undergraduate students and 9 faculty members participated in the study. The student sample was distributed across the three institutions to ensure comparative representation of different pedagogical environments (Table 1).

Table 1. Participants distribution

Institution	Type	Region	Students (n)	Faculty (n)	Program Context
Institution A	Public Technical University	North India	42	3	Engineering design + product design studios
Institution B	Private Interdisciplinary Design Institute	South India	40	3	Interaction design + interdisciplinary studios
Institution C					
Total			126	9	

5 DATA ANALYSIS

The study used a two-stage analytical approach combining quantitative and qualitative methods. First, student outputs were coded for socio-economic indicators, language patterns, and occupations, using statistical tests such as chi-square, proportion tests, and ANOVA to identify trends. Second, qualitative analysis of studio discussions and reflections examined implicit assumptions and user representation.

Key themes included the “universal user,” empathy abstraction, and institutional bias. Methodological rigour was ensured through dual coding of 20% of the data, achieving an inter-coder reliability of 0.82. A content analysis of 126 students across three Indian design institutions reveals a significant over-representation of middle-class, urban attributes in user profiles (Figure 2). (Figure 3).

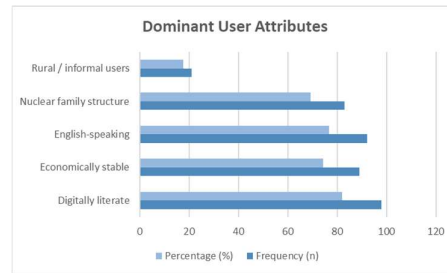


Figure 2. Dominant User Attributes in Student-Generated Design Personas. Source: Author

A chi-square goodness-of-fit test was applied to examine whether these attributes were evenly distributed across socio-economic categories.

$$\chi^2 (df = 4) = 46.72$$

$$p < 0.001$$

$$\text{Cramér's } V = 0.44 \text{ (large effect)}$$

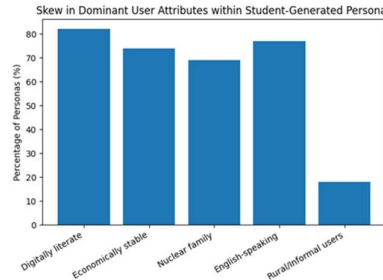


Figure 3. Skew in Dominant User Attributes within Students. Source: Author

Empathy maps (n = 90) were coded to distinguish between generic emotional abstractions and context-specific experiential descriptions (e.g., caste discrimination, migration stress) (Table 2).

Table 2. Nature of Empathy Representations in Design Studios

Empathy Representation Type	Frequency (n)	Percentage (%)
Generic emotional labels	67	74.4
Context-specific insights	23	25.6

Statistical Test and Effect Size

A one-sample proportion z-test was conducted against an expected proportion of 0.50.

$$z = 4.31$$

$$p < 0.001$$

$$\text{Effect size (Cohen's } h) = 0.51 \text{ (large)}$$

Empathy mapping overwhelmingly relied on abstracted emotional categories, significantly exceeding balanced representation. This reduction of perceived complexity into basic emotional categories turns empathy into a symbolic activity. Instead of fostering shared understanding, this strengthens the designer's power. Quantitative evidence supports criticisms of empathy as a depoliticised notion in design thinking courses.

The stakeholder matrices (n = 60) were analysed by using the mean priority ratings on a 5-point scale. The lowest priority was represented by a score of 1, and the highest priority was represented by a score of 5 (Table 3).

Table 3. Mean Stakeholder Priority Scores

Stakeholder Group	Mean	SD
Institutional actors	4.32	0.61
NGOs	3.78	0.74
Community members	2.41	0.83

Statistical Test and Effect Size

There was an analysis of variance performed using a single way.

$$F(2, 177) = 39.58$$

$$p < 0.001$$

$$\eta^2 (\text{eta squared}) = 0.31 \text{ (large effect)}$$

Tukey post-hoc: Institutional vs Community ($p < 0.001$)

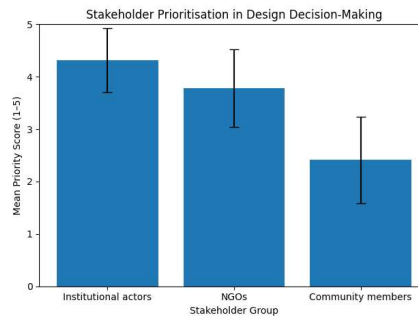


Figure 4. Stakeholder Prioritisation in Student Design Frameworks. Source: Author

It is important to note that the priority of stakeholders follows a particular hierarchical ordering, with institutional participants being valued more than members of the community to a higher extent. The enormous effect size indicates that the group of stakeholders has a large influence on design attention, which in turn pushes the outcomes toward feasibility and scalability rather than social justice or lived equality (Figure 4). This is because the design attention is influenced by the group of stakeholders.

6 FINDINGS

In accordance with the findings, students characterise users as "working professionals" and "digitally connected." The fact that this is the case suggests that the depiction of customers in design education is impacted by unconscious preconceptions that are linked with urban and middle-class origins. This is supported by the remarks made by members of the faculty, who advocate for a standardised "universal user." The technique of simplifying empathy mapping to generic emotional categories, while ignoring socio-cultural elements such as gendered work and caste, is a frequent practice. Students approach empathy as if it were a checklist, rather than participating in activities that have a significant impact on their behavior. Other biases are revealed via the investigation of stakeholders, such as the fact that institutions are given more weight than communities, that power dynamics are reflected, and that feasibility is given more weight than inclusive and participatory design.

7 DISCUSSIONS

The data imply that bias in design thinking teaching is mostly evident in personas, empathy maps, and stakeholder matrices. Since the results show that prejudice transcends these broad frames, this is true. These technologies turn design processes into operational procedures, enabling bias replication. Frameworks provide structure and turn design into operation. The study also shows that design education enhances efficiency, scalability, and homogeneity. This follows market-driven thinking but ignores social complexity and lived realities. This condenses socio-cultural realities into consumer-friendly images. Kimbell's critique of abstraction, Escobar's design methodology, and Costanza-Chock's design justice concept all align with these ideas. The research also shifts critique from framework to tool

analysis. This admits systemic and instructional prejudice. This is crucial in India, where caste, informality, and inequality require context-sensitive design solutions.

8 CONCLUSIONS

Design thinking promotes creative problem-solving, issue framing, and iterative learning in design and engineering education. When presented as a universal technique, it often hides social and cultural biases. Personas and empathy maps may promote urban middle-class views while marginalising others. Critical design pedagogy uncovers hidden assumptions by challenging representation, authority, and power in design processes. This method reframes design thinking as context-sensitive rather than discarding it. Critical, feminist, and decolonial perspectives improve design education understanding. This transformation is important in India because design interventions intersect with deep socioeconomic and geographical inequality. Critical design pedagogy may make engineering and design education more ethical, culturally relevant, and inclusive.

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THE COLOUR + GENDER FRAMEWORK: RE/DECOLOURING GENDERED SYMBOLISM IN PRODUCT LANGUAGE

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ABSTRACT

Designers use product language to construct meaning through visual and material features. Among these, colour plays a central role in evoking gender associations and narrowing the imagined user to a gendered default. Design practice, often driven by market logic, relies on the stereotypical female-male dichotomy, reinforcing binary “pink and blue” assumptions. Yet colour can also support alternative pathways beyond gender-targeting rooted in normative roles, fostering more inclusive and gender-sensitive design approaches. This paper tests the Colour + Gender (C+G) Framework, which addresses two persistent gaps in design education: the uncritical use of colour as a carrier of meaning and the limited resources and knowledge for recognising how gender shapes product languages. The study draws on a qualitative focus group with product design students. The session combined reflection on positionality, a chromatic mapping exercise, and a recolouring exercise, all examined through a gender lens. Participants analysed selected products to surface their interpretations of gendered meaning and to assess how such reflection informs design practice. Results confirm recurring relational patterns in colour parameters: lightness acts as a directional cue, mid-range values increase ambiguity, and extreme saturation reinforces binary readings. However, the product category emerged as the primary filter in gender attribution. The study refines the C + G Framework as a pedagogical tool to support more conscious, gender-sensitive design decisions.

Keywords: Design education, colour, product language, gender-sensitive design, design methods

1 INTRODUCTION

Product language examines how products communicate nonverbally [1]. The materiality of everyday objects conveys meanings that are deeply tied to their context [2]. These meanings both shape and are shaped by sociocultural constructions, often reinforcing existing inequalities. Namely, gendered narratives remain subtly yet pervasively embedded in products [3]. In this context, colour operates as one of the most powerful and immediate aesthetic cues, reinforcing gender biases and stereotypes [4–5]. As a result, intentional and unintentional colour-based gendering affects people’s choices and hinders efforts to design more inclusive, gender-plural products [6,7].

As designers, we hold agency in aesthetic decisions, acknowledging that responsibility and final choices might be shared with other stakeholders. Aesthetics, however, is typically seen as a product of designers’ “intuition” [8], paradoxically described as “indescribable” [9]. When aesthetic elements, such as colour, can potentially carry stereotypical meanings, acting on “gut feeling” can be risky [10,11]. Scholars and practitioners advocate for ongoing multidisciplinary research to develop stronger theories, methods and tools that assist designers in being intentional [12,13]. The lack of awareness and training on colour is pervasive in most educational design contexts, especially in top polytechnic schools [14]. Design students are rarely taught to address colour purposefully and in relation to its emotional and social impact [14]. Therefore, our work aims to contribute to the gap in the uncritical use of colour as a carrier of meaning, starting with design education, and the limited resources and knowledge for recognising how gender shapes product languages.

1.1 Colour beyond hue: lightness, saturation and gendered meaning

Although gendered colours feel long-established, associations such as “pink for girls, blue for boys” are modern and are largely driven by Western culture. By mid-century, widespread marketing of gender-coloured toys and clothing cemented these associations as “natural,” despite their cultural origin. Such cues continue to signal expected behaviours and reinforce social norms. Among the three colour attributes, hue remains the primary indicator people use to identify a product’s intended gender (98%), followed by name and description [15]. Beyond hue, the other two colour attributes, namely lightness (how light or dark a colour is) and saturation (its intensity, from vivid to muted), also play a role: lighter, multi-coloured, or shiny products are typically coded as feminine, while darker, restrained, or matte products are coded as masculine [16,17]. Colour plays a central role in shaping gendered perceptions of products, yet its influence is frequently oversimplified or reduced to hue-based assumptions.

1.2 The Colour + Gender (C + G) Framework: rationale and structure

Our previous study [18] demonstrated that gender coding in product design emerges from the interplay of lightness, saturation, hue, and form or shape rather than from hue alone. Based on this, a preliminary version (v.1.0) of the **Colour + Gender (C+G) Framework** was proposed, articulated around three overarching goals: (i) preventing the reinforcement of gender stereotypes through binary chromatic decisions, (ii) challenging reductive strategies such as “pink-it-and-shrink-it”, (iii) and promoting ambiguity and plurality to broaden the spectrum of product identities.

To operationalise these goals, the framework proposes a set of design implications based on HSL colour parameters and their relationship to gender perception (Table 1). In the following sections, we present the testing of the C+G Framework in an educational context to evaluate its practical effectiveness and capacity to support students in navigating gendered assumptions embedded in product aesthetics.

Table 1. C + G Framework guidelines for gender-sensitive colour decisions in product design

Parameter	Pattern	Design implication
Lightness	Lighter tones: femininity Darker tones: masculinity	Primary directional lever
Saturation	Low saturation: femininity High saturation: masculinity Mid-range values: androgyny	Mid-range values create more ambiguity and plurality
Colour relationships and proportions	Polychromatic with dominant hue: binary Balanced polychromies: androgyny Near-zero saturation monochromia: gender neutrality	Varied palette structure shifts or blurs gender reading
Form features	Primary shapes: masculinity Organic shapes: femininity	Form-colour interaction is strongest in archetypical categories

2 METHODS

The study used a qualitative methodology. Data were collected during a half-day focus group involving four product design students at Politecnico di Milano, Italy. The session began with an exercise in which participants examined their own privilege and reflected on how their positionality may shape their design choices. They then explored how this became explicit in their personal colour-gender associations. The group extended this examination to product colour palettes. These activities laid the groundwork for the final exercise, in which participants proposed a new chromatic solution for a selected product to shift its gendered perceptions.

2.1 Positionality mapping

Participants received a printed canvas featuring a “wheel of privilege” (adapted from the Canadian Council of Refugees), a visual representation of factors that shape social power imbalances (e.g., Gender, Citizenship, Skin Colour, Formal Education, Ability, etc.). They were asked to colour the area they identified with, considering that positions closer to the centre indicate fewer systemic obstacles and greater privilege, while positions closer to the margins indicate higher vulnerability. A blank space allowed participants to add any factors they considered relevant. The activity was anonymous and completely voluntary, so participants could share to the extent they felt comfortable doing so.

2.2 Chromatic compass: surfacing personal colour-gender associations

To surface participants' gender biases, a Miro board featuring a "gender identity compass" was provided. This activity took place before any explanation or discussion, to avoid influencing their choices. The compass included four main coordinates: masculine, feminine, androgynous (i.e., both feminine and masculine), and gender-neutral (i.e., neither feminine nor masculine). Students were asked to choose a colour for each coordinate and for the intermediate positions between them.

2.3 Palette-to-product mapping: analysing colour-gender readings

In this phase, colour, gender, and products intersected. A paper-based canvas featuring a two-axis map (i.e., feminine–masculine and androgynous–gender-neutral) was given to each participant. The androgynous side appeared as a closed semicircle to represent the binary constraint, whereas the opposite side lacked an explicit boundary to allow openness. A separate area was reserved for "uncertain" cases.

Participants mapped 15 product palettes across four typically gender-connoted product categories (i.e., electric razor, hair dryer, game controller, and electric screwdriver), see Figure 1. The colour palettes under analysis were derived from product images to enable a more detailed chromatic analysis. Proportions were qualitatively estimated based on visual dominance, and each palette was ordered from the most prevalent colour (dominant hue) to the least. Using the HSL model (hue, saturation and lightness), five levels classified colours by lightness and saturation (low, medium low, medium, medium high, and high). During the exercise, participants first mapped the products using only their palettes, then repeated the mapping with the full product images. This allowed the examination of colour associations independently of, and in relation to, product shape and category.

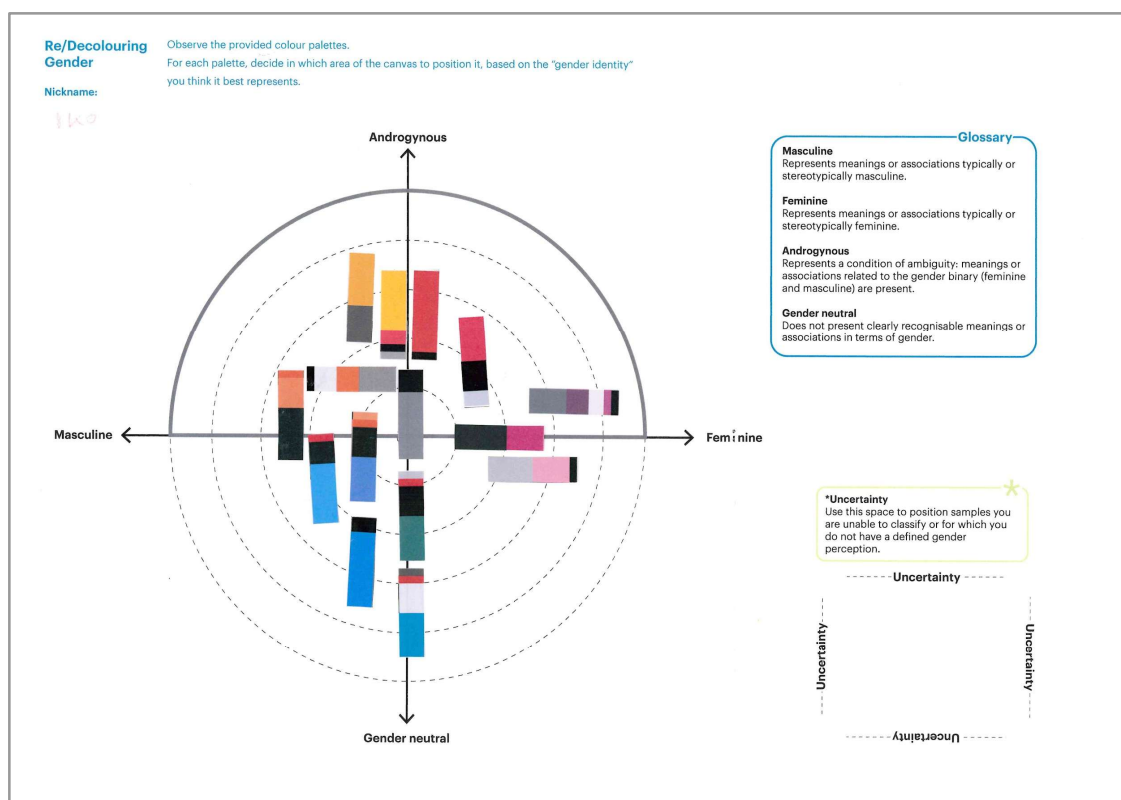


Figure 1. Mapping of the chromatic palettes of products using the chromatic compass canvas, corresponding to the category 'electric screwdriver'

2.4 Re/Decolouring exercise: proposing alternative chromatic solutions

Here, the focus shifted from analysis to decision-making. Each student was assigned one product from the same category they had worked with, along with a provocation to shift the product's perceived gender. The "recolouring" process unfolded in four sequential steps, each allowing modification of only one colour property while keeping the others fixed. At each of the four sequential steps, students

proposed two alternatives and selected one to carry forward: varying hue (step 1), shifting lightness toward lighter or darker (step 2), shifting saturation toward more desaturated or more saturated (step 3), and adjusting colour proportions within the palette (step 4). Students documented their choices for each step on a Miro board. Colour adjustments were made in a preset Photoshop file.

3 RESULTS AND DISCUSSION

3.1 Positionality shapes design perspective

The self-positioning exercise highlighted several missing dimensions perceived as shaping privilege and vulnerability. Participants noted that although they had reflected on some of these aspects at a personal level, they had never been given space to consider them in an educational academic context. The activity, beyond providing an operative way to map one's privilege, led participants to consider how their identity shapes their design practice.

3.2 Colour-gender associations reflect binary intuitions

The chromatic compass revealed that participants initially approached gender as a binary construct. Masculine and feminine coordinates were filled in first and more quickly, while gender neutrality emerged only after discussion. Colour choices were guided by intuition, self-expression, and social acceptability, often referencing clothing and trends.

Neutrality was frequently associated with desaturated tones such as black, grey, and white, or with colours perceived as detached from gender coding, such as green. However, even in this abstract task, colour was rarely considered independently from context. As one participant observed, the same colour applied to a hoodie or to a razor carries different implications. This anticipation of context foreshadowed later findings.

3.3 HSL parameters directionally guide gender attribution

Lightness acts as the primary directional cue across palettes. Lighter palettes clustered toward femininity, darker palettes toward masculinity. Even when hue remained similar, shifts in lightness altered gender attribution.

Colour relationships and proportions shape gender reading relationally, not in isolation. Palettes dominated by a single hue or strong contrast tended toward binary positions, whereas balanced palettes gravitated toward the centre or the androgynous axis. Gender perception was therefore relational rather than dependent on isolated colours.

Saturation alone is ambiguous. Its effect depends on combined HSL values. Highly saturated palettes often reinforced binary readings, while mid-range lightness and saturation repeatedly produced more ambiguous or androgynous placements. These mid-range combinations appeared to soften categorical cues and reduce polarity.

3.4 Product archetype overrides chromatic cues

When participants evaluated full product images rather than palettes alone, product category emerged as the strongest determinant of gender attribution. For instance, the razor retained strong gender associations despite a colour change, suggesting that normative archetypes stabilise gender readings. In addition, one game controller was placed along the androgynous axis despite the presence of stereotypically feminine features (pink colour and organic shape) because it did not align with expectations of a "gamer's room."

Archetypal form overrides colour in strongly gender-coded categories. Sturdy geometries were described as harder to neutralise through recolouring. Softer or less defined forms were easier to reposition. Some hairdryers were described as resembling construction tools, while others appeared "gentler" aesthetically. These formal qualities shaped the mapping more than colour adjustments alone. This finding indicates that stereotypical male-coded cues might be harder to challenge.

Neutrality is reframed as personal expression rather than the absence of gender. In some cases, participants deliberately positioned a product at the centre because they perceived it as lacking gender coding. Within this reasoning, colour was framed less about how others read you and more about what you like. Gender neutrality was described as allowing greater freedom from preconceptions and was surprisingly associated not only with desaturated colours but also with bolder, more complex shades.

3.5 Re/Decolouring reveals both potential and limitations

The Re/Decolouring gender exercise further tested the initial assumptions on HSL properties and gender perception (Figure 2). The results confirmed several patterns already observed in the mapping phase, but they also revealed limitations.

Lightness consistently shifts gender attribution across the recolouring steps. Each increase in lightness pulled the product away from masculinity, confirming it as a directional variable.

Colour proportions within the palette carry more gender weight than hue. In the razor case, a dominant beige base was described as neutral and stable, while a bluish-purple accent carried the gender shift. Neutrality functioned as ground; connotation resided in the accent.

Saturation effects are context-dependent and resist generalisation. In some cases, higher saturation aligned with femininity; in others, reduced saturation was used to approach neutrality. However, desaturation was sometimes perceived as restrictive. For one participant, neutrality meant expanding interpretive possibilities rather than flattening the palette with muted colours.

Black is not perceived as neutral when applied to gendered product archetypes. In the hairdryer case, black-only solutions were rejected in favour of bolder combinations. Lightness adjustments alone produced limited variation, and technical constraints occasionally influenced decisions.

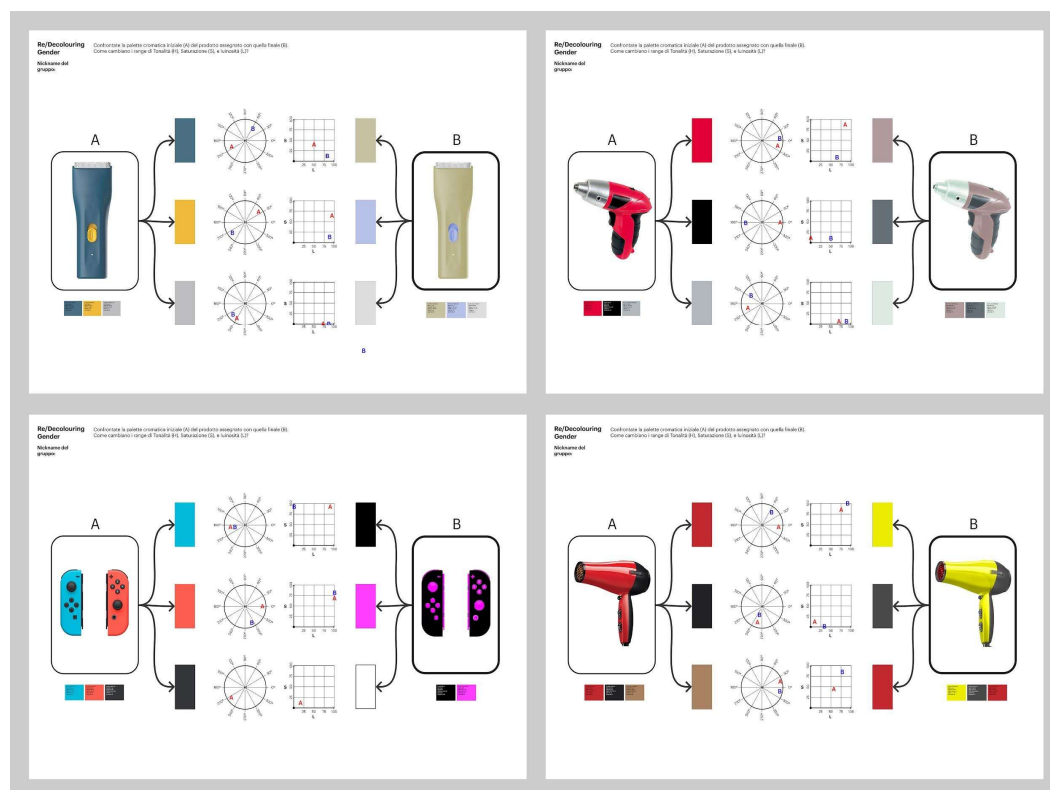


Figure 2. The Re/Decolouring exercise canvases explicitly show a shift in the initial colour palettes in terms of their hue, lightness and saturation, for a change in the perception of products' gender

Across cases, shifts toward femininity tended to strengthen non-neutral accents, while shifts toward neutrality increased the dominance of balanced or stabilising tones.

4 CONCLUSIONS AND FUTURE WORK

The study examined how gendered colour cues are perceived and interpreted and evaluated the practical utility of the Colour + Gender (C+G) Framework. The findings confirm that lightness acts as a directional cue, shifting gender attributions even when other chromatic variables stay constant. They also corroborate the importance of colour relationships and proportions, which more clearly shaped gender than hue alone. Mid-range combinations of lightness and saturation repeatedly produced ambiguous or androgynous readings, revealing a perceptual zone that operates beyond binary coding.

Our work also identifies areas requiring further investigation. Product category and archetype strongly guide gender attribution, which means chromatic parameters cannot be examined in isolation and warrant systematic testing across broader object families. Together, these insights refine the pedagogical value of the C+G Framework by showing how it can support more critical, reflective, and gender-sensitive colour decisions in design education. By framing colour as the interplay of hue, lightness, and saturation (and the proportional relationships among them), we give students a methodical way to navigate colour choices in practice. A strong grasp of these processes, we argue, underpins more intuitive and creative work; we believe mastering the tools frees you to create. Making explicit how colour performs gender gives students a solid foundation for reflection and agency in driving change. We also witnessed how reflection can encourage more plural and less stereotypical chromatic thinking. Students' tendency to reinterpret rather than erase gender cues points to a more nuanced design ambition than simple neutralisation. Future work will test the framework within course curricula as a tool to help students navigate colour choices in design studio projects.

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MAKING SENSE BEFORE MAKING THINGS. BUILDING DESIGN RESEARCH LITERACY AND EPISTEMOLOGICAL AWARENESS IN FIRST-YEAR MASTER STUDENTS IN DESIGN

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ABSTRACT

This paper presents a pedagogical model developed within the MA Design for Sustainable Futures programme to introduce design research foundations to first-year master's students. The course Design Research & Methods, conceived in close relation to Design Studio, functions as an entry point to academic inquiry in design, supporting students in understanding how design generates, structures, and communicates knowledge, providing a research scaffold intended to inform early-stage studio work by strengthening problem framing, evidence use, and the articulation of design decisions. Placed at the start of the Master's path, it builds a shared research vocabulary and familiarises students with diverse epistemological and methodological approaches. Through an iterative trajectory—from defining design and knowledge production to framing research questions, selecting methods, and analysing data—students learn to navigate the design research process systematically and reflectively. Hands-on exercises (literature dataset building, mind mapping, and IMRAD-based writing) translate these principles into practical skills. The paper outlines the course design and reports diverse assessments grounded in students' experiences. Overall, the study examines how early exposure to design research competences may foster intellectual autonomy, critical thinking, and methodological awareness, supporting a research-oriented mindset for future challenges

Keywords: Design research education, design epistemology, research literacy, design for sustainable futures

1 INTRODUCTION

The MA Design for Sustainable Futures (DfS) programme at KTU Kaunas University of Technology aligns with sustainability and circular-economy agendas, integrating design, management, and environmental engineering to develop systemic design and sustainability competences for products, services, and supporting systems. This responds to EU policy drivers framing circular economy as a pathway to redesign production–consumption systems [1] and linking the Green Deal to lived environments via initiatives such as the New European Bauhaus [2], as well as to the growing link between future competences, employment, and sustainability transitions [3]. Design is a core “green” capability, yet designers must demonstrate impact accountability and operate in interdisciplinary innovation settings [4]; accordingly, the programme adopts GreenComp as an overarching competence framework. Given the centrality of information and sources for problem framing and action, design research literacy is introduced early through the first-year course Design Research & Methods to help students navigate complexity, make evidence-informed sustainability claims, and articulate design as knowledge production. This also aligns with realities where design and R&D are intertwined in projects [5]. Design research can shape early problem framing and direction-setting in technological innovation [6], and designers can translate knowledge in R&D-oriented open innovation [7]. Building on this rationale, the paper evaluates whether—and how—these research competences change students' design approaches, examining perceived shifts in decision-making/accountability, problem framing, evidence use, and reflexivity, and contributing (i) a pedagogical model for early research foundations, (ii) an assessment based on end-of-course student perspectives, and (iii) implications for studio practice and inclusion through shared research vocabularies and methodological awareness.

2 BACKGROUND KNOWLEDGE

2.1 Sustainability in education: from principles to actions

Several research efforts have framed the key dimensions of sustainability competences [8] [9]. Among EU competence frameworks designed to embed EU value frameworks and inform members' educational systems, GreenComp is adopted here; it organises these capabilities into four “building blocks”: embodying sustainability values, embracing complexity, envisioning sustainable futures, and acting for sustainability [10]. These competences are increasingly critical given the climate crisis, biodiversity loss, and systemic social inequalities, which demand a paradigm shift beyond technological innovation alone, and in design and manufacturing sustainability has shifted from a “nice-to-have” to a mandatory requirement requiring agency to address wicked problems and make reasoned decisions [11]. To support competence development, Education for Sustainable Development (ESD) is increasingly discussed as a transformative learning process enabling responsible decisions for environmental integrity, economic viability, and social justice. UNESCO's “ESD for 2030” positions lifelong learning as a key enabler for all 17 SDGs and for transformations needed to remain within planetary boundaries [12]. Within this frame, research literacy is a foundational academic competency—data management, critical thinking, and evidence-based decision-making—supporting complex sustainability problem solving [9] [10]. Accordingly, ESD treats sustainability as a fundamental design requirement, demanding not only values but enactable competences expressed through concrete practices [13]; GreenComp defines these as the integrated mobilisation of knowledge, skills, and attitudes that enable empathetic and responsible thinking, planning, and action for the planet [10]. These competences are operational, shaping how students “do” design to restore ecosystem health and enhance justice rather than remaining declarative knowledge [14]. Organisational research similarly notes that action can be limited by “decoupling” (symbolic commitments not translating into practice) and cognitive dissonance (knowledge without agency or implementation skills) [10].

2.2 Bridging design research literacy with project-based learning for sustainability

Design education is rooted in project-based studio learning where students “learn to design by designing” in a simulated professional environment [15]. These projects can foster sustainability competence through forward-looking thinking within a planetary consciousness paradigm [18], functioning as a “gym” for responsible innovation where futurable solutions align feasibility with planetary well-being. However, project-based learning does not automatically ensure epistemically robust sustainability action [16]: studios may privilege solution-oriented making while assumptions, systemic implications, and evidentiary bases remain under-scrutinised, leading to action without equal capacity to justify, validate, and situate interventions. Conversely, when sustainability is taught mainly as principles or content, students often struggle to translate ideals into reasoned decisions and project conduct [13]. To address this gap in a situated context, the study examines an instructional innovation within a specific curricular, institutional, and cultural setting where such integration had not been attempted, investigating how design research connects to early-stage project-based learning and related outcomes. An action research approach allows treating pedagogical advancement as a study of context-embedded change, generating practice-based insights through iterative implementation, while offering analytically transferable considerations beyond the immediate context [17].

3 FRAMING THE CONTEXT FOR ACTION RESEARCH

3.1 The curriculum planning: Master's in design for Sustainable Futures

Aligned with ESD purposes, the DfS programme was launched in 2025 to equip graduates with integrated knowledge across design, management, and environmental engineering, strengthening systemic design capabilities and sustainability competencies for future-oriented products, services, and supporting systems. It welcomes first-cycle graduates from diverse design domains and related disciplines, while requiring solid foundational design skills (composition, colour/aesthetics, visualisation, and software-supported project development). A distinctive curricular feature is the central role of design research as a bridge between project praxis and scientific inquiry [19], spanning design-based research (design as methodology) and design-oriented research (artefact as outcome), complemented when relevant by social science methods on industry and societal impacts. The pathway is organised into four thematic elements: Design Research (hands-on inquiry/experimentation), a “0-mindset” (mission-led systemic thinking, collaboration, impact anticipation, reducing planetary burdens, futuring), Hands-on Future (prototyping via traditional making and advanced digital

fabrication), and Interdisciplinary Knowledge (boundary-crossing integration for complex sustainability challenges). These elements align with the GreenComp “building blocks”, shaping a designer–sustainability expert profile and enabling students to address challenges across business, industry, nature/environment, and society, developing solutions for communities, ecosystems, industry, the city, and the university while opening opportunities for new directions in design research (Figure 1).

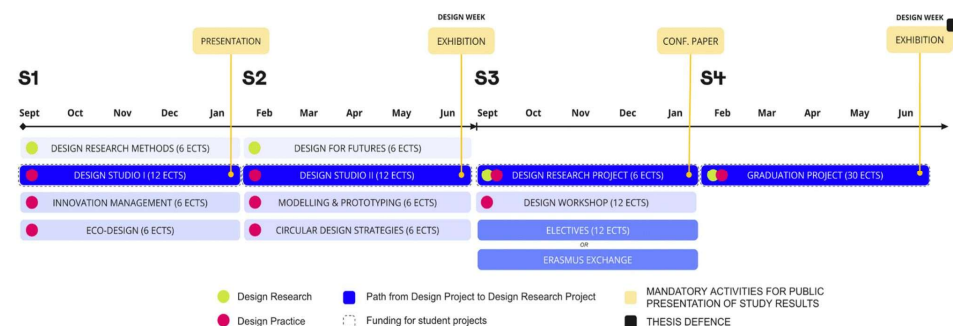


Figure 1. MA Design for Sustainable Futures programme path

This work evolves into a two-year design research project: it begins with a practice-driven design project in the first year and, in the second year, becomes an explicitly research-oriented endeavour in which the practical project is progressively merged with design research activities and outputs from the very beginning. A coherent learning trajectory—supported by sequential studio and research modules (more distinct in the first year and increasingly integrated in the second) and culminating in the final project—enables students to iteratively frame questions, select and apply methods, build evidence, and test interventions in laboratory and real-world contexts. The pathway prepares graduates for contributing to transitions through design-led action grounded in evidence-based practice.

3.2 The course design: Design Research & Methods

Within this framework, concerning specifically Design Research & Methods course, the authors adopted an iterative learning trajectory that is explicitly designed to feed into Design Studio 1, where students begin their first integrated, sustainability-oriented design project. The course progressively moves from foundational conceptual framing to applied research-design competencies that students mobilise in the studio. Learning activities were designed to translate abstract research principles into situated practice through a sequence of concrete exercises. The first phase defines design as knowledge production, situating it within broader epistemic paradigms (science–arts and “designerly” knowing) and introducing ontology, epistemology, and methodology to clarify what counts as knowledge and how it is generated in/through design. This grounding supports early studio work—sustainability challenge exploration, stakeholder/ context understanding, and sustainability-relevant intents—by helping students frame research problems and questions and treat inquiry as a structured yet non-linear, iterative cycle. The trajectory then addresses method selection so that data gathering becomes a decision-making resource for Design Studio 1. As a hands-on exercise, students conducted an initial literature search on their studio topic using library databases and scholarly repositories (i.e. Scopus), applied explicit inclusion criteria to build a coherent corpus, and recorded metadata and brief analytic notes to create a reusable dataset. This trained information seeking, critical judgement of relevance/quality, and literature organisation for framing, question formulation, and method selection. In parallel, students produced a mind map reconstructing key concepts from the introductory lecture on academic design research; together with the literature search, this formed the first assessment element, enabling evaluation of students’ articulation of an “academic design research logic” and identification of ambiguities or missing links. In the second phase, students then addressed method selection and its justification in relation to objectives, followed by data analysis, showing how analytical procedures transform “raw data” into evidence that can inform design directions and accountability claims within the studio process. The trajectory culminated in communicating knowledge, presenting research design as a blueprint including data presentation and reporting, operationalised through concise academic writing (i.e., an IMRAD-style abstract) to consolidate learning and train a transferable competence for more disciplined problem framings. Unlike the first phase, this stage relied on conversational reviews of students’ research process (no additional lectures) and focused on the second deliverable: an IMRAD-based speculative abstract.

Here, students reframed their Design Studio 1 project as academic design research, practising coherent communication of questions, methods, and emerging insights, and allowing teaching staff to observe their ability to “wear the design researcher’s glasses” when interpreting their own projects.

4 METHODS FOR ASSESSING THE COURSE EFFECTIVENESS

This study adopts a qualitative course-evaluation design centred on students’ perspectives, using two sequential measurement points—a mid-term self-evaluation administered after the initial instructional block on design research foundations and process, and an end-of-course self-assessment—to trace perceived changes in research competence and their relevance for design practice. The two datasets were compared to examine perceived uptake and translation into “ways of designing” (framing, method choices, evidence-informed decision-making, reflective practice).



Figure 2. Mid-term students’ self-evaluation

Participants were first-year master’s students in Design Research & Methods; while sharing the National background, the cohort was academically and professionally diverse (i.e., Design Engineering, Graphic Design, Art Studies, Landscape Architecture, Business Analytics and Marketing, Multimedia Design), shaping differing familiarity with research language and practices. The mid-term self-evaluation (Figure 2) used a low-threshold dot-mapping across eight research design components (objectives & questions; data collection methods; sampling; instruments; data analysis; time frame & ethics; resources; data presentation & reporting) rated on a three-level colour scale (red/yellow/green), producing a readiness map used diagnostically and as an early reference point after the foundations block (not a true pre-course baseline) for comparison with end-of-course reflections on transfer. End-of-course data were collected via an anonymous Microsoft Forms survey on course organisation and personal reflections, eliciting open-ended narratives on links to students’ way of designing, connections to design tasks in Design Studio 1, and anticipated future integration. Data were analysed through thematic analysis and cross-time comparison: end-of-course responses were inductively coded for learning, the mid-term mapping was synthesised as a competence snapshot, and themes were compared to assess perceived shifts, persistent uncertainties, and evidence of research competences becoming enactable. The literature dataset with mind map and the speculative IMRAD abstract served as assessment artefacts and teaching evidence but were not systematically coded as a separate dataset; future work should analyse these artefacts to triangulate self-reported transfer.

5 RESULTS

The cohort comprised 10 first-year students; the mid-term self-evaluation was completed by all students, the end-of-course survey by 6. The three open-ended questions were analysed through thematic analysis, with iterative reading, inductive line-by-line coding, and clustering into higher-order themes through repeated review and refinement. Themes are reported with a simple frequency indicator (number of respondents out of 6 contributing at least one coded excerpt); counts are non-exclusive because responses may include multiple themes, and they replace vague terms (i.e., “most”, “a minority”) with approximate denominators (i.e., 5/6; 1/6) without implying statistical inference. The mid-term self-evaluation indicates a differentiated competence profile: most ratings cluster in “partly clear” (yellow), with higher confidence for Research Objectives & Questions and Resources (more green), and lower confidence for Sampling (more red) and Data Analysis (mostly yellow, few green). Data Collection Methods and Instruments are intermediate, with mixed yellow/green and occasional red, suggesting

partial, procedural understanding. End-of-course thematic analysis suggests an overall positive but heterogeneous perceived transfer into students' "ways of designing", from foundational research literacy to research-to-design translation (i.e., "Through this course, I learned that design is not only about creating a product, but about understanding the decision-making processes, perceptions, and constraints that influence whether a product is adopted"). Foundational gains concerned information practices (locating reliable sources, keyword scanning, structuring knowledge via databases and mind mapping) to manage complexity. More operationally, students described research supporting framing and question formulation, shifting from solution-first exploration to a more deliberate inquiry logic (i.e., "From this course, I would incorporate a more structured research approach... define the problem... identify stakeholders... formulate focused research questions"), and, where concrete examples were provided, informing material and construction decisions under sustainability constraints and stakeholder logics. Interpreted through the programme's GreenComp positioning, these examples indicate that research literacy supported the *enactment* of sustainability competences rather than only generic "better research" skills. In particular, students' reported shifts toward systemic reframing of constraints and stakeholders ("embracing complexity") and toward evidence-informed material and construction trade-offs ("acting for sustainability") make the sustainability framing empirically visible within the reported transfer to Design Studio 1. A minority reported limited or delayed transfer due to insufficient opportunity to "really design" or difficulty integrating research practices within demanding studio workflows, indicating that timing and curricular coupling condition how readily competences become enactable. The two assessment points differ in format and construct: the mid-term instrument captures self-perceived clarity/confidence via a three-colour scale across predefined research components, while the end-of-course survey elicits retrospective, situated narratives of learning and transfer. Therefore, the datasets are not treated as directly commensurable measures of "change" but are related through analytic alignment: the mid-term mapping provides a competence snapshot after the foundations block, and end-of-course narratives are analysed for application, persistent uncertainty, or barriers in the same domains (framing, method choice, analysis-to-decision links). Cross-time comparison maps end-of-course themes and excerpts onto mid-term component areas to interpret progression, persistence, or friction, while acknowledging self-report limits and instrument non-equivalence. Read alongside the end-of-course survey, the mid-term profile offers a baseline for students' subsequent calls for more hands-on practice, particularly in sampling and data analysis, which appear most fragile at mid-course. The two assessment points indicate a shift from partial clarity—especially in procedural components—to end-of-course accounts where many students report using the course framework for problem framing, question formulation, and evidence-informed decisions. However, the comparison shows that perceived competence does not translate uniformly into practice: transfer depends on opportunities for application and on the alignment between research and design activities, helping explain persistent uncertainties and variable impact. In GreenComp terms, these accounts most directly point to 'embracing complexity' and 'acting for sustainability': students used research practices to relate material choices, stakeholder systems, constraints, and longer-term implications rather than treating sustainability as a general value statement.

6 CONCLUSIONS

In conclusion, this paper presented an iterative pedagogical model that introduces design research literacy and epistemological awareness at the start of a sustainability-oriented master's programme, proposing that "making sense before making things" can strengthen responsible action in project-based learning. End-of-course reflections suggest a shift from foundational research literacy (source discernment and knowledge structuring) toward research-to-design translation, where framing, question formulation, and evidence-informed decisions become more visible in studio work. However, transfer was uneven and could be delayed when research practices were weakly coupled with studio timelines, highlighting the need for curricular alignment and scaffolded opportunities for application. Research literacy thus functions as enabling infrastructure for accountability, critical thinking, and reflective iteration in sustainability-driven design, but the exploratory, self-reported dataset limits claims: despite the framing that sustainability competences should be enactable rather than declarative, the evidence captures only perceived development and declared transfer, not verified enactment in outcomes. Future work should triangulate self-reports with studio artefacts, process documentation, observational data, and longitudinal follow-up, and refine the course through more hands-on method workshops and tighter integration with studio milestones. A further implication concerns the sustainability–design research

relationship: sustainability may not require a wholly “different” paradigm, but it increases epistemic demands, so studio work benefits from research approaches that make framing, method choice, and evidence-building explicit to articulate trade-offs and accountability beyond solution-led making. Consistent with the course’s scaffold role, this specifies the contribution to sustainability-oriented design education: research literacy supports more situated, evidence-informed, and accountable sustainability claims.

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CAREER PATHWAYS OF INDUSTRIAL DESIGN GRADUATES

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ABSTRACT

Understanding where industrial design graduates go after earning their degrees can illuminate the diversity of roles, industries, and trajectories that define contemporary design practice. This study investigates the career paths of individuals who earned university-level degrees in industrial or product design. Referencing professional data on LinkedIn, the study identifies patterns in employment including job titles, length of employment, and geographic mobility. Preliminary findings suggest that industrial design graduates pursue a wide range of roles, including positions in user experience, strategy, marketing, and entrepreneurship—fields that both intersect with and extend beyond traditional product design practice.

This research invites reflection on how educators define and evaluate the “success” of a design degree. If a graduate builds a career outside of core industrial design practice, does that indicate a limitation of the curriculum, or evidence of the discipline’s expanding relevance? By examining graduate outcomes, this work offers insight into how design programmes might better prepare students for an ever-changing professional landscape. The study also discusses methodological considerations for using publicly available data to explore alumni trajectories and outlines opportunities for future research integrating larger datasets and longitudinal analysis. In doing so, it contributes to ongoing discussions about aligning educational practices with the evolving realities of design work.

Keywords: Industrial design, career, design education

1 INTRODUCTION

On the first day of the second year of my undergraduate programme, we gathered in a classroom. In the midst of a spirited monologue, one of the senior faculty said, “Look to your left and look to your right. Only one of you will become an industrial designer.” The subtext was that the only successful graduates of the programme would be those individuals with the role of ‘industrial designer’ on their business cards.

As a design educator myself I take a different stance, positioning an industrial design degree as a competitive advantage. It is a versatile credential that readily supports a multitude of career paths. While anecdotally I am aware of friends and former students landing jobs beyond industrial design, to date there has not been a formal study of career paths in industrial design.

Part of the reason for this gap in scholarship is that alumni records from degree-granting institutions are typically private, making it challenging to conduct a multi-institutional study. Publicly available information used for online networking offers an opportunity to bridge the gap. A pilot analysis of 120 LinkedIn profiles across eight universities confirms that individuals earning industrial design or product design degrees have a variety of career trajectories. This work investigates the question: How should design programmes define and evaluate the “success” of a degree?

If an alumnus from an industrial design programme builds a career as a UX researcher or a strategist, traditional metrics might categorise this as attrition from the field. Alternatively, this could be considered evidence of the discipline’s expanding relevance—proof that the core competencies of industrial design (including human-centricity, iterative problem-solving, and systems thinking) are highly transferable. By examining graduate outcomes across both public and private institutions, this paper offers empirical insight into the evolving realities of design work and how curricula might adapt to support an increasingly divergent professional landscape.

2 METHODS

This study's dataset was compiled using quota sampling of self-reported LinkedIn profile information, targeting alumni from eight comprehensive, degree-granting universities. One public and one private university from four distinct geographic regions are included in the sample. Importantly, the industrial and product design programmes represented in the sample range in maturity, with the oldest being nearly 100 years old and the newest being 46 years old.

Alumni were grouped into cohorts (with graduation year 2010-2014, 2015-2019, and 2020-2024), and the dataset includes five alumni from each cohort for each university (n=120). Alumni were chosen based on LinkedIn profile availability, so this is a convenience sample. For each subject, the study recorded graduation year, employer history, job titles, and geographic location.

To analyse the divergence from traditional design practice, career paths were coded into four primary pillars:

1. Core Industrial Design: Roles focused on the physical development of products (e.g., Industrial Designer, CMF Designer, Footwear Developer).
2. Digital Product/UX Design: Roles focused on digital interfaces and virtual ecosystems (e.g., UX Designer, Interaction Designer).
3. Design Strategy/Management: Roles focused on process, corporate leadership, and business strategy (e.g., Design Strategist, Design Programme Manager).
4. Divergent Paths (Outliers): Roles outside conventional design disciplines (e.g., Ministry, Pure Engineering, Media).

Data analysis was conducted using an Augmented Intelligence approach, where initial categorical coding and statistical clustering were performed by Gemini 3.0 Flash, a Large Language Model (LLM) developed by Google. To ensure data integrity, a manual verification protocol was implemented, cross-referencing LLM-generated outputs against the raw dataset to correct for grouping errors and ensure a balanced sample size (n=120).

Limitations: Using publicly available LinkedIn data introduces inherent limitations, notably "survivorship bias." The dataset captures individuals who actively maintain professional digital profiles, which may underrepresent alumni who left the professional workforce or moved into trades that do not utilise digital networking platforms. Additionally, the sample size of 15 alumni per institution reflects a pilot study rather than a comprehensive longitudinal census.

3 FINDINGS

The analysis of 120 alumni profiles across eight institutions reveals an academic discipline in the midst of a transition. By comparing initial post-graduation roles with current employment, the data illustrates how the industrial design degree has evolved from a specific vocational track into a versatile strategic credential.

3.1 Cohort Evolution and the Digital Pivot

Analysis of graduation years reveals a generational divide in career trajectories. The "Traditionalist" cohort (graduating 2010–2014) exhibits high job stability and a heavy concentration in core physical product design, often holding Senior or Principal titles at legacy manufacturing firms. In contrast, the "Bridge" cohort (2015–2019) demonstrates the highest career volatility and marks the inflection point of the digital pivot. A significant percentage of these alumni started their careers with traditional "Industrial Designer" titles before transitioning into UX or Digital Product Design by their second or third role. The "Specialist" cohort (2020–2024) further entrenches this shift, with many bypassing generalist industrial design roles entirely to enter the workforce as specialised UX Designers, CMF (Colour, Material, Finish) experts, or Design Strategists.

The data reveals that attrition from core industrial design is not a single event, but two distinct phenomena: initial divergence (entering a non-ID role immediately) and the mid-career pivot (transitioning after a period of traditional practice).

- Initial Divergence: Among the 2020–2024 cohort (n=40), 18 individuals (45%) secured their first professional role in digital product design or strategy without first holding a "traditional" industrial design title.
- Mid-Career Pivot: Among the 2015–2019 "Bridge" cohort (n=40), 34 alumni (85%) began their careers in core industrial design. Four of these individuals have since transitioned into UX or Strategy roles.

Disciplinary Retention in the Traditionalist Cohort

In contrast, the 2010–2014 cohort (n=40) shows the highest levels of both initial and long-term retention. 37 alumni (92.5%) entered the field via core ID roles, and 35 (87.5%) remain in the field today. In this group, the "Mid-Career Pivot" is rare (5%), with the majority of career movement occurring vertically within manufacturing and consultancy firms (e.g., moving from "Industrial Designer" to "Director of Design").

3.2 The "Outlier" Effect and Transferability

Beyond the digital pivot, approximately 15% of the total sample occupies "Divergent Paths." These individuals hold titles in fields such as visual journalism, creative ministry, and product engineering. A key finding within this group is the "Seniority Jump." Outliers who moved into strategy or non-traditional leadership roles often achieved "Senior" or "Lead" titles faster (average 3.5 years) than those who remained in core industrial design roles at traditional manufacturing firms (average 5.2 years).

3.3 Funding Models and Industry Pipelines

When comparing the two funding models (public vs. private institutions), patterns of employment emerge. With a balanced sample of n=60 for each group, the study found that alumni of public universities were more likely to pivot into digital ecosystems.

Table 1. Employment Categories, Public vs. Private Institutions

Metric	Public Universities (n=60)	Private Universities (n=60)	Total (n=120)
Initial Core Industrial Design Role	44 Individuals (73.3%)	49 Individuals (81.7%)	93 (77.5%)
Current Core Industrial Design Role	39 Individuals (65%)	48 Individuals (80%)	87 (72.5%)
Current Digital/Strategy Role	21 Individuals (35%)	12 Individuals (20%)	33 (27.5%)

3.4 Geographic Concentration and the "Hub" Effect

Industrial design employment is not evenly distributed; it is highly concentrated in regional hubs that dictate the nature of the work. The data shows strong regional retention, indicating that a school's geographic location acts as a gravitational pull for its graduates.

4 DISCUSSIONS: REDEFINING 'SUCCESS' IN DESIGN EDUCATION

The findings of this study directly address the tension outlined in the abstract: does a career outside of core industrial design indicate a curriculum's limitation or the discipline's expanding relevance?

The data suggests the latter. As Buchanan posited in his exploration of the "four orders of design," the discipline has naturally evolved from the design of symbols and objects to the design of complex interactions and systems [1]. The high percentage of alumni pivoting into UX and corporate strategy—particularly from public universities—indicates that modern industrial design education functions less as a vocational training programme for manufacturing, and more as a foundational logic for human-centred problem solving.

When an alumnus transitions from designing physical appliances at SharkNinja to mapping user ecosystems at Google, they have not abandoned their degree; they have scaled it. The ability of these graduates to navigate the "Digital Pivot" speaks to a post-disciplinary agility [2]. Therefore, defining the "success" of a design degree solely by the production of physical artifacts relies on an outdated, 20th-century metric. Success in the contemporary landscape is defined by adaptability.

However, this reality presents a challenge for design educators. If nearly a third of graduates will ultimately work in digital product design or strategy, curricula built exclusively around physical shop skills, traditional CAD, and physical prototyping may be under-serving students. Programmes must grapple with how to integrate systems thinking, digital UI/UX frameworks, and business strategy without diluting the tactile, spatial intelligence that makes industrial design unique.

5 NEXT STEPS AND CONCLUSION

The industrial design degree is undergoing a fundamental identity shift, evolving from a specialist credential into a versatile toolkit for navigating complex, multifaceted industries. To better prepare students for this reality, academic programmes should consider formally integrating cross-disciplinary coursework—such as human-computer interaction and business strategy—early in the curriculum.

Future research is required to fully understand the implications of this shift. Specifically, longitudinal studies utilising larger datasets are needed to track the 10- and 20-year career arcs of alumni. Furthermore, qualitative research examining the salary trajectories and job satisfaction of those who pivoted to digital roles versus those who remained in physical design could provide crucial context for prospective students. Ultimately, by expanding how we measure alumni outcomes, design institutions can ensure their pedagogy remains as innovative and adaptable as the professionals they produce.

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A STRATEGIC PERSPECTIVE FOR FUTURE-PROOF WORKFORCE DEVELOPMENT: INSIGHTS INTO THE DIGITAL LIFECYCLE LAB

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ABSTRACT

Rapid technological change, digital transformation, and labour shortages are reshaping the requirements placed on the engineering workforce, increasing the need for interdisciplinary and *systems engineering* competencies. The *Digital Lifecycle Lab* (DLL) at *Graz University of Technology* addresses these needs as an educational concept supporting engineering transformation through student training and the upskilling and reskilling of industry professionals. However, effective workforce initiatives also require systematic academia-industry knowledge transfer interfaces to develop future-proof qualifications.

Building on research presented at *E&PDE 2024* and *2025*, this study develops strategies to advance the engineering workforce while fostering diversity across educational formats, backgrounds, disciplines, and career stages. It examines how global trends shape workforce orientation and identifies critical future skills. As a key characteristic, the DLL integrates modelling and representation of lifecycle-spanning system phases, enabling learners to recognise interdependencies between disciplines and their contribution to holistic system creation. Moreover, the DLL's structure enables comprehensive system understanding and empowers learners from both academia and industry to identify and apply *artificial intelligence* solutions across development stages. By aligning educational content with technological demands and workforce trends, the DLL provides transferable solutions to close skill gaps and enhance inclusion, positioning itself as a model for building a resilient, future-ready engineering workforce.

Keywords: Digital lifecycle lab, workforce development, academia-industry collaboration, engineering education, systems engineering

1 INTRODUCTION

Rapid technological progress, accelerating digitalisation, and increasing system complexity are fundamentally reshaping the demands placed on the engineering workforce. Beyond technical expertise, engineers must adapt continuously, collaborate across disciplines, and manage complex systems across the lifecycle. At the same time, demographic change, labour shortages, and intensified international competition increase pressure on both engineers and educational institutions. As a result, engineering education is undergoing a profound transformation, requiring interdisciplinary collaboration across diverse teams and career stages. Such collaboration is increasingly recognised as a driver of innovation [1]. This shift moves engineering practice from isolated, sequential activities toward interconnected, model-based, and reusable development approaches. Within this context, *Systems Engineering* (SE) has emerged as an integrative competence, supporting holistic system understanding, tool and data integration, coordination across disciplines, and informed decision-making [2].

Because of these developments, traditional academic credentials alone are increasingly questioned in light of rapidly evolving workforce demands [3]. Engineering education often remains organised around discipline-specific degree programs or isolated training initiatives, thereby limiting flexibility and scalability. In parallel, industrial organisations act as technological drivers and scalers due to substantial research and development investments [4], requiring practice-oriented competencies applicable across organisational and technical boundaries. This misalignment between academic education and industrial needs highlights the necessity for approaches that extend beyond rigid, traditional formats. Prior work presented at *E&PDE 2024* and *2025* provides the background for this study by discussing networked academia-industry structures and bidirectional knowledge exchange [5], as well as an end-to-end SE-

based learning environment covering the system lifecycle [6]. Building on this foundation, the present paper uses this learning environment to examine how concrete educational designs can be scaled toward broader workforce development. It examines how global workforce trends and skill demands (*Section 2*) can be translated into requirements for engineering education (*Section 3*) and operationalised through an educational design (*Section 4*), with particular attention to organisational embedding and broader workforce impact (*Section 5*). Accordingly, this paper provides a methodological foundation for workforce-oriented engineering education through a practical concept study using an educational reference environment, complemented by pilot observations from a system development project.

2 WORKFORCE DEVELOPMENT AND FUTURE ENGINEERING SKILLS

To frame workforce-oriented engineering education, it is necessary to clarify this evolving context. In engineering, workforce development is increasingly understood as a continuous process spanning formal education and professional practice [2], requiring not only university training but also ongoing upskilling and reskilling of professionals in response to technological and organisational change [7], [8]. As highlighted by *Graham* [9], conventional engineering education often remains characterised by siloed disciplinary structures and fragmented curricula that limit cross-disciplinary learning and flexibility. This constrains heterogeneous learner groups and results in isolated educational initiatives. *Figure 1 a)* illustrates the scope of engineering education and the impact of global trends on educational pathways, ranging from student training to industrial upskilling and reskilling. Workforce development thus emerges as a shared responsibility across institutional actors. The trends outlined below provide the basis for the future-oriented competencies identified in *Section 2.2*.

2.1 Global trends shaping the engineering workforce

The engineering workforce is influenced by interrelated megatrends, including digital transformation, smart systems, *artificial intelligence* (AI), globalisation, and sustainability [10], [2], which reshape competence requirements and educational pathways. These trends alter how engineered systems are created and how engineering teams operate, while increasing complexity and expanding lifecycle integration. As engineering tasks span multiple domains and technologies, interdisciplinary and diverse teams become essential for addressing complex challenges. Research highlights the importance of heterogeneous teams for multidisciplinary problem-solving and sustained performance [11], [1], thereby extending required competencies beyond technical expertise.

Demographic decline in many industrial societies [12], combined with a persistent shortage of qualified engineers [13], intensifies pressure on educational systems and organisations to develop competencies earlier in the educational lifecycle, referred to as knowledge frontloading, as illustrated in *Figure 1 b)*. In addition, accelerating technological change reinforces the importance of structured academia-industry cooperation to align educational content with industrial needs [14], [2]. Together, these trends underscore the necessity of integrated and systematic approaches to workforce development.

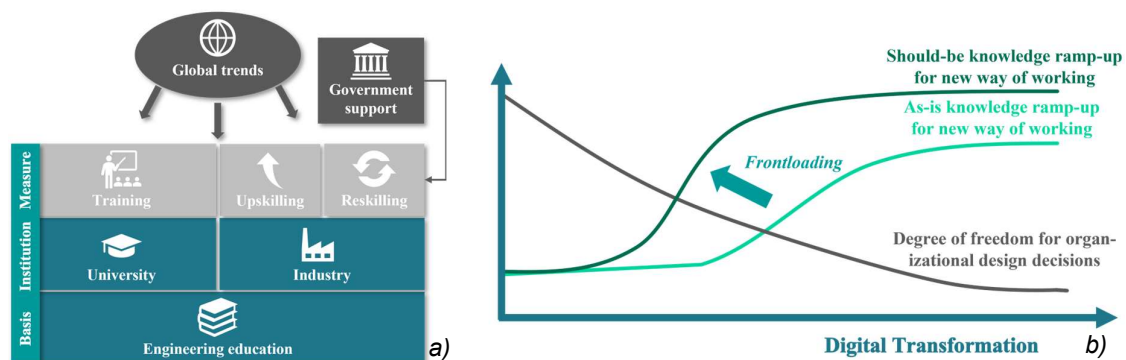


Figure 1. a) Impact of global trends on education pathways and b) Knowledge frontloading
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2.2 Future-oriented engineering competencies

The trends described in *Section 2.1* broaden the required engineering competence profile. Recent studies on engineering skills emphasise systems thinking, AI and digital fluency, complexity handling, flexibility, adaptability, lifelong learning, teamwork and leadership, and diversity awareness [15], [3].

At its core, this profile combines technical-methodological competencies that enable engineers to manage complex systems with collaborative competencies for working in heterogeneous teams. SE, *Model-Based Systems Engineering* (MBSE), and *Product Lifecycle Management* (PLM) support this integration by enabling abstraction, cross-disciplinary coordination, and lifecycle coherence. Within such approaches, AI competencies and digital fluency are central to automated and data-driven processes. Additionally, diversity-aware competencies strengthen innovation and resilience in heterogeneous teams. Across competence dimensions, lifelong learning is a major pillar of future-oriented engineers.

3 DIDACTIC REQUIREMENTS FOR MICRO-LEVEL EDUCATIONAL DESIGN

The future-oriented engineering competencies identified in *Section 2* expose a growing mismatch between traditional educational structures and emerging workforce demands. While engineering practice increasingly requires systems thinking, teamwork, and adaptability, many educational formats remain shaped by static curricula and disciplinary silos. This limits flexibility, scalability, and the ability to address heterogeneous learner groups across career stages. Workforce-oriented engineering education must therefore move beyond isolated courses or rigid degree programs. To achieve this, labour market demands must be translated into actionable educational design requirements. These requirements should support continuous competence development, accommodate diverse prior knowledge among both students and industry professionals, and provide realistic, system-oriented learning environments. Within this context, five core *didactic requirements* (DR) are derived and summarised in *Table 1*. They form the basis for the educational design introduced in *Section 4*.

Table 1. Didactic requirements for workforce-oriented engineering education

DR1	Modularity: Educational formats must be modular to enable flexible learning paths and targeted competence development for diverse learner groups.
DR2	Scalability and transferability: Didactic concepts must be scalable beyond individual courses and transferable across institutional and organisational contexts, supported by structured academia-industry transfer interfaces for broader workforce impact.
DR3	Practice orientation: Learning environments must reflect real-world complexity and lifecycle considerations, enabling the application of methods and tools in realistic engineering contexts.
DR4	Collaborative learning: Educational design must foster interdisciplinary collaboration, teamwork, and diversity-aware interaction within heterogeneous learning groups.
DR5	Support for lifelong learning: Educational formats must enable continuous upskilling and reskilling beyond formal degree programs through flexible and adaptable learning structures.

4 MICRO-LEVEL EDUCATIONAL DESIGN AND TRANSFER

To operationalise *DR1-DR5* from *Section 3*, this section translates the workforce-oriented requirements into architectural, didactic, and organisational elements. Located at *Graz University of Technology* (TU Graz), the *Digital Lifecycle Lab* (DLL) serves as a reference implementation for a concrete educational design, referred to as a micro-level educational design. While prior work introduced its technical-didactic setup in detail [6], the following sections summarise its structure, practical use, and observed outcomes as the basis for examining its scalability beyond a single institutional setting.

4.1 Concept of the Digital Lifecycle Lab

The DLL is realised as a hybrid digital-physical learning environment developed through collaboration between TU Graz, *Antemia GmbH*, and *Siemens Digital Industries Software*. As illustrated in *Figure 2 a)*, it provides an end-to-end engineering environment in which learners explore complete system lifecycles through SE, MBSE, and PLM-based data integration. In practice, learners work on connected engineering models and artifacts such as requirements, system models, simulations, and test results, which are connected through a PLM backbone and managed across role-specific workspaces. By embedding lifecycle-spanning system creation within real-world complexity, the DLL directly addresses *DR3* while fostering systems and lifecycle thinking, AI competencies, and digital fluency.

The DLL primarily serves learners across different career stages, while educators, DLL coordinators, and industry partners act as facilitators who develop and maintain the environment and infrastructure. Bachelor students are addressed mainly through introductory modules, Master students through project-based system development courses, PhD students through research-oriented method development, and industry professionals through upskilling and reskilling formats such as workshops, micro credentials,

and online training. These flexible learning paths operationalise *DR1* and *DR5* by enabling competence development across career stages. A central element is the DLL knowledge transfer triad, depicted in *Figure 2 b)*, which integrates university education, scientific work and solutions, and industry workshops into a continuous exchange between education, research, and application. This structure establishes the basis for scalability and transferability in line with *DR2*.

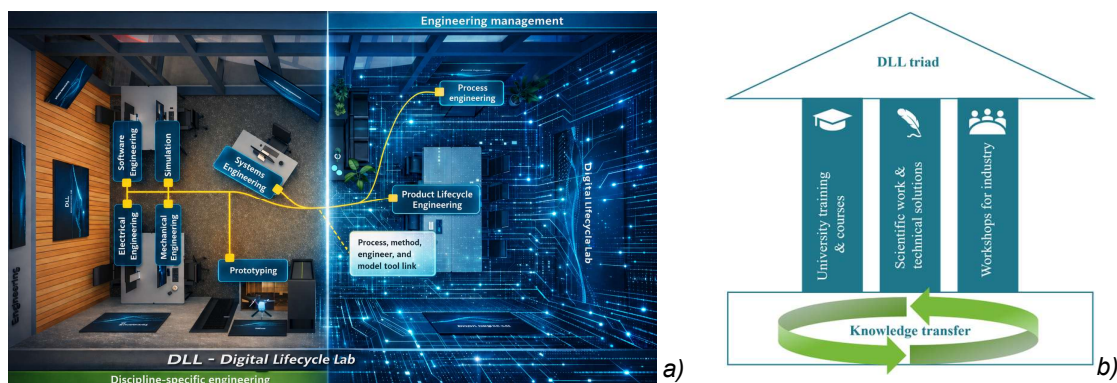


Figure 2. a) Overview of the DLL © Antemia GmbH [adapted from an original illustration with AI assistance] and b) DLL triad transfer model

4.2 Didactic design principles of the Digital Lifecycle Lab

The educational design of the DLL builds on learning-by-doing and project-based learning in hybrid formats for diverse learner profiles. Interdisciplinary project settings address realistic system challenges and operationalise *DR4* through structured collaboration and diversity-aware interaction. To ensure reproducibility and scalability, the DLL prioritises team roles, flexible learning paths, and engineering methodologies over specific software tools. Derived from *DR2* and *DR4*, these principles support transferability across institutional contexts while keeping systems thinking and lifecycle-oriented methods at the core. The DLL knowledge transfer triad reinforces feedback between education, research, and industrial application.

To illustrate these principles, the master-level *Project of Mechatronic Systems* (PMS) course serves as a blueprint, in which groups of 5-10 students physically and digitally develop a mechatronic system over one semester with an effort of 150 hours per student, as discussed in [6]. The course applies role-based collaboration, formalised MBSE, and documented system architectures as reusable artifacts. In initial implementations, SE-related activities accounted for approximately 25-30% of total project effort, as captured in detailed time and task recording. In subsequent PMS courses, reuse of formalised models and artifacts reduced overall effort by up to 15%, indicating the transferability of the model-based methodology. However, these figures are reported as limited pilot observations rather than statistically generalisable results from systematic learner evaluation. Beyond measurable efficiency gains, the availability of reference models improved system understanding, traceability awareness, and interdisciplinary coordination, as reflected in learner and instructor feedback.

4.3 Organisational embedding and academia-industry transfer interfaces

For the DLL to function as a scalable template, it is embedded in academia-industry transfer interfaces connecting academic education with industrial competence development, as required by *DR2*. These structures extend micro-level educational design beyond isolated learning environments and enable diffusion toward broader workforce contexts.

Within industrial organisations, exemplified by Siemens' *Science, Academics & Transfer* unit, boundary-spanning teams – meaning teams connected across different organisational units, disciplines, and institutions – operate at universities, where embedded PhD candidates and researchers act as translators between education, research, and application. These teams support universities and industrial partners in adapting the DLL concept to new institutional settings by aligning educational objectives, technical constraints, and workforce needs while preserving its didactic and methodological principles. In practice, they moderate alignment between academic instructors and industry representatives by translating industry needs into academic learning objectives while feeding innovative impulses back

into industrial practice. Industry partners provide relevant use cases, while academic instructors remain responsible for curricular coherence and assessment.

The DLL also serves as an industrial validation environment in which new engineering approaches and emerging technologies are tested early under realistic conditions before broader application. In parallel, industrial credential ecosystems, such as micro credentials, underline the need to align academic training with industrial upskilling and reskilling. Together, these structures enable the replication and scaling of micro-level educational designs and support their translation into macro-level workforce development.

5 FROM MICRO-LEVEL EDUCATION TO MACRO-LEVEL IMPACT

Building on the didactic design principles, organisational embedding, and transfer mechanisms described in *Section 4*, the DLL shows how concrete learning environments can contribute to broader workforce development goals at the macro-level. Rather than relying on isolated learning interventions, the DLL operationalises workforce-oriented engineering education through modular and adaptable formats that support continuous competence development across learner profiles and career stages. Through its integration into academia-industry transfer interfaces, the DLL functions as a transferable model for workforce development by providing adaptable design principles rather than a fixed technical setup to be replicated one-to-one. As a result, individual learning environments can contribute to broader objectives such as skill-gap reduction, workforce resilience, and lifelong learning in response to accelerating technological and demographic change.

The scalability of such educational concepts depends less on individual learning formats than on enabling framework conditions. Replication of the DLL concept requires qualified personnel, digital infrastructure, faculty training, sustained institutional commitment, long-term financing models, and locally adaptable core elements such as role-based workspaces, lifecycle integration, and academia-industry alignment. Its distinct value lies in integrating project-based SE education with PLM-based lifecycle continuity, reusable engineering artifacts, role-based collaboration, and moderated academia-industry transfer. Potential barriers to adaptation include high setup and maintenance effort, institutional resistance to curriculum change, and the risk that software tool complexity may overshadow didactic objectives. Sustainable financing models that combine academic funding, industrial co-investment, and public support are therefore essential to ensure continuity beyond project-based initiatives. Targeted governmental programs and policy frameworks can further amplify impact by incentivising structured academia-industry collaboration and long-term investment in workforce-oriented educational infrastructures. Central to this scaling process are strategically designed collaborations, in which boundary-spanning teams and intermediary roles, as outlined in *Section 4.3*, coordinate stakeholders, align educational objectives with workforce needs, and adapt the DLL concept to diverse institutional and regional contexts.

By linking project-based SE education, PLM-supported lifecycle continuity, reusable engineering artifacts, role-based collaboration, and moderated academia-industry transfer, the DLL's distinct role lies in demonstrating how engineering education can move beyond isolated interventions toward scalable and sustainable workforce development.

6 CONCLUSION AND OUTLOOK

This paper addresses the growing need for systematic workforce-oriented engineering education in response to accelerating technological change, increasing system complexity, and shifting labour market conditions. Building on prior work presented at *E&PDE 2024* and *2025*, it advances the discussion from isolated educational environments toward a structured linkage between micro-level educational design and macro-level workforce development. The contribution lies in the conceptual and methodological grounding of workforce-oriented engineering education. By deriving requirements from global workforce trends and future-oriented competency demands and operationalising them through the DLL, the paper demonstrates how educational design can be aligned with long-term workforce objectives. Additionally, diversity and inclusion are treated as functional design principles, supporting innovation and resilience in heterogeneous engineering contexts.

Through its organisational embedding and academia-industry transfer interfaces, the DLL illustrates how micro-level educational designs can be transferred beyond isolated institutional settings. At the same time, the approach is subject to limitations related to resource requirements, organisational complexity, faculty training, institutional resistance, and the risk that software tools may overshadow

didactic objectives. This underlines the importance of sustained institutional commitment, industrial co-investment, and supportive governmental frameworks.

Future work should focus on systematic learner evaluation and long-term impact assessment, including perceived learning value, learning effectiveness, competence development over time, and organisational workforce outcomes, building on the initial observations reported in *Section 4.2*. Further research on transferability and policy-driven support mechanisms will be essential to strengthen scalability. In this context, the DLL provides a promising foundation for continued experimentation and collaboration toward resilient and future-ready engineering workforce development.

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INTEGRATING POSTGRADUATE, UNDERGRADUATE, AND K-12 DESIGN LEARNING THROUGH INTERNATIONAL VIRTUAL MOBILITY

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ABSTRACT

This paper presents preliminary results from a project to create and implement an International Virtual Mobility Centre for Design Education across three educational levels: postgraduate, undergraduate, and basic education. The initiative seeks to promote a transcultural approach to Design learning, focusing on training high-level researchers and consultants (postgraduate), professionals for the job market (undergraduate), and fostering Design literacy in elementary and secondary education. The project builds on two previous international collaboration experiences developed in undergraduate Design courses and teacher education programmes. The undergraduate initiative focused on developing competencies for teamwork in geographically distributed contexts and for understanding the impact of culture and context on Design. The postgraduate initiative aimed to prepare educators for teaching Art and Design in primary and secondary schools. The main goal is to establish a framework for international virtual mobility in Design education that connects the three levels of instruction. This involves developing a pedagogical model adaptable to different stages of learning and promoting sustained international collaboration, which represents the first concrete contribution of this project. Expected outcomes include: (a) continuously and systematically offering courses that support international virtual mobility at each educational level; (b) offering courses that integrate at least two levels of education; (c) establishing foundations for expanding participation to other Design-related programmes and institutions; and (d) developing and testing Design-based teaching and learning frameworks and methodologies. Ultimately, the project aims to foster innovation in Design education through international collaboration and the integration of multiple learning levels within a shared pedagogical structure.

Keywords: Design education, international virtual mobility, collaborative learning

1 INTRODUCTION

This project addresses the following research question: **How can Design education be integrated across different levels through collaborative activities in an international context?** The overall objective is to establish an international virtual mobility hub for Design education at postgraduate, undergraduate, and K-12 levels, fostering integration across these levels. The specific objectives are: (a) to develop a pedagogical framework for virtual mobility across different levels of Design education; (b) to develop a web platform for virtual mobility by integrating free digital information and communication technologies (DICTs); and (c) to evaluate the framework and platform through courses in basic education, undergraduate, and postgraduate programmes.

The project is based on same-level and cross-level course interactions in an international setting. Expected outcomes include: (a) the continuous and systematic offering of courses enabling international virtual mobility at each educational level; (b) the continuous and systematic offering of courses integrating at least two educational levels; (c) the establishment of conditions for the future inclusion of additional Design-related undergraduate and postgraduate programmes and institutions; and (d) the development and testing of Design-based teaching and learning frameworks and methods. Figure 1 illustrates both interaction models: solid lines represent same-level interactions, while dashed lines indicate cross-level interactions.

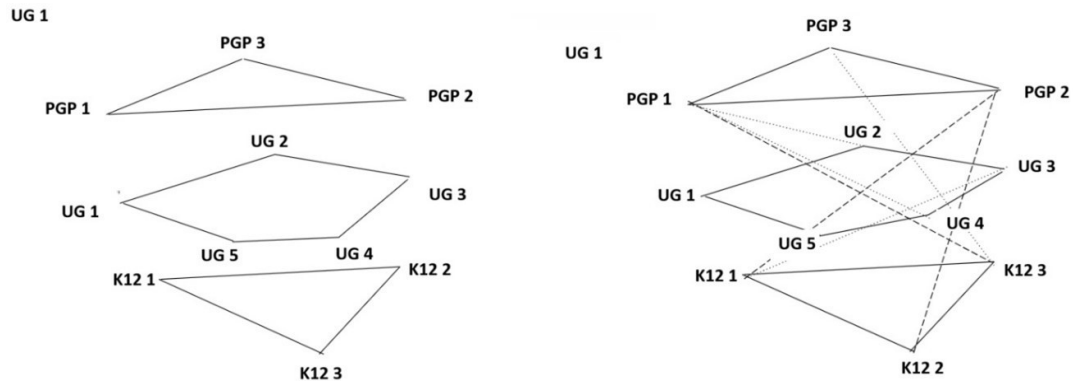


Figure 1. Interaction model for same-level and cross-level courses, including graduate programmes (PGP), undergraduate programmes (UP), and K-12 education (K12)

The project's originality and relevance lie in its collaborative, virtual, and international approach to Design education across three educational levels, integrating both perspectives on the nature of the Design process: designerly ways of knowing and design thinking. Postgraduate education will address both perspectives due to its interdisciplinary character; undergraduate education will emphasise designerly ways of knowing; and K–12 education will adopt design thinking, reflecting its general education focus. This initiative will be operationalised through the International Virtual Mobility Centre for Design Education, which will involve researchers from universities in Europe, North America, and South America, and schools from the same countries.

2 STATE OF ART AND RESEARCH CONTEXT

2.1 Internationalisation and Virtual Academic Mobility

In recent years, initiatives, programmes, and projects promoting education have increasingly emphasised student retention, qualification, recognition, support, and academic expansion. This trend presupposes scientific, technological, and academic cooperation across horizontal, vertical, bilateral, and multilateral levels [3], shaping internationalisation policies and practices in higher education, including design-related fields such as Design Education.

Global interconnectedness has intensified, particularly through physical international academic mobility, which grew from approximately 2.1 million students in 2000 to 6.9 million in 2022 [1], consolidating mobility as a central pillar of internationalisation [4]. In parallel, new forms of interaction have expanded, accelerating the adoption of digitally mediated learning strategies on a global scale. Virtual academic internationalisation increasingly relies on collaborative learning methodologies that develop digital, linguistic, and intercultural competencies to support joint projects and multi-institutional learning initiatives in transnational contexts. This is especially relevant for Design Education, as it enables collaborative experiences in globally distributed, inter-, multi-, and transdisciplinary networks, fostering knowledge creation, skills development, and the ability to address complex contemporary challenges.

2.2 International Collaborative Learning and Design Education

The internationalisation process involves international institutional partnerships and projects implemented through at-home actions (within the institutional context), curriculum adaptation, virtual mobility and exchange, and collaborative teaching projects with international partners in globally connected learning environments [5]. Collaborative Online International Learning (COIL) has been highlighted in literature as a key methodology for virtual internationalisation in higher education. Pedagogically, COIL structures collaborative experiences through synchronous and asynchronous digital technologies, connecting geographically distant academic communities from diverse linguistic and cultural contexts. It promotes interaction and mobility by encouraging engagement with national and international sources in virtual learning environments, fostering the development of intercultural and global competencies through shared projects [5][6].

COIL aligns with the broader movement of internationalisation of the curriculum, understood as the intentional integration of international and intercultural dimensions into teaching, research, and outreach [2], with the potential to democratically expand institutional reach and support new knowledge-oriented learning pathways [5]. In Design, these challenges are framed as wicked problems, characterised by the absence of definitive or singular solutions [7][8]. Problem understanding and solution creation are inseparable and concurrent, as challenges are fully grasped through attempts at resolution, rendering design a continuous process of problem redefinition [7][8]. Addressing such challenges requires cognitive strategies centred on synthesis, modelling, and experimentation, aligning with designerly ways of knowing—a constructive knowledge culture grounded in conceiving, testing solutions, and making new things [9].

2.3 Articulation Across Educational Levels in Literature

Findings from a systematic literature review indicate that virtual mobility has been explored mainly in initial higher education, with limited presence in basic education and a scarcity of approaches that promote broader articulation across educational levels. There is a lack of models that coherently connect basic, undergraduate, and postgraduate education in international virtual mobility experiences. This gap demonstrates that virtual mobility in Design Education remains underexplored and highlights the need to develop new pedagogical artifacts capable of supporting collaborative, continuous, and integrated practices across educational levels. Such structures should address the pedagogical specificities of each level, as well as the institutional, curricular, and technological challenges involved, contributing to the consolidation of pedagogical models for international virtual mobility in Design Education.

2.4 Challenges and Pedagogical Needs

Virtual mobility is recognised as a key mechanism for internationalisation, strengthening international academic collaboration. The literature highlights benefits such as improved intercultural communication, competency development, cultural awareness, respect for diversity, and democratised access to internationalisation. However, significant challenges persist, including unstable internet connectivity, unequal technological infrastructure, language barriers, time zone differences, and the absence of institutional policies to ensure continuity. These constraints indicate that even well-structured initiatives face organisational, pedagogical, and technological limitations, underscoring the need for pedagogical artifacts that better organise and integrate virtual mobility experiences. Flexible and adaptable pedagogical frameworks are therefore identified as promising avenues for innovation in Design Education, supporting collaboration and articulation across educational levels in international contexts [19].

3 LEARNING FROM DESIGNERS

Before engaging international K–12 partners, a pilot experience was conducted with a local school to examine cross-level interaction without the influence of cultural differences. Prior COIL experiences at undergraduate and graduate levels informed the handling of cross-cultural issues in design learning. The study brought together undergraduate Visual Design students and high school students through a partnership with a nearby public school.

Students enrolled in the Design Methodology course were organised into four Design Studios (DS1–DS4), each defining its brand and design market focus. The project comprised eight meetings. In the first session, undergraduate students welcomed the high school students and presented their studios and areas of interest. In the following session, high school students presented everyday problems to be addressed through peer learning and co-design. Both groups exchanged ideas, after which the Design Studios selected a problem, and high school students chose the teams they wished to join. The problems addressed were as follows:

- Dopamine and social media - too much time on the phone
- Inequality and Prejudice
- Raising awareness of inequality

To work together, they used the Double Diamond process (Design Council, 2004) to go through the stages of: Discovering the problem to be solved, to understand the chosen problem (3rd Meeting); Defining the focus and framing to be given to the problem (4th Meeting); Developing possible solutions by prototyping models, testing and iterating to finally (5th, to 7th Meetings); and Delivering the best

possible solution within the deadline and with the available resources (8th Meeting). The results obtained are shown in Figure 2.



Figure 2. Proposed solutions

Throughout the process, data and information were collected using four tools: a questionnaire to create a student profile; a comprehension map to assess students' self-perception; a questionnaire to assess students' perceptions of their abilities; and a questionnaire to evaluate the project process. Additional information was collected from photographs, videos, and researcher notes (Figure 3).

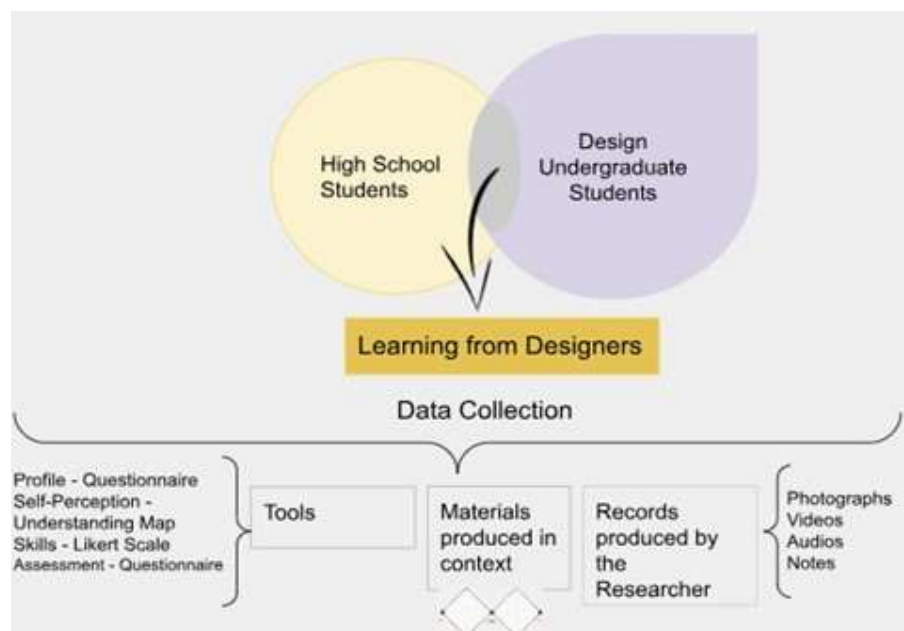


Figure 3. Synthesis

This experience suggests that undergraduate design students have the skills to support high school students to understand the design process through peer-learning projects. Literature emphasises that peer learning fosters social bonding, work organisation, appreciation of materials, and encourages questioning—reducing shyness and increasing confidence—as well as connection through identity, communication, and the valuing of shared experiences and knowledge [11].

Observations indicate that peer interactions between high school students and undergraduate design students of similar age facilitate concept understanding, as the use of shared language and terminology enhances comprehension. Peer groups with mixed ages promote experiential proximity, enabling a deeper understanding of learning challenges and strategies to overcome them for both groups. Structured peer interactions involving students from higher grades further reinforce learning by expanding knowledge through co-participation.

4 PEDAGOGICAL FRAMEWORKS

An adaptable pedagogical framework was proposed to enable replication in other contexts (Figure 4). The experience is structured into three stages: Pre-Project, Intermediate, and Finalisation. In the pre-Project stage, partnerships between the university and the school are established. At the university, the Project Methodology course prepares students to organise design studios, defining a brand and market niche to be presented during the initial meeting with high school students. At the school level, the focus is on fostering contextual exchange and learning among students, promoting a form of literacy that supports sustainable futures and change-oriented learning [12]. Students are encouraged to identify everyday problems to be collaboratively addressed with design students.

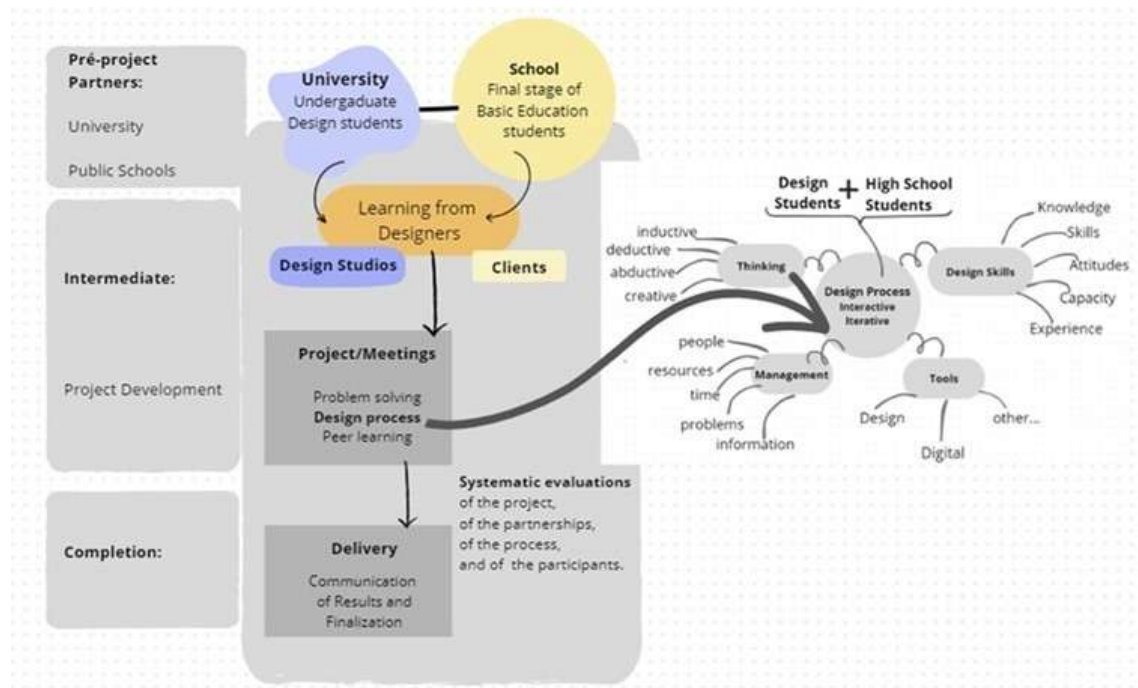


Figure 4. Pedagogical Framework

In the Intermediate stage, the focus is on defining the problems to be addressed by the Design Studios. High school students select the teams they wish to join through peer learning and collaborative participation, applying a design process that integrates multiple ways of thinking, design skills, tools, and project management practices.

In the Finalisation stage, outcomes are communicated, and the process is evaluated through team presentations, delivery of solutions within the course and at the school, and continuous assessment supported by project tools. This stage also includes the identification of necessary adjustments and, when feasible, the implementation of solutions, valuing the learning process and the resolution of everyday challenges through partnerships and available school and community resources.

5 CONCLUSIONS

As stated in the abstract, this paper presents preliminary results from a project aimed at creating and implementing an International Virtual Mobility Centre for Design Education across three educational levels: postgraduate, undergraduate, and basic education. The proposed pedagogical framework is intended to be one of the elements that will generate a more complex framework that will include the three levels of education and the interactions among them. Prior experiences in COIL involving undergraduate students and graduate students have been at the same level and have not generated some kind of framework that could formalise the process.

The prior experiences provided several insights and data about transcultural issues related to Design Education. Systematising data and developing new and more complex experiences will contribute to creating new Design-based teaching and learning frameworks and methodologies.

5.1 AI-assisted writing disclosure

ChatGPT (OpenAI) was used exclusively for language editing and improvement of textual clarity. The authors fully reviewed and validated the final content.

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CULTURAL AESTHETICS IN DESIGN LEARNING: BUILDING SPARSH, AN EMOTIONALLY DURABLE HYBRID GRINDER THROUGH NAVARASA AND EDD9

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ABSTRACT

This paper examines the journey of learning emotional design from an Indian aesthetics perspective. The research was initiated by the question of why most contemporary appliances seemed impersonal and easily replaceable, unlike traditional tools once cherished by families. This question led to research into whether emotion, memory, and culture could be designed into everyday products and what such an approach might signify for design education in India. The Navarasa framework, a classical Indian aesthetic theory of nine emotional states, was examined and integrated with Jonathan Chapman's Emotional Durability Design Nine (EDD9) framework in order to establish a hybrid approach. This integration resulted in CEEDD9 (Culturally Embedded Emotional Durability Design Nine), a pedagogical framework for emotionally durable design learning. Through this reflective, learning-by-doing process, emotional design was understood as not merely user satisfaction but as engagement with empathy, care, and context. Ethnographic fieldwork with 27 Indian households and emotional mapping workshops involving 150 products were carried out using Navarasa cards. These interactions highlighted that the emotional durability of products is rooted in rituals, sensory engagement, and personal narratives. Thematic analysis of the mapping activities identified five positive emotional states Shringara (love), Hasya (joy), Karuna (compassion), Adbhuta (wonder), and Shanta (peace) as the strongest contributors to product attachment within domestic life. This understanding manifested in Sparsh, an emotionally durable mixer grinder that drew inspiration from the old silbatta. Made of wood, stone, glass, and brass, it reintroduced slowness, tactility, and visual honesty back to cooking. The study positions sustainability as an outcome of emotional attachment rather than efficiency alone, demonstrating how culturally grounded frameworks can support emotionally and contextually sensitive design learning within engineering and product design education.

Keywords: Emotional durability, Navarasa, cultural frameworks, design education, product attachment, Indian aesthetics

1 INTRODUCTION

Engineering and product design education has increasingly realised that successful products are not only based on how well they perform technically, but also on what the emotional meaning of the product is for the user and the long-term relationship developed with the user. Products designed with both narrative and sensory value are likely to be retained, thus supporting sustainability through longer periods of use [1,2,4]. While emotional durability as a concept is recognised, it is not operationalised in the design learning process. Emotional design frameworks develop from Western sources and are based on the universality of emotional response [1,3], which may overlook culturally embedded systems from which emotional meaning is generated through everyday practices. In studio environments, students often prioritise functional and aesthetic characteristics over emotional intention during ideation. However, culturally embedded emotional frameworks are still absent from product design pedagogy [6,7]. As a result, students often lack structured methods for translating culturally situated emotional insights into actionable design decisions. This paper reflects on a master's thesis-based learning experience in which a Culturally Embedded Emotional Durability Framework, CEEDD9, a pedagogical framework operationalised through card-based emotional mapping and reflective evaluation, was developed by merging Emotional Durability Design Nine (EDD9) [2] and India's Navarasa aesthetic theory. EDD9 provided strategies for long-term attachment, while Navarasa contributed culturally

grounded emotional interpretation. A reflective practice perspective [5] is used to examine how the development of CEEDD9 informed the learning developed while designing Sparsh, a hybrid grinder designed to be emotionally durable, and to explore how CEEDD9 informed, challenged and limited student learning.

2 BACKGROUNDS: EMOTION, CULTURE AND DESIGN LEARNING

Research on emotional design has shown that interactions between users and products are influenced by more than functional capabilities; they include meanings associated with a product, memories made using it, and its relation to identity [3]. Norman discusses emotional engagement at visceral, behavioural, and reflective levels, while Chapman indicates that creating products with long-lasting emotion results in longer use and less frequent replacement or disposal [1]. The Emotional Durability Design Nine (EDD9) framework translates these theories into practical strategies for continued emotional engagement through narrative, materials, and supporting long-term relationships between products and users [2]. Although emotional durability has received increasing academic attention, operationalising it within design education remains challenging. Studio education relies on reflection-through-making, where learning occurs between actions performed and critique received [5]. Without structured scaffolding, emotional reasoning often remains implicit, and emotional interpretation is culturally located rather than universally understood [6]. As a result, students may struggle to translate emotional and cultural insights into consistent design decisions during studio-based learning. In Indian domestic settings, meaning is formed through use, sensory experience, and family memory. The Navarasa framework, derived from Bharata Muni's Nāṭyaśāstra and later expanded by Abhinavagupta to include the ninth rasa (peace), is a classical Indian aesthetic theory describing nine emotional states experienced through human interaction and expression. Traditionally applied in performance, literature, and visual arts, Navarasa provides a culturally grounded structure for interpreting emotional experience but has rarely been explored within product design pedagogy [8]. To address this pedagogical gap, CEEDD9 (Culturally Embedded Emotional Durability Design Nine) was developed as a pedagogical framework integrating the attachment-oriented strategies of EDD9 with the culturally grounded emotional interpretation provided by Navarasa. Operationalised through card-based emotional mapping and reflective evaluation, the framework was intended to support emotional decision-making within studio practice [7].

3 METHODOLOGIES: REFLECTIVE PRACTICE APPROACH

This study adopts a reflective practice methodology examining learning generated during a master's thesis [5]. This research presents a reflective case analysis focused on pedagogical learning rather than experimental validation.

3.1 Research approach

Using Schön's reflective practitioner model [5], iterative cycles of action and reflection informed design development and framework formation. CEEDD9 emerged iteratively through the synthesis of recurring emotional patterns identified during Navarasa mapping activities and the attachment-oriented strategies of EDD9, supporting clearer articulation of emotional concepts within design decisions.

3.2 Data sources and learning evidence

Data sources included exploratory surveys (50+ responses), Navarasa mapping exercises involving 30 participants who each evaluated five personally meaningful products, observational discussions across 27 households, iterative sketching and prototyping, faculty critiques, and reflective documentation.

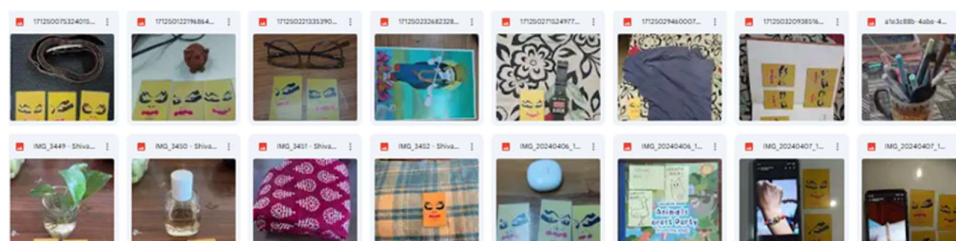


Figure 1. Selected examples from the Navarasa mapping activity, where participants associated emotionally meaningful household products with culturally grounded emotional categories during early framework development

3.3 Analytical process

Reflective thematic analysis was used to identify patterns across the Navarasa mapping activities, household discussions, reflective journals, and iterative design evaluations. Emotional associations repeatedly identified across participants and products were clustered according to Navarasa categories. Five positive emotional states Shringara (love), Hasya (joy), Karuna (compassion), Adbhuta (wonder), and Shanta (peace) emerged most consistently in relation to long-term product attachment and domestic rituals. These recurring emotional patterns informed the development of the CEEDD9 framework and later guided reflective evaluation during design iterations. Faculty reviews provided external indicators of learning progression, while the overall analysis sought an interpretive understanding of design development.

3.4 Ethical considerations and limitations

As a single-student study, findings are context-specific. CEEDD9 is presented as an exploratory pedagogical artefact requiring broader classroom testing.

4 CEEDD9 AS A LEARNING FRAMEWORK

4.1 From emotional theory to design learning

Early stages of the thesis revealed difficulty translating emotional intentions into consistent design decisions. Although EDD9 provides strategies for attachment [2], the application required interpretation, revealing the need for structured support. CEEDD9 was therefore developed not simply as a theoretical model, but as a pedagogical framework operationalised through emotional mapping cards, reflective evaluation, and culturally guided design reasoning.

4.2 Integrating EDD9 and Navarasa

EDD9 outlines strategies supporting emotional durability through narrative, identity, and material engagement [2]. Navarasa provides culturally grounded emotional categories, including Shringara (love), Hasya (joy), Karuna (compassion), Adbhuta (wonder), and Shanta (peace) [8].

Combining these systems allowed emotional durability strategies to be interpreted through culturally grounded categories. Navarasa functioned as an interpretive layer guiding emotional intent. The integration was developed to address a gap between abstract emotional intention and actionable design reasoning within studio practice. While EDD9 provided strategies for sustaining long-term product attachment through interaction, narrative, and material engagement, Navarasa contributed culturally situated emotional categories that enabled these strategies to be interpreted within Indian domestic contexts. The resulting framework allowed emotional intentions to be externalised, discussed, and evaluated more systematically during the design process.

Table 1. Example mapping between Navarasa and EDD9 strategies

Navarasa Emotion	EDD9 Strategy	Design Interpretation
Shringara (Love)	Attachment / Identity	Warm materials, tactile surfaces, intimate scale
Hasya (Joy)	Pleasure / Interaction	Playful engagement and intuitive controls
Karuna (Compassion)	Narrative	References to memory and shared practices
Adbhuta (Wonder)	Imagination	Visibility of process and experiential curiosity
Shanta (Peace)	Materiality / Sensory	Calm interaction, reduced noise, earthy palette

This mapping externalised emotional intentions by linking abstract emotional goals with tangible material, interactional, and experiential design decisions.

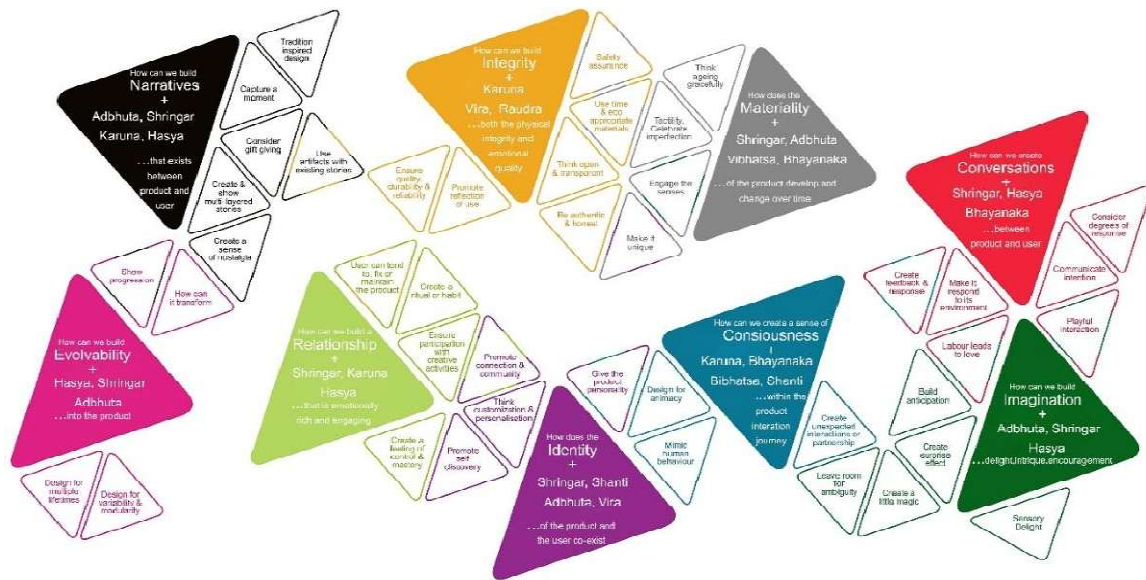


Figure 2. CEEDD9 framework integrating Navarasa emotional categories with EDD9 attachment strategies to support reflective and emotionally durable design learning

4.3 CEEDD9 as a cognitive scaffold

Rather than functioning as a rigid prescriptive method, CEEDD9 was utilised as a cognitive scaffold supporting reflective learning, emotional articulation, and iterative decision-making throughout the thesis process. The framework was designed using card-based emotional mapping to facilitate the evaluation of design iterations and decision-making through:

- **Clarification of intent:** Early design direction was informed by emotional goals.
- **Decision justification:** Choices of materials and interactions were made using emotional reasoning.
- **Reflective evaluation:** The emotional coherence of each design iteration was determined during critique sessions.

5 LEARNING THROUGH DESIGN: THE SPARSH CASE

5.1 Initial learning challenges

Emotional durability was the primary goal from the beginning, but user research and emotional insights did not always inform design decision-making. Early ideation relied heavily on personal intuition, and maintaining emotional intent during iterative development remained challenging.



Figure 3. Learning progression showing how CEEDD9 supported transition from intuitive design decisions to structured reflective reasoning during the thesis project

5.2 Learning transformation through CEEDD9

As a result of introducing the CEEDD9 framework, the design decision-making process transformed, connecting emotional intentions with identifiable criteria for purpose-based evaluation. This highlighted three significant changes in ways of learning about product development:

- Justifying material and form choices based on emotional intent; linking stone and wood to Shanta and Karuna reinforced the rationale for critique.
- The process of iteration began to focus more on tactility, sound, and the pace of interaction to redefine how we measure efficiency through experiential engagement [1].
- Collectively evaluating design elements based on emotional coherence encouraged systemic thinking versus feature-based design.

These changes demonstrate reflective learning through structured emotional mapping.

5.3 Faculty critique as educational feedback

Studio critiques provided a means of determining learning progression. Early critiques focused on alignment between research data and the design outcome, whereas later critiques focused on rationales related to design intent and experience. Faculty feedback indicated improved coherence between concept, materiality, and interaction. At the same time, tension between emotional storytelling and engineering feasibility became a significant learning outcome.

5.4 The artefact as learning outcome

The final product, Sparsh, serves as a reflective artefact that embodies the insights gained through this framework. It illustrates how emotional structure can shape studio-based product design learning.



Figure 4. The Sparsh hybrid grinder prototype developed through the CEEDD9 framework, reflecting culturally grounded emotional durability through materiality, tactility, and ritual-inspired interaction

6 REFLECTIVE ANALYSES OF LEARNING

6.1 Learning enhanced

Structured emotional reasoning.

The shift from relying solely on intuition to intentional reasoning through CEEDD9 allowed emotional intent to drive form, material, and interaction choices while providing clarity during critique.

Integration of cultural context into design thinking.

Cultural insights derived from Navarasa shifted from symbolic references to active drivers in the project designs. Empathy expanded beyond individual user experiences to become more culturally situated through Navarasa mapping.

Reflective learning through iteration.

Repeated use of the framework created opportunities for reflection-in-action [5], allowing assessment of emotional coherence during development rather than after completion, improving critical evaluation skills.

6.2 Learning challenged

Translating abstract emotions into tangible form.

The Navarasa framework offered structured emotional categories; translating these into project deliverables required experimentation and negotiation between ideas and physical limitations.

Balancing symbolism and usability.

Faculty critiques revealed tensions between emotional expression and physical practicality, indicating the need to negotiate symbolic intent with usability and manufacturability.

Maintaining analytical distance during reflective work.

In relation to the project and framework, the evolution of the framework facilitated the separation of reflection and justification through purposeful engagement between critique and documentation.

6.3 Learning limited

Single-designer application.

The framework was implemented and evaluated in a singular thesis project, limiting insight into how other learners might interpret it and indicating that broader classroom testing would be beneficial.

Dependence on facilitation and prior cultural familiarity.

Implementing Navarasa concepts required pedagogical guidance.

Scope constrained by academic timeframe.

Due to semester constraints, long-term validation was not possible, limiting findings to design reasoning rather than long-term outcomes.

6.4 Reflection as a learning outcome

Using CEEDD9 to mediate between conceptual knowledge and design action enabled reflective learning within studio practice.

7 IMPLICATIONS FOR ENGINEERING AND PRODUCT DESIGN EDUCATION

Reflections presented in this study offer implications for incorporating emotional durability and cultural frameworks into engineering design and product design education. While CEEDD9 was developed as part of an individual thesis, the learning outcomes show it has much broader pedagogical potential. Structured emotional frameworks can connect conceptual discussions of empathy with practical design decision-making. Furthermore, culturally responsive approaches to human-centred design education can use this framework to open the design process by employing a culturally situated emotional context instead of relying solely on global definitions of emotions. Finally, because of the structured mapping of emotions, the intent of design can be communicated more effectively during critique so that the discussion can focus more on articulated reasoning rather than subjective preferences.

In order to implement these materials, facilitated guidance is required, as culturally based frameworks rely on contextual understanding. Future research may explore the applications of these materials in classrooms with diverse learners and disciplines to determine the broader educational impact.

8 CONCLUSIONS

By combining the Emotional Durability Design Nine framework with the Navarasa emotional system, this study developed CEEDD9 as a learning scaffold supporting the transition from emotional concepts to design decisions. Culturally grounded emotional frameworks can support reflective design development by strengthening reasoning clarity, deepening engagement with cultural context, and maintaining emotional intent throughout the design process. The findings demonstrate how culturally grounded emotional frameworks can support emotionally durable and culturally sensitive design education.

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ENGINEERING INCLUSION THROUGH TACTILE INNOVATION: CO-DESIGNING ACCESSIBLE URBAN MODELS FOR DISABLED USERS IN LAMBETH

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ABSTRACT

Many citizens are marginalised from making decisions that affect their lives, including urban planning, with disabled users often excluded due to how spatial information is presented. For example, infrastructure decisions are often made without adequate consultation with disabled users, with a reliance on non-inclusive tools such as visual maps and plans. This project, delivered in partnership with MP Smarter Travel (MPST) and ASU-London, undertook this work to aid disabled citizens in engaging with urban planning in the London Borough of Lambeth. Working with an Accessibility Working Group (AWG), a diverse team of visually impaired, neurodivergent, and mobility-impaired residents, the project developed a system of interchangeable, tactile models that translate complex street and transport designs into accessible, tangible forms. Through an iterative co-design process, AWG members became collaborators and shaped refinements in texture, colour contrast, feasibility, and ergonomics, producing a robust “kit-like” co-design tool that enables users to physically build and critique real-world proposals. Using 3D printing, laser cutting, and embedded magnets, the models aimed to balance detail, portability, and durability for project consultation. Key outcomes include empowering disabled people to actively implement change, creating a reusable model adaptable to user intentions, and demonstrating co-creation as essential for inclusive understanding and evaluation of urban design.

Keywords: Co-design, visual disability, accessibility

1 INTRODUCTION

Urban planning processes have been developed to engage a range of stakeholders in upcoming projects. This includes changes to current infrastructure, such as modifications to road layouts, as well as larger new infrastructure developments [1]. Typically, ‘users’ have been a key stakeholder whose concerns and opinions on the changes have been influential in the urban planning process. However, disabled users have often been under-represented or excluded from engaging with this process [2].

This collaborative project helps to address the critical issue of disability discrimination in urban planning and development. The project collaborated with Lambeth Council, MP Smarter Travel (MPST) and an Accessibility Working Group (AWG). MPST works to promote active travel and community engagement in a range of councils. This project aimed to bring about significant changes across the borough to ensure that urban transport systems and infrastructure are inclusive and accessible to all, with a particular focus towards active travel. The AWG has, for the past 2 years, played a pivotal role in this endeavour, providing feedback on all aspects of accessibility throughout various site projects and policy meetings; however, co-design processes have, until recently in the AWG, been somewhat limited by the lack of accessible mapping tools. By working closely with the AWG, this project gained a deeper understanding of the challenges faced by disabled individuals and aimed to collaboratively design a tool to enable the co-design of urban infrastructure projects with the AWG.

This paper shows the progress made towards the co-design of a tool for advocating for accessible transport systems that cater to the needs of disabled citizens and the challenges still faced.

2 BACKGROUNDS

2.1 Co-design

The co-design process in this paper operates on two levels: first, AWG members were active co-designers in the development of the tool itself; second, the resulting tool (a reconfigurable, modular map) is designed to be used by those same communities to express and co-design how they want future infrastructure in Lambeth to look and function. This concept deviates from consultation design, in giving the users the ability to make design decisions rather than only giving feedback. This process offers benefits such as richer insights into user needs, deeper understanding of user knowledge and experience and earlier validation of designs [3]. In particular, co-design can be particularly beneficial when designing for users with disabilities, ensuring users' needs are incorporated into the design process.

Co-design aims to bring the voices of relevant stakeholders into the design process, and case studies across a range of sectors, from healthcare to urban infrastructure, have shown how to use co-design principles in the development of products [4]. Co-design has an ethos of empowerment for the stakeholders, using their lived experience to inform the design process. In theory, this process is well aligned for users who experience impairment; however, this can act as a barrier to involvement in the design process. Disabled users can often struggle to engage with traditional co-design tools that rely on discussions and or visual tools. Research has shown the creation of tactile tools, enabling users to overcome these limitations and create meaningful connections between users and designers [5]

2.2 Urban Planning Consultation

Urban planning within the UK follows a series of government and council documents to advise planners and developers on requirements. The Manual for Streets [6] is a UK government document with guidance for designing, constructing, and maintaining residential and lightly trafficked streets. This highlights key fundamentals, including that (i) roads are designed for motor vehicles to move from A to B and (ii) streets are designed for communities to thrive in. This was highlighted in the following extract: "Streets make up the greater part of the public realm. Better-designed streets, therefore, contribute significantly to the quality of the built environment and play a key role in the creation of sustainable, inclusive, mixed communities". There is particular emphasis on the point that "Inclusive design places people at the heart of the design process". This is further detailed in subsequent documents [8], outlining inclusive street design principles through the use of user hierarchy, placing pedestrians at the top priority in urban planning design. This ensures an inclusive environment that recognises the needs of all.

Research publications have extensively explored how disabled people interact with urban planning and travel. For example, the review of Park *et al.* [8] underscored the challenges faced by disabled individuals in navigating urban environments, including physical barriers and a lack of accessible infrastructure. Ulahannan *et al.* [9] highlighted the importance of inclusive design principles that prioritise the needs of disabled users, ensuring that urban spaces are accessible and user-friendly for everyone and that inclusive design principles are essential for creating environments that cater to the diverse needs of all individuals.

Despite the emphasis on inclusive design principles, many studies [10] reveal that disabled individuals frequently feel that they are not being heard and that they are isolated from decision-making and planning. This results in those users having to put up with inconsiderate design features when traversing the urban environment. This literature underscores the need for a more inclusive approach to urban planning that actively involves disabled individuals in the decision-making process.

3 INDUSTRY PROJECT AND AIMS

This project was undertaken as part of a final year individual project over a 6-month period. The industrial partner, MP Smarter Travel, is a transport consulting firm based in Southwark, London, and played a pivotal role in facilitating the project between the student and the AWG. The purpose of the AWG is to bring together members from various backgrounds, ranging from vision and mobility disabilities to members with neurological disabilities, to consult on and co-design urban redevelopment projects. The group has a particular focus on active travel, including walking, wheeling (such as wheelchairs and mobility scooters), cycling, and other forms of non-motorised transportation. Active travel has gained significant attention in recent years [6] and is promoted for its numerous benefits, including improved public health, reduced traffic congestion, and reduced environmental impact. Research highlights street layout being critical to the promotion of active travel [11].

AWG meetings are comprised of 9 members, with sessions ranging from 2 to 3 hours. Meetings may include in-person site visits to conduct walkthroughs or workshops discussing potential changes and covering policy-based issues and early project proposals. All meetings were used to allow AWG members to express their feelings about a project and enable changes to be discussed. A total of 6 meetings were attended for this project.

At the start of this project, the team at MP Smarter Travel relied on rudimentary card models, as shown in Figure 1, to show members of the AWG how the area changes were being proposed. In the field of spatial awareness and mapping, various tools have been developed to increase inclusivity, such as smartphone-based applications [12] and tangible maps that utilise tactile clues to facilitate comprehension, collaborative editing, and discussion [13]. This form of co-design is central to the AWG's ethos. It shifts the dynamic from council and stakeholders merely "informing" or "consulting" members toward a partnership, wherein AWG members wield greater agency. By actively shaping design decisions, they improve outcomes for both disabled and non-disabled users.

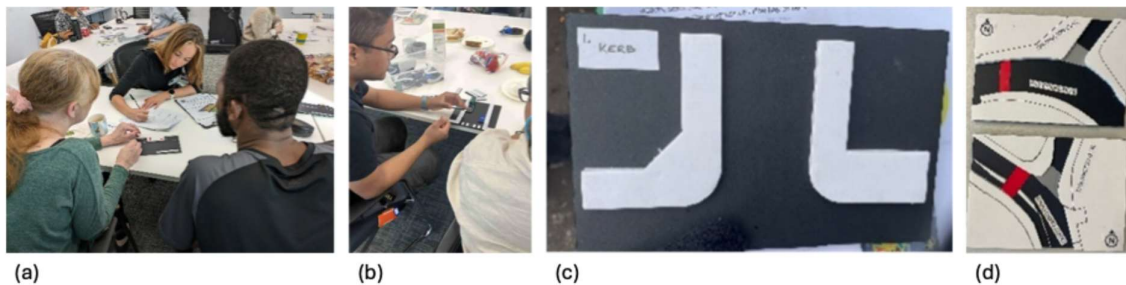


Figure 1. shows (a & b) the AWG meetings and different iterations of the initial cardboard prototype used at the start of the project. (c) example of kerb layout, (d) example of changes to road layouts

4 PROJECT METHODOLOGY

Before beginning the co-design process, the student spent the first two weeks attending meetings, building an understanding of the style of projects and the users of the AWG. The user interactions with the current solutions were observed with discussions around how members of the AWG worked and interacted with the information and area models being present. The following reflection was given: *"These first few weeks were insightful as they allowed me to build a good working relationship with member of the AWG, as I got to understand their background and what they would like to see in an urban redevelopment project"*. Following this, the co-design process with members of the AWG was started to improve the cardboard models. The prototype developed was a simple T-Junction as shown in Figure 2. The main purpose of this initial, lo-fi prototype was to understand how the AWG reacted to this new, more tactile model and to understand what they wanted from the models in the future. Feedback from members included: *"It feels like a T-Junction, and it is very easy to understand"*, and *"This texture feels more realistic compared to the previous models and feels more like a pavement."*

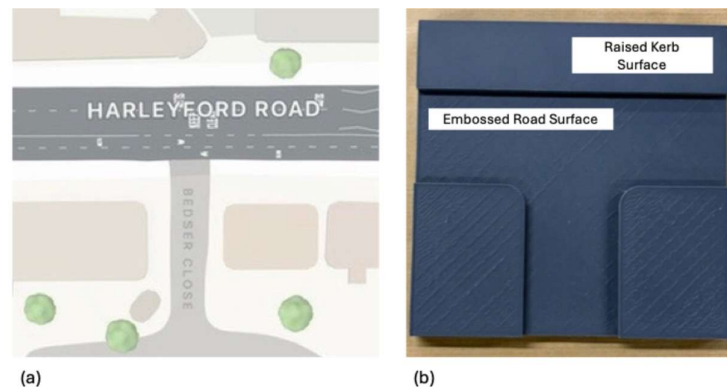


Figure 2. (a) Road layout of T-Junction via map, (b) the initial prototype of a T-Junction

Following this, subsequent sessions of the AWG were used to further co-design a solution. Members identified using different textures, colours and markings to identify different features such as roads, pavements and crossings. Figure 3 shows the next version of the prototype, incorporating this into the model. A more complex road layout was used, with the Oval site being selected. This aided the design process as members had already been familiar with the site due to previous site visits.

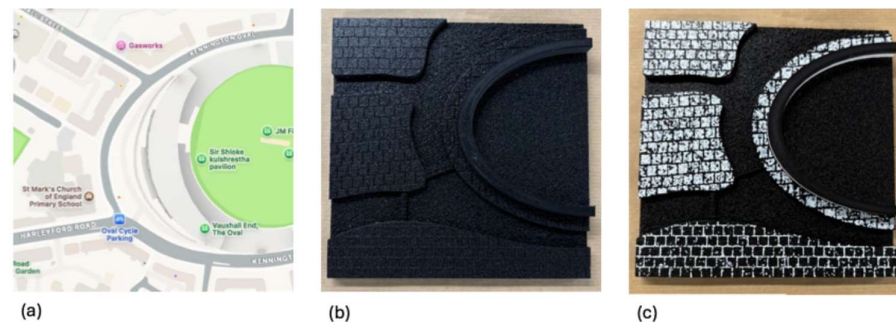


Figure 3. shows (a) a Maps screenshot of Oval London, (b) the first prototype including textures and (c) the second iteration based on AWG member feedback

Following the production of these prototypes, further discussions with members were conducted, feedback of which included: “Liked the different textures”, and “They were different, and they were more realistic in regard to the texture.”

This feedback proved that the process of co-designed development was heading in the correct direction. Once the positive feedback was collected, the AWG gave working feedback on where the model could be improved. The main consensus, particularly from the visually impaired users, was “More colour contrast and should include visual clues for roads like yellow lines and zebra crossings”. The visually impaired users found it easier to discern spatial information from models when the colour contrast was significant, such as black/white; therefore, moving forward, the models had a significant colour contrast. The improved Kennington Oval section can be seen in Figure 3 (c). Following this feedback, the next step was turning the model from a “one-off” static model to a more texture-refined and interchangeable model. This facilitates further dialogue and co-design with the members of the AWG.

4.1 Model Refinement

Discussions with AWG members allowed the designers to model a range of different surface textures to represent a range of urban landscapes such as concrete, asphalt and man-hole covers. A range of depths of textures was presented, with feedback from the group agreeing on the use of a 2 mm raised texture.

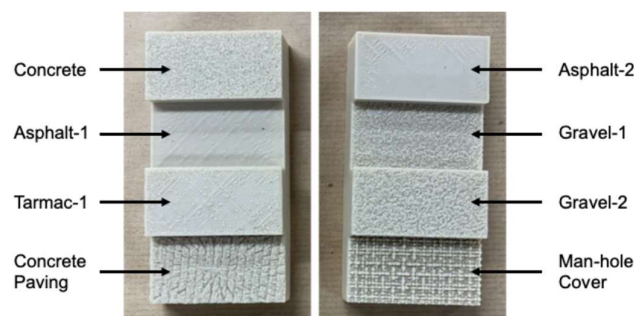


Figure 4. Example 3D printed textures of common urban landscape surfaces

The next phase of the project was making the models interchangeable to help facilitate co-design and a two-way collaborative process. A demonstration prototype model showcased how an interchangeable model using magnetic pieces could be used to replicate real-world sites. This was presented to AWG members and the staff of MPST. Both groups approved of this interchangeable model method, with the staff saying, “It resembles Lego” and that it would be great going forward to have a reusable and interchangeable “kit-like” model. This corresponds with the ‘Lego serious play’ movement, which was a useful inspiration for the kit [14].

Ultimately, the project culminated in the development of two sizes of the final prototype, featuring pieces of pavement, crossings, parking bays and other urban features. Figure 5 shows an example of the movable objects and possible scenarios. The baseplates came in two sizes; the smaller size was sized to the original card models used in the meetings for similarity, whilst the larger baseplate is sized to an A4 piece of paper, meaning that more detail could be included for larger layouts.

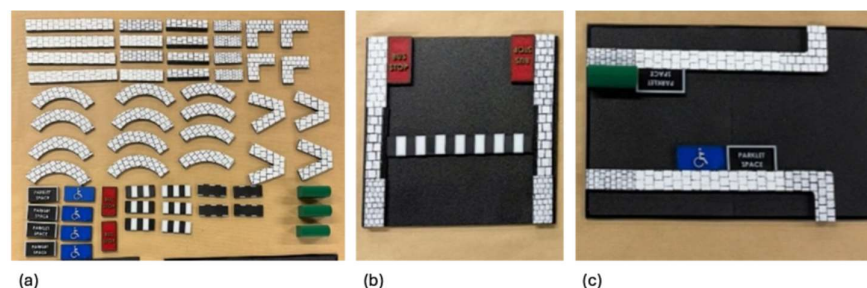


Figure 5. The final prototype with (a) showing a range of individual magnetic pieces, (b) showing a zebra crossing with bus stops, and (c) showing a road with parking

The final prototype proved successful with the AWG and MPST. The AWG liked the ability to move pieces around and could easily recognise different features such as junctions and crossings. Some members of the AWG said that “*Something like a Key*” would help recognise certain pieces which should be implemented in future development of this project.

The impact of this project has been substantial. The 3D tactile models provided the AWG with a more accessible and understandable way to engage with urban planning and road design. The iterative co-design process ensured that the models were tailored to the needs of the users, resulting in a tool that is both practical and user centred. This project has not only improved the AWG's ability to provide essential feedback but also has given MPST a reusable and interchangeable tool that can be used to discuss complex and in-depth projects in the future.

5 RESULTS AND REFLECTION

The project achieved significant progress in making urban planning and development a more inclusive process. The members of the AWG at the beginning of this project were passive listeners to the various projects and redevelopments that were presented to them. The prototype tool turned the members of the AWG into active designers and developers, enabling them to fully understand projects and enact their design changes. As an additional positive, the MPST staff had a tool that they could repeatedly use for various sites due to the projects continually changing to different sites across the borough.

The main limitation of the design is the lack of exposure to a range of scenarios, which would have given further feedback on the prototype. This would enable further co-design and co-creation with the AWG group to ensure the balance between customisability and accuracy could be improved.

5.1 Student Reflection

As a student, this was the first time I faced real-world clients in a design context. I learned the importance of building a good working relationship with co-designers, understanding their needs and viewpoints, to create an impactful design. An example of this was experienced when one member of the AWG refused to engage in the co-design processes, with their opinions set in stone from the start of the session. The members' central argument was that existing infrastructure (pavements and roads) was already broken and should be repaired before any new projects were funded. This created a repetitive loop in discussions and significant disruption within the session. To engage this member, a change of approach was needed, moving from a passive observation to an active, fact-based mediation. In this session, delicate communication was needed both from the design team and MPST with this member to ensure they did not feel opinions were not being forced upon them. An intervention method I used during this was to use facts and statistics rather than emotive language to engage the member.

This project allowed me to theory of co-design and turn passive listeners into active contributors in practice with the AWG. The diversity within the AWG required me to develop my own style in interacting and co-designing with the AWG. Examples of this include building personal relationships with the members and adapting the session and content to best engage members in the process.

The project provided valuable insight into real-world stakeholders; in particular, it taught me the complexities of managing a range of stakeholder opinions and requirements. This causes significant resistance in the design processes, something which is rarely experienced during academic projects. I learned that a successful project requires work, empathy and negotiation with resistant stakeholders to co-design relevant and meaningful designs. The impact of this project is significant as the AWG has a prototype that can be easily used and adapted to suit various site locations and scenarios.

6 CONCLUSIONS

This project represents a significant step forward in supporting visually impaired and other disabled members of the AWG. The 3D printed, tactile models have proven to be an invaluable resource, facilitating better comprehension and interaction with urban planning elements. However, it is important to recognise that this project is only the beginning. It serves as the foundation for enabling people with disabilities to make more impactful changes in their environment. Ensuring that their voices are integrated into the decision-making process is essential for creating inclusive and equitable urban spaces. Furthermore, this project has the potential to serve as an example for other UK boroughs. By adopting tactile maps that are co-designed, other boroughs across the country can create meaningful changes in urban environments that are inclusive and accessible to all.

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DESIGNING COLLABORATION, NOT ONLY PROJECTS. EMBEDDING PROJECT MANAGEMENT TO FOSTER COLLABORATIVE TEAMWORK IN PROJECT-BASED LEARNING

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ABSTRACT

Collaboration and project-based learning are central to design and engineering education, yet their integration often lacks systematic pedagogical support and explicit instructional design. This paper investigates how instructional innovation can strengthen the integration of collaboration and project management within a multidisciplinary and international PBL course. It presents the iterative development of a teamwork-focused module in a Design & Engineering master's programme at Politecnico di Milano, initially introduced to foster collaborative competences and later expanded to incorporate project management practices. Over six years and three research-through-instructional-design (RTID) cycles, structured tools, peer review formats, visual frameworks, and a digital platform were implemented to make team processes visible, coordinated, and reflective. The study draws on qualitative analysis of voluntary student feedback (n=18 in the final cycle), focusing on self-reported learning and course appreciation. Findings show that collaboration and project management are mutually reinforcing students framed teamwork as a professional responsibility while developing organisational and relational competences. Those reporting gains in planning and workflow organisation also valued collaboration most strongly. The iterative cycles enabled consolidation of effective practices while sustaining ongoing refinement. The findings highlight the importance of systematic teaching staff self-assessment in fostering inclusive, adaptable, and relationally grounded PBL environments.

Keywords: Collaborative learning, project-based learning, teamwork, project management

1 INTRODUCTION

Collaborative learning is widely employed in design and engineering pedagogy, especially in project-based learning (PBL) courses [1]. The learning experience in PBL becomes particularly rich when collaborative learning in culturally plural classes is also integrated: students learn to draw on diverse expertise and viewpoints to tackle complex projects, thereby exercising their social competencies. Despite the centrality of collaboration in PBL education, instructional design and coaching methodologies to foster collaborative competences remain largely unexplored and have only recently been addressed [1, 2]. Building on the mutual influence of collaboration and project management (PM) identified in the literature, this paper addresses the following research question: *How can instructional design innovation support the integration of PM and collaboration within complex, multidisciplinary PBL courses?* The research presents an assessment of students' self-reported perceptions of learning in a PBL course, in which collaboration and PM have been robustly incorporated into a six-year process.

2 THEORETICAL BACKGROUNDS

2.1 Mutual relationship between collaboration and PM

Research shows that project success becomes more likely as intra-team collaboration improves. Collaboration functions as a critical human success factor, shaping both project outcomes and team morale. It supports the integration of diverse knowledge, fosters innovation, and connects interpersonal satisfaction with tangible performance indicators such as schedule compliance. Empirical evidence indicates that collaboration—remarkably when grounded in trust—is a strong predictor of overall project success [3]. Conversely, project management provides structures and tools that enable sustained collaboration. PBL can provide coordination mechanisms (e.g., task allocation and milestone tracking),

while contemporary PM applications support task organisation, timelines, and communication [4]. Project management roles further ensure alignment and accountability through tools such as work breakdown structures and communication plans. This reveals a dialectic relationship: collaboration fuels project performance, while project management provides the framework that enables it.

2.2 Framing research-through-instructional-design (RTID)

We frame research-through-instructional-design (RTID) as an approach that examines learning—and learning about instruction—within a constructivist paradigm, where learners actively construct knowledge through experience and interaction, and their experiences in turn inform instructors’ understanding of instructional design [5]. Within this paradigm, instructional designers and educators no longer treat instructional design as a linear planning activity; instead, they enact it as an iterative process that continuously moves between reflection and action in complex learning environments [6]. Because contextual and social factors strongly shape teaching, educators increasingly rely on action research approaches that integrate inquiry with practice and support the continuous improvement of learning settings [7]. Among the possible relationships between research and instructional change, RTID can be framed as instructional research *as* improvement [6]. Educators’ professional actions themselves generate knowledge, but if they lack explicit self-reflective methods, many teaching experiments remain tacit and difficult to consolidate as research. RTID addresses this gap by treating instructional modifications as situated research opportunities. When educators document how they iteratively reconfigure interconnected components of teaching practice—such as activities, assessment, grouping, and curriculum resources [8]. Through documented RTID, instructional researchers can transform local experimentation into cumulative knowledge about learning ecosystems.

3 METHODS: A SIX-YEAR RETROSPECTIVE ON THREE CYCLES OF RTID

The research is framed as a retrospective of three RTID cycles across six editions of a PBL course, with results focused on the final cycle. The course, Final Project Work (FPW), is a mandatory design studio in the Design & Engineering master’s programme at Politecnico di Milano, with 50–60 students annually, coming from different world-regions, different background disciplines (i.e., industrial design, engineering) and professional experiences. The teaching staff includes 5–6 lecturers from diverse backgrounds (e.g., product design, mechanical and materials engineering), each leading a module, and a teaching assistant. The first and second authors served as lecturer and teaching assistant, respectively.

Table 1. Previous publications associated with the three RTID cycles

Cycle	Associated publication			
	Title	Authors	Year	Venue
First Cycle	Never Take Teamwork for Granted! A Tutorship Experience on Soft-Skills	Mattioli F. & Ferraris S. D.	2021	E&PDE Conference
	Learning and Teaching Global Cooperation Skills in Culturally Plural Design. Collaborative Learning Practices and Experiences in Plural Classes	Mattioli F.	2022	Doctoral Thesis
Second Cycle	Peers as Experts to Cooperate with: a Case Study of Teaching Activities to Switch from Inter-Group Competition to Collaboration in a Design Studio	Mattioli F., Figoli F.A. & Wilhelm G.	2023	E&PDE Conference
Third Cycle	Seeing the Process: Empowering Students in Design and Engineering through Visual Frameworks	Labarta Labrador M., Mattioli F. & Ferraris S.D.	2025	E&PDE Conference
	Prototyping collaboration: managing collaborative projects in design education	Labarta Labrador M. & Mattioli F.	2025	Section of the book <i>Prototyping and Experiential Knowledge</i>

The six years of RTID are summarised by highlighting the key instructional design elements of each cycle. Insights were gathered after each edition via voluntary, non-anonymised surveys completed after the final marks, in which students reflected on what they learned, what they liked most and least, and any suggestions for improvement. De-anonymisation seeks to ensure that students’ feedback remains assertive and meaningful. The survey included a notice informing of its voluntary nature and the potential use of anonymised data for academic publication. Around 15-20 students (about 20-30% of the class) answered each year. A voluntary participatory design session with students followed the questionnaire. Here, teaching staff guided students in addressing questionnaire-identified issues and formulating instructional design solutions, some of which were implemented. Involving students as

research participants turns RTID into a co-design methodology in which meaningful educational changes can emerge bottom-up rather than top-down, as in many instructional settings. Sharing decision-making can enhance students' self-agency and aims to achieve more targeted benefits. Although yearly adjustments drew on prior insights, reporting is organised in two-year cycles, reflecting the introduction of major design changes. Table 1 lists publications documenting these intermediate steps.

The results of the survey were analysed qualitatively, following a thematic coding methodology. The coding process helped find patterns in answers to questions "What I learned" and "What I liked." Frequent answers were clustered in macro-topics to find tensions and correlations between what students perceived they had learned and what they valued.

3.1 First cycle (Intra-team Collaboration): academic years 2020-2021 and 2021-2022

In response to the lack of explicit support for student teamwork, the first RTID cycle implemented the "Teamwork Module" as a mandatory, evaluated component of the FPW. Initially, students—especially those with prior PBL experience—underestimated the module, but structured activities such as team agreements and reviews highlighted that teamwork is a professional competence requiring active management. Mandatory integration proved more effective than optional seminars in this grade-oriented context. The cycle also investigated global cooperation skills—specifically the ability to express views, build consensus, and defuse conflicts—, showing that a teaching staff expert can act as a bridge between students and instructors, providing crucial feedback on transferable competences.

3.2 Second cycle (Inter-team Collaboration): academic years 2022-2023 and 2023-2024

The first cycle demonstrated that, beyond intra-team collaboration, a highly competitive culture characterised the context where FPW was situated (i.e., class, curricula, school level). Such competition, especially emerging at the inter-team level, was hindering the effectiveness of collaborative competence development. Thus, the iteration focused on the poor class-level collaborative climate by designing instruction to enhance the relevance of peer support and knowledge sharing across teams. Findings showed that introducing the "large design studio" metaphor and shared technical research tasks significantly mitigated competition. Activities such as simultaneous multi-team reviews and shared digital boards for peer reviews during milestone presentations (e.g., Padlet) fostered a culture of help and collaboration at the class level, alleviating the pressure and stress on intra-team dynamics. Data confirmed that students perceived this as a unique advantage compared to other team-based courses.

3.3 Third cycle (Project Management): academic years 2024-2025 and 2025-2026

Given persistent negative feedback on overall course organisation, particularly in coordinating design, technical, material, and manufacturing modules, the teaching staff undertook systematic self-assessment and optimisation. The Teamwork Module was restructured and renamed the Project Management Module, integrating a Notion-based platform to unify communication and make collaborative processes tangible. Students recognised project management tools as essential for navigating complexity and making trackable design decisions. The FPW process was visually presented using a Gantt-style chart, which proved too rigid, leading to a revised visualisation reflecting divergent-convergent phases. Finally, a randomised team assignment system replaced self-selection, incorporated student preferences, and prevented previous exclusionary dynamics. These changes were informed by results collected after the first year of the two-year cycle. The next sections present the results of the latest assessment of the course's last edition (i.e., fall semester, AY 2025-2026) through qualitative coding of responses to the open questionnaire (n=18; 35% of students). The analysis is here limited to self-reported learning (i.e., what I learned) and the appreciation of the course experience (i.e., what I liked) because these two allowed building an interpretation around learning related to collaboration and PM, as well as the elements of course design that were appreciated and connected with these learning outcomes.

4 RESULTS

4.1 What I liked: Appreciation of the course experience

The findings show that measures introduced across the three RTID cycles have consolidated, become established, or gained renewed recognition among successive cohorts. Some practices persisted positively for six years, others remained valued after four, and recent interventions show early signs of sustained impact beyond their initial two-year testing phase.

Consolidated teaching staff support. One of the most meaningful actions taken at the very beginning of the RTID pathway was assigning a member of the teaching staff to support and mentor students as they navigated the complexity of teamwork (Fig. 1). This innovative effort has since become a vital component of the course. Nearly one-third of the respondents (n=5) clearly recognised and valued “the level of interest and care” the teaching staff invested in organising the course. One student reflected that the teaching staff’s primary priority genuinely seemed to be helping students succeed while fostering a safe space for “open and honest discussion”. Also, supporting teams based on their individual needs and struggles through one-to-one, on-demand reviews proved highly valued and helpful. Overall, a collaborative student–teacher relationship took shape and consolidated over time.



Figure 1. Codes clustered under “Consolidated Teaching Staff Support”

Established collaborative and teamwork practices. Some students (n=7) reported experiencing a more collaborative and open dynamic among peers than in previous courses (Fig. 2). Multi-team reviews and peer review sessions (n=2 respondents) emerged as particularly effective practices for fostering class-level collaboration. Students described them as reducing performance pressure while creating space for team-to-team dialogue. The new randomised team-formation format was overall well received (n=4). One student shared that they were actually “very happy with the random teams”. This increased teams’ cultural plurality and pushed students beyond their comfort zones, encouraging self-awareness. As one noted, “I got proof that general communication (mine first) needs urgent improvement”.



Figure 2. Codes clustered under “Establishment of Collaborative & Teamwork Practices”

Enhanced course structure and organisation. The effort to make project and course phases explicit, structured, and cohesive was noted (Fig. 3). One student wrote, “what I liked most was the organisation of the design phases and the time allocated to each”. Students appreciated that the thematic modules were interrelated and highlighted the course’s pacing, with one noting, “it was great to see a course that actually values our free time and holidays, allowing us to balance the workload effectively”. Clear milestones and deadlines supported self-management and reduced stress, while enabling students to “thoroughly explore every aspect of the project”.



Figure 3. Codes clustered under “Enhanced Course Structure & Organisation”

4.2 What I learned: Self-reported learning

The perceived learning outcomes clustered around three areas (Fig. 4): Design Process Understanding (n=13), Project Management and Organisation (n=10), and Teamwork and Interpersonal Skills (n=10).

Design process understanding. Students described how they began to see the Design and Engineering (D&E) project as a whole rather than as a sequence of disconnected phases. They recognised the complexity of the process and reframed iteration as a necessary act of refinement rather than repetition. Several highlighted learning how to craft a counter-brief, a moment that marked a shift from executing

tasks to questioning and reframing them. Others stressed the importance of contextual research and of grounding design decisions in a clear understanding of product meaning.

Project management and organisation. Respondents emphasised learning to define roles more clearly and allocate tasks more deliberately, which led to more structured workflow planning. They did not describe project management tools as mere technical additions. Instead, they linked them to a growing sense of responsibility and foresight. Managing time under pressure, balancing uneven workloads, and organising milestones pushed them to shift from reactive coordination to intentional planning. One student described this shift as a move toward a more mature way of structuring complex projects.

Teamwork and interpersonal skills. Students generally reported gaining experience in intra-team and class-level collaboration, practising compromise, and regulating emotions. Peer review moments and collaboration beyond personal comfort zones challenged established habits and required active negotiation, which proved essential in fostering a sense of self-efficacy in “handling teamwork more civilly and professionally”. Students described learning to listen—particularly in giving and receiving constructive criticism within the team—to tolerate ambiguity, manage tension, and self-assessment.

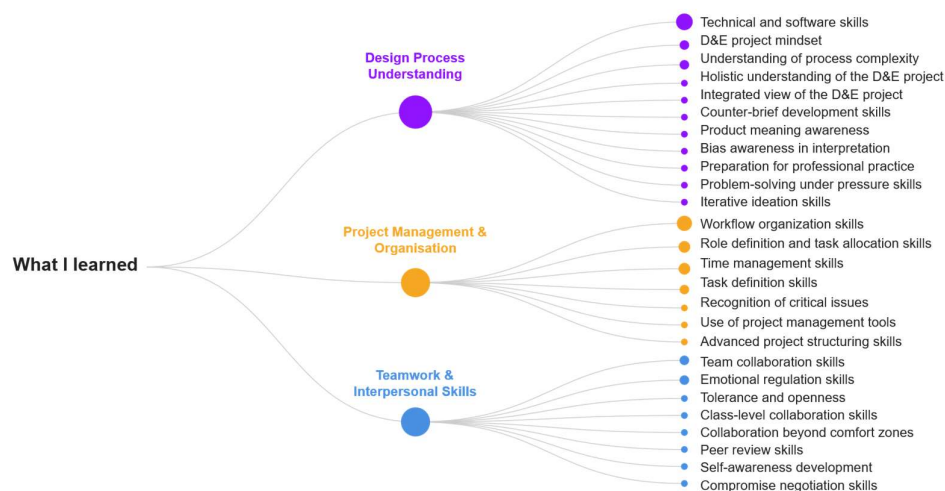


Figure 4. Code clusters related to the students' self-reported learning areas

5 SO-WHAT: ANSWERING THE RESEARCH QUESTION

The following analysis is based on the patterns visualised in Fig.5, which map the intersections between students' reported learning and their appreciation of course elements.

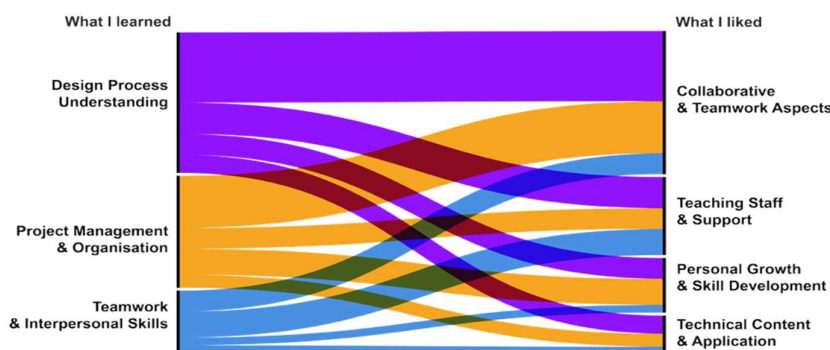


Figure 5. Intersection of learning and appreciation clusters; link thickness represents the number of respondents mentioning both in their responses

Hard learning, soft appreciation. “Hard” domains dominate students' descriptions of learning, while “soft” domains emerge in what they valued most. Students report process literacy, role definition, and workflow planning as outcomes, yet emphasise collaboration, dialogue, and teamwork. This crossing suggests complementarity: technical and organisational learning unfolds within relational conditions, with those gaining project management skills also valuing collaboration, moving between domains.

Collaboration as the central dimension. “Collaboration and Teamwork Aspects” is the most appreciated dimension of the course. Many students who reported gains in “Design Process Understanding and Project Management” identified collaboration as one of the course's strongest values. The same respondents often appear in both clusters. Students who strengthened their understanding of process and organisation also saw the importance of collaboration in shaping that growth.

The collaboration and project management synergy. The data show a mutual relationship between project management and collaboration, supporting theoretical claims that they reinforce each other. While project management emerged mainly as a learning domain, collaboration was the most appreciated aspect. Students who gained skills in planning, role definition, and workflow organisation also valued collaboration highly, suggesting that structured project management clarifies responsibilities and communication, while collaboration gives these tools meaning in everyday team interactions. The findings point to a reciprocal link: organisational clarity supports collaboration, and collaboration, in turn, strengthens organisational learning within the project-based environment.

Teaching staff as a driver of relational learning. Another meaningful intersection concerns “Teaching Staff Support”. Students who valued mentoring, structured feedback, and facilitated dialogue often reported growth in teamwork and interpersonal skills. The teaching staff's approach shaped how teams negotiated roles, managed tension, and practised peer review. Appreciation for support aligns with reported development in relational competence.

CONCLUSION AND FUTURE WORK

This study reinforces the idea that collaboration is not merely a complementary element but an intrinsic component of both project management implementation and learning in PBL environments. The research empirically supports the view that structured project management practices and collaborative dynamics are mutually reinforcing, especially in culturally plural contexts: clear roles, milestones, and workflow planning provide the conditions for effective teamwork, while active collaboration gives project management its practical and relational significance. The iterative approach adopted over six years demonstrates the value of consolidating established practices and enhancing them, ensuring that successful interventions become embedded while remaining open to refinement and adaptation. A limitation is survey responses: participants who choose to answer the questionnaire may differ from the broader student population. Finally, the results underscore the importance of teaching staff engaging in systematic self-assessment: their reflective practices not only guide instructional improvements but also shape students' relational learning, reinforcing collaboration as a central outcome of PBL.

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IMPLEMENTING CONTRACT GRADING IN A PRODUCT DESIGN COURSE TO PROMOTE ITERATION AND LEARNING THROUGH BUILDING

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ABSTRACT

We offer here a rationale for using contract grading in combination with design sprints in an upper-level undergraduate product design project course. Alternatives to grading, in particular contract grading and specification grading, have been gaining popularity in project-based courses across engineering disciplines. While students are highly motivated by grades, the fear of getting a poor grade can make students reluctant to experiment with unfamiliar design methods, and they often then resist building mock-ups early or often enough since they don't yet know the "right" answer. To address these challenges, we have introduced: (1) contract grading based on completing a checklist of design activities to shift the focus from performance outcomes to process engagement and iterative learning, and (2) structured design sprints to require the creation of mock-ups at each stage. We find that combining the two promotes both flexibility and rigor: we communicate that trust in the design process will yield results, but we insist that the steps in the process be followed and documented. We detail the structure of this integrated approach, share insights from its evolution over multiple course offerings, and reflect on its impact on student behaviour, learning outcomes, and project quality.

Keywords: Design, contract grading, alternative grading, design sprints

1 CONTRACT GRADING AND DESIGN SPRINTS IN DESIGN EDUCATION

Contract grading is based on a mutual acceptance by students and instructors of clearly stated expectations for how completion of assignments will translate into grades for those assignments [1]. It can be traced back to the 1960's and 70's and has been applied to all grade levels and many subjects [2]. It is similar to other grading strategies that focus on mastery, such as specifications grading [3]. However, the elements of negotiation and agreement remain distinguishing characteristics. Quintana and Quintana report the application of specifications grading to an engineering design course during COVID [4], and their description of renegotiations of the grading criteria resemble contract grading. Marti notes that while contract grading is underrepresented in the engineering education literature compared to communication, it "is especially applicable in process-oriented courses" [5]. Design sprints, on the other hand, are widely applied in industry and frequently used in design education; Thomas and Strickfaden offer a distinctive example from industrial design, which is less common in the literature than computer science, and assert that sprints promote better collaboration and toleration of ambiguity while helping students overcome design fixation [6]. While both contract grading and design sprints are widely used, we are not yet aware of examples in the literature of a purposeful combination of the two. However, such a combination reveals how the two practices reinforce each other.

2 COURSE CONTEXT

Interdisciplinary Product Design Projects is a two-quarter sequence for undergraduate juniors and seniors enrolled in any degree program on campus. Students work in teams of 3-5, each on a different open-ended physical product design project for an external client. It is co-taught by one instructor with expertise in product design and one with expertise in communication. Learning objectives focus on applying user-centred design principles and methods to real-world problems through research, prototyping, evaluation, project management, teamwork, and professional communication.

Although there is a pre-requisite of an introductory design class, the students enter the course with a wide range of experience in design. Some may have completed only 1-2 design-related classes while

others may have taken several, plus participated in extracurriculars that embrace design methods. As the class focuses on applying design methods over teaching them, this mix of experience creates challenges in getting students to engage in prototyping and other design activities early and frequently enough. Faculty regularly discuss how students seem to resist building physical mock-ups of ideas until they have “figured them out,” rather than using prototyping to do that. Similarly, students seem to resist using design methods they have not experienced before. Both relate to fear of doing something “wrong.” We identified a need to improve engagement with the design process and make it easier for students at all levels of design experience to participate without fear of a low grade on something new to them. We explored variations on contract grading, implemented one with checklists, observed student performance, and evolved the checklists into design sprints. Sprints, with their connections to digital product development and start-up culture, feel more energetic than checklists. This approach has led to more prototyping iterations and design activities completed by teams, reflecting increased engagement.

3 INTEGRATED APPROACHES: CONTRACT GRADING + DESIGN SPRINTS

We combined two approaches: (1) contract grading based on completing a checklist of design activities to shift the focus from performance outcomes to process engagement and iterative learning, and (2) structured design sprints that require the creation of mock-ups at each stage. This combination promotes both flexibility and rigor: we communicate that trust in the design process will yield results, but we insist that the steps in the process be followed and documented.

In the first quarter, 90% of the student’s grade is the contract grade for the design sprints and 10% is for individual contribution. This changes in the second quarter to 50% for design sprints, 40% for final deliverables, and 10% for individual contribution. This shift increases accountability for the quality of final deliverables: a written report (15%), presentation (10%), and the final design and prototype (15%). In both quarters, individual contribution is based on attending and participating in class plus a small number of individual assignments. Students complete peer evaluations twice each quarter that are seen only by the faculty. These help identify issues requiring intervention, especially team work-sharing. If there are significant gaps in contribution to sprint activities, team members may receive different grades. Each quarter has four sprints of 2-3 weeks each, depending on holidays and deliverables. This length allows teams to make meaningful progress while also accounting for scheduling challenges. Teams use an online whiteboard called Miro [7] where the sprints are laid out. Each sprint has a set of deliverables for things any team at this stage should complete, such as mock-ups, journey map, specifications chart, etc. There are also design activities aligned by sprint, but these are more flexible. Teams can move activities between sprints with faculty approval. For example, a team that can’t get to a client site for observations in sprint 1 will move that to sprint 2. In exchange, they would move a sprint 2 activity into sprint 1, such as additional research or meeting a subject matter expert. Checklists for Sprint 1 are shown in Figure 1.

Deliverables	Link Google docs / Miro frames	Faculty comments
Exploratory mockup , a physical model that demonstrates the project challenge		
Journey map reflecting the existing experience that you are addressing		
Team dynamics update		
Plan for next sprint - update Gantt chart & to-dos		
Activity Checklist	Link Google docs / Miro frames	Faculty comments
Draft client interview guide , get faculty feedback, and revise		
Conduct client interview , post summary, get faculty feedback, and revise		
Capture needs on Miro (desirability, viability, feasibility)		
Draft user observation guide , get faculty feedback, and revise		
Create a research plan and document findings		

Figure 1. Sprint 1 checklist

The second quarter is more flexible. There are still deliverables for each sprint, but instead of pre-assigning design activities, there is a reference list to select from and distribute across the sprints according to project needs. The reference checklist is shown in Figure 2.

Testing, Analysis, Feedback - Checklist
Get feedback from your client on mockups and prototypes - Draft interview/feedback guide, get feedback from faculty, and revise - Document results, get feedback from faculty, and revise
Get feedback from two experts on at least two different rounds of mockups and prototypes (outside of design review) - Draft interview/feedback guide, get feedback from faculty, and revise - Document results, get feedback from faculty, and revise
Perform at least FOUR (4) DIFFERENT types of analysis or testing, documenting the approach and the findings (one of these must relate to your DfX topic) - Statistical analysis - Design of experiments (DOE) - Engineering analysis – forces, heat transfer, fluid dynamics, etc. (using hand calculations, finite element analysis, MATLAB) - Manufacturing analysis – tolerance analysis, assembly time analysis, cost analysis, etc. - Physical testing – bending tests, drop tests, crush tests, etc. - User feedback and testing - Materials analysis - Life cycle analysis, carbon footprint calculations

Figure 2. Reference checklist for second quarter (sprints 5-8)

Teams add links to their work in progress and faculty review the work and provide feedback, adding notes to the “Faculty comments” field. Sample comments are shown in Figure 3.

Deliverables	Link Google docs / Miro frames	Faculty comments
2-4 feasibility mockups, partial mockups that show how parts of the design will work	Link omitted	Done!
Updated specs chart	Link omitted	See comments in Google doc
Initial FMEA	Link omitted	Okay for Sprint 5 It will need to be revised and included in your design review brief. Do this early to get feedback from faculty!
Client update email (show draft to faculty first)	Met client in-person	Done!
Team dynamics	Link omitted	Done!

Figure 3. Sample feedback comments on sprint progress

While the emphasis for grading is done/not done, work must be completed to a “reasonable level,” good enough to advance the project. Faculty provide feedback and students make revisions, often including a second iteration. Faculty base the degree of feedback and revision on experience working with teams at this level and factoring in student’s past courses and areas of study. This approach allows faculty to focus on giving feedback and coaching rather than trying to assign numerical values to things that can be difficult to measure. The sprint grade is an A if the team completes all deliverables and activities, and if not, the grade is lowered by three percentage points for each item not completed. Teams can continue to respond to faculty feedback after a sprint is done and their grades will be revised.

4 DISCUSSIONS: IMPACT ON STUDENT BEHAVIOUR

The desired changes to student behaviour include building earlier and more often, engaging in more design methods, sharing work across the team, and making steady progress. We have seen improvements in each, though there are still challenges. We evaluated the mock-ups and design activities of seven teams from two course sections prior to adding contract grading plus design sprints, and seven teams from the two most recent course iterations. There are typically 3-4 teams per section. We excluded the years when COVID-19 impacted the approach for the course.

4.1 Build earlier and more often

Students build more mock-ups with a sprint structure compared to using a course management system (CMS) to assign them. The CMS requires a specific due date for an assignment, but teams may build at different dates due to project variations. Sprints address this by creating a window for completing mock-ups while still providing a deadline. Mock-ups are required in each of the first four sprints and teams share their mock-ups in a class activity. Seeing what other teams create often raises the bar for the next iteration. Tables 1 and 2 show the number of mock-ups made in the first eight weeks (or sprints 1-3), representing the part of the design process with rapid iteration of early concepts. This information is shown graphically in Figure 4. The average number of mock-ups increased from 6.4 to 10.3 per team.

Table 1. Number of mock-ups in the first eight weeks **without** sprints + contract grading

AY 2018-19				AY 2019-20		
Team A	Team B	Team C	Team D	Team E	Team F	Team G
7	7	7	10	6	4	4

Table 2. Number of mock-ups in eight weeks (sprints 1-3) **with** sprints + contract grading

AY 2024-25				AY 2025-26		
Team H	Team I	Team J	Team K	Team L	Team M	Team N
10	6	12	13	14	9	8

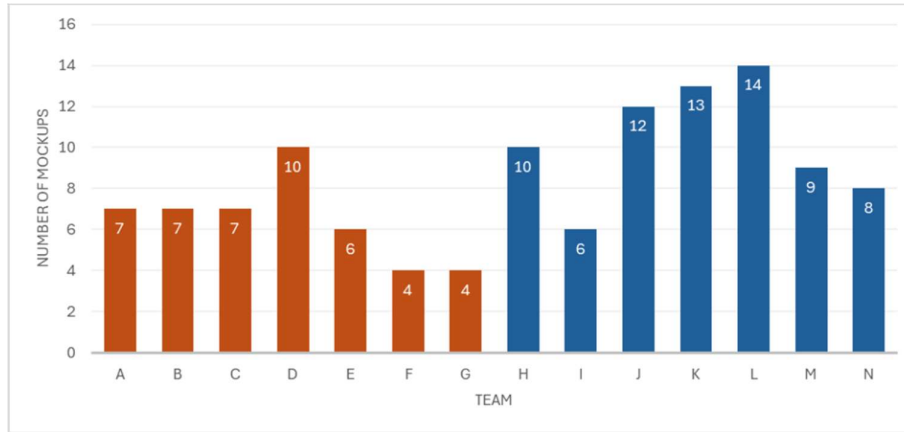


Figure 4. Teams A-F did not have the sprint + contract grading structure; Teams H-N did

Limitations & next steps: When teams build mock-ups as sprint deliverables, sometimes they do just that - build to meet requirements rather than build to learn. Instead of considering how to use a mock up to advance their learning, they just focus on making it. They will learn something with each build, but it would be more impactful if they identified key questions then built mock-ups to get answers. Going forward, we will frame deliverables within the bigger picture, asking students to identify what they need to learn and how they will use the mock-ups, to help them see mock-ups as more than a box to check.

4.2 Use more design methods

The sprint checklists, especially in the second quarter (sprints 5-8), have helped teams apply more design methods. Students entering this class tend to be familiar with the front-end of design, from need-finding through idea generation, as these topics are covered in the pre-requisite introductory design classes and again in design classes at the next level. However, due to time limits of a 10-week quarter, most non-capstone design classes don't cover the later stages of design in detail. In the past, this led to students struggling to identify and apply design methods beyond the initial concept stage. Now, the reference list for sprints 5-8 provides options and faculty help teams pick activities aligned with their project. Faculty also encourage students to consider design activities that they might want to show in a portfolio. Since design activities are not graded, students seem more willing to try new things. They get credit for doing what designers in industry do: identify what needs to be done, put in the effort, and make progress.

Tables 3 and 4 show types of design activities completed in the second quarter. The tables exclude secondary research, design reviews, and other activities required for all teams, such as conducting a Failure Modes and Effects Analysis; nor do they reflect how many of each activity was completed, focusing only on type. After introducing design sprints plus contract grading, the average number of activity types increased from 4.7 to 6.3 per team. In these tables, "functional testing" refers to evaluating performance characteristics specific to project goals, and "physical testing" refers to evaluating durability and robustness, such as drop, strength, and crush tests, corrosion testing, etc.

Table 3. Types of activities in the second 10 weeks **without** sprints + contract grading

AY 2018-19				AY 2019-20		
Team A	Team B	Team C	Team D	Team E	Team F	Team G
User feedback SME interviews Functional testing Simulations	User feedback SME interviews Functional testing Physical testing Force calculations	User feedback Stakeholder feedback SME interviews Functional testing Tolerance analysis	User feedback SME interviews Functional testing Physical testing System calculations Electrical analysis	User feedback SME interviews Functional testing Physical testing Materials analysis	User feedback SME interviews Functional testing Patent analysis	Stakeholder feedback SME interviews Functional testing Physical testing
4	5	5	6	5	4	4

Table 4. Types of activities in the second 10 weeks **with** sprints + contract grading

AY 2024-25				AY 2025-26		
Team H	Team I	Team J	Team K	Team L	Team M	Team N
User feedback SME interviews Functional testing Physical testing	User feedback SME feedback Functional testing Physical testing Thermal analysis Materials analysis Carbon footprint calculation	User feedback Stakeholder feedback SME interviews Functional testing Physical testing Force analysis Simulations	User feedback SME interviews Functional testing Physical testing Tolerance analysis Materials analysis Standards mapping	User feedback SME interviews Functional testing Physical testing Ergonomic analysis	User feedback SME interviews Functional testing Physical testing Precision analysis Force analysis Materials analysis	User feedback SME interviews Functional testing Physical testing Geometric evaluation
4	7	7	7	5	7	5

Limitations & next steps: Sometimes teams select activities without understanding what's entailed and faculty may assume they know more than they do or that they have read the course resources. For example, teams often select "Design of Experiments" thinking it is simply creating a test plan, not realising there is a specific method for identifying variables and for planning, controlling, and analysing results. Without this understanding, teams don't account for time needed to get support from faculty or other resources. Going forward, teams will need to identify not just which activities to put in each sprint but also list 3-4 subtasks per activity, to help teams identify support needed and plan more effectively.

4.3 Enable more equitable team participation

The sprint checklists clarify the types and number of design activities expected. This helps students who have less design experience understand what to do now and what comes next. It also shows many design activities that don't require engineering experience. In the past, students from outside of engineering have struggled to feel they were an equal member of the team due to a perception that design was an engineering-based discipline. Through the checklists, we can show the full breadth of activities, enabling students of different disciplines to identify activities related to their experience and skill sets.

Limitations & next steps: An ongoing challenge is determining if work is shared evenly. Teams are required to use a work-sharing tool, such as a RAM chart, but they don't always maintain it to reflect reality. They also complete reflections on team dynamics and progress and provide feedback on their peers to faculty. These tools help faculty to identify issues, but do not fully meet the need. Faculty rely heavily on student participation in meetings and discussions to assess individual learning. We will continue to revise team-based and individual peer feedback to improve insights.

4.4 Complete work steadily across each quarter

Combining sprints with contract grading helps to even progress across each quarter. In the past, due dates were assigned on the course management site. However, since each project is different, the details of the activity and target dates vary by team. Misalignment between the online system and a given team's

progress makes it difficult for teams to track their work, and they can easily fall behind. In contrast, sprints require a set of activities to be completed within a set timeframe but allow flexibility within that timeframe to align dates to project needs and student schedules. As mentioned earlier, teams can consult with faculty to move activities between sprints. Since teams can see all sprint requirements in one view on Miro, without having to navigate the course management site, they can better plan their work.

Contract grading reinforces adherence to the sprint structure, ensuring teams complete each sprint. As a result, we have generally seen teams doing more work earlier in the project. Some teams still struggle to manage their work and may try to complete all sprint activities just before a sprint deadline, but with four sprint deadlines pre quarter, even that is more distributed than in past iterations of the class.

Limitations & next steps: While grading each sprint encourages teams to take the checklists seriously, we also want to avoid demoralising them if early grades are low as they learn to collaborate. This led us to allow revisions beyond a sprint deadline. However, some teams still delay. In the past two offerings, we announced a final revision deadline part-way through the quarter. This helped, but there should be a clear policy at the start that preserves the importance of the initial deadline. We plan to try a decreasing ability to raise sprint grades. For example, a B could be raised only to an A- after the first deadline, and to a B+ after a later deadline. We have not yet determined the number or spacing of these deadlines.

5 CONCLUSIONS

Contract grading paired with design sprints has meaningfully impacted how students engage with design process in this course. With an emphasis on process over performance and a clear structure for advancing projects, students build earlier and more frequently, apply a wider range of design methods, and distribute the work more evenly across team and project, while faculty focus on coaching over grading. We identified important areas for continued improvement. Some students still treat the project as a series of assignments rather than working toward a goal, and they may commit to design activities without knowing what is involved. Also, while the sprint structure improves work distribution over time, ensuring equitable team participation remains a challenge. These issues are not new to design education, but the current approach gives clearer points of intervention and creates opportunities to adjust to project needs and student learning. Moving forward we plan to:

- Reframe sprint deliverables to more explicitly connect building to the bigger picture.
- Require teams to break complex activities into visible subtasks to clarify scope and distribute work.
- Create a tiered revision policy that preserves flexibility without diluting the initial deadline.

The intent is to further shift from “checking the box” to a more thoughtful and intentional design process. Combining contract grading with design sprints for project-based design courses is a promising approach to promote earlier and more frequent building, a broader use of design methods across disciplines, and steadier progress. It allows more flexibility than typical course management systems, helping faculty and students to adapt to different projects, student needs, and other, unexpected factors.

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FROM INDIVIDUAL TO INTERCONNECTED: AI-MEDIATED MICRO-STORIES AS A PEDAGOGICAL BRIDGE FOR RELATIONAL AND ETHICAL DESIGN LEARNING IN AUSTRALIA

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ABSTRACT

This paper outlines the development of an AI-assisted narrative framework using micro-stories, designed for the Australian design education context to support relational and ethical design learning. With increasing pressure to offer more courses in asynchronous modes to cater to self-paced learning, running a traditional studio, which is the backbone of reflective practice, is becoming challenging. We designed this study to utilise AI tools to integrate Indigenous-informed pedagogical principles into asynchronous learning environments as a means for relational and ethical design learning. Conversations and micro-stories, central to many Indigenous knowledge traditions, are often used as reflective and relational learning methods. We developed a narrative framework using micro-stories to humanise a technology-mediated design course, prompting students to use AI as a dialogic partner and to consider the ethical, social, and cultural dimensions of design while remaining aware of their own positionality.

The framework was developed under Senior Ngunnawal Elder oversight, with AI governance rules that explicitly prevent cultural simulation, fabrication, or the generation of restricted content. The paper reports the design and configuration of the framework, including boundary-preserving refusal and redirection patterns, and outlines a forthcoming comparative study between an AI-mediated and a non-AI narrative condition. At this stage, the contribution is conceptual and methodological: a governance-oriented approach to integrating Indigenous-informed relational principles into asynchronous studios while concentrating cultural oversight during design to reduce ongoing cultural load.

Keywords: Decolonisation, Indigenous pedagogy, AI-assisted storytelling, design education, asynchronous learning, relational design, micro-stories, dialogical conversation

1 INTRODUCTION

Many design programmes are moving to asynchronous and blended delivery. Most of those going online are still using old face-to-face teaching user-centred design (UCD) logic that frames design problems around individual users, discrete needs, and technical optimisation. At the same time, there is growing pressure to respond to equality, diversity and inclusion and indigenisation of design curricula. In this space, Indigenous-led studios demonstrate powerful ways of reconfiguring design education, but they are difficult to scale because Indigenous educators are significantly underrepresented in higher education and often carry a substantial “cultural load” and consultation fatigue.

This paper addresses the question of how an asynchronous, technology-rich design course can support Indigenous-informed, relational and ethical design learning without further overburdening Indigenous knowledge holders. At the same time, it explicitly avoids cultural appropriation, the representation of specific cultural knowledge, and any simulation of Indigenous voices by the AI system.

2 BACKGROUNDS

Design and technology programs have widely adopted UCD as a dominant paradigm, supporting systematic stakeholder engagement, iteration, and evaluation. However, critiques from Indigenous scholarship highlight how UCD’s focus on individual users, short timeframes and bounded problem spaces obscures broader relational, cultural and ecological dimensions of design situations. In parallel,

there is increasing recognition that efforts to “Indigenise” curricula must attend not only to content, but also to the labour and wellbeing of Indigenous staff and communities who are repeatedly asked to lead such initiatives. This study, therefore, situates our work at the intersection of UCD and its limitations, Indigenous-informed relational design pedagogies, the realities of cultural load and consultation fatigue, and emerging uses of artificial intelligence (AI) to scaffold reflective and dialogic learning in asynchronous settings.

2.1 Indigenous-informed relational design pedagogy

Across Aboriginal and Torres Strait Islander communities, conversations are often used as a mode of knowledge transmission, governance, and relationship-making, not as a supplementary teaching technique [1]. Story is inseparable from Country, kinship, and obligation, embedded within specific linguistic, cultural, and ecological contexts, and governed by protocols that determine who may tell which stories, when, and under what conditions [2]. Story thus functions as a living medium through which responsibilities to people, place, and more-than-human relations are articulated and renewed across generations. For non-Indigenous educators, this requires recognising that some stories are not public, meanings may be layered and restricted, and classroom practice must be guided by permission, cultural authority, and awareness of limits.

2.2 Using story-based approaches in design teaching

Within design education, we often use narrative and speculative scenarios to support ethical reasoning, future-oriented thinking, and critical engagement with context [3]. For non-Indigenous educators in predominantly non-Indigenous settings, the challenge is to draw on the pedagogical strengths of story-based approaches without appropriating Aboriginal or Torres Strait Islander stories, symbols, or voices [4]. A culturally safe approach focuses on relational and ethical principles informed by Indigenous pedagogical thinking, while making it explicit that classroom activities do not reproduce, simulate, or translate specific cultural narratives [5].

Practically, this involves using fictional scenarios clearly framed as invented, yet grounded in real-world ethical tensions around power, accountability, and environmental and social impact. These scenarios require students to attend to who is affected by design decisions, whose expertise and authority are relevant, what harms might arise, and what accountability looks like over time. Relational principles, listening, consent, respect, reciprocity, and responsibility can be taught explicitly and woven into assessment criteria, reflective prompts, and studio critique. Educators can translate ethical values into design criteria. Reciprocity informs shared benefit and fair access; care for Country shapes environmental limits and lifecycle thinking; accountability operates through governance, consent, and review mechanisms.

2.3 Cultural fatigue

Aboriginal and Torres Strait Islander educators across Australian universities and schools carry substantial ‘cultural load’ in the form of uncompensated responsibilities, including committee representation, cultural education of non-Indigenous colleagues, ceremonial obligations, and pastoral support [6]. Approximately 39% of First Nations university staff report “high cultural load”, contributing to vicarious trauma, compassion fatigue, and burnout from “working between two worlds” [7].

This under-representation concentrates the workload on available Indigenous educators, creating unsustainable demands that intersect with broader ‘consultation and research fatigue’ from repeated over-consultation across sectors, delivering minimal benefit or structural change. Which makes elder-led studio models such as UTS’s four-year collaboration embedding Gadigal Elders and Indigenous scholars in final-year design teaching, which demonstrates pedagogical best practice [8], challenging to replicate.

AI-supported pedagogy may alleviate unsustainable demands on knowledge holders while maintaining relational, place-based, protocol-governed principles central to Indigenous pedagogies, provided rigorous Indigenous leadership governs implementation. The ‘Out of the Black Box’ report argues that when AI is designed ‘by’ or ‘with’ Indigenous communities, grounded in regional protocols, governed by Indigenous data sovereignty and cultural and intellectual property principles, and maintaining “Custodians in the loop”, technology can encode agreed governance as “rules-as-code”, automating routine pedagogical tasks while preserving Indigenous authority over sensitive knowledge [9].

3 COURSE DESIGN FRAMEWORK

In response to this context, we designed and configured an AI-assisted narrative framework for integration into an asynchronous design course for students accustomed to UCD-oriented methods. The framework has been implemented within the learning platform and tested by the teaching team, with student delivery scheduled for the following semester. The framework uses generative AI as a dialogic partner that prompts students to engage with bounded fictional scenarios, interrogate their positionality, and explore relational and ethical implications before proposing interventions. Contextual reference materials were drawn from publicly available, education-oriented resources or sources with clearly articulated permission pathways [10]. No sacred content, no invented lore, no simulated Dreaming narratives.

The framework operates under Aboriginal cultural oversight from Aunty Dr Caroline Hughes AM, a respected Senior Ngunnawal Elder. Oversight focused on ethical framing, boundary protection, and the avoidance of cultural misrepresentation, and did not extend to the provision of cultural content. The full acknowledgement appears at the end of this paper.

3.1 Fictional Persona as a Pedagogical Scaffold

The framework uses a fictional persona, May Harper, as a teaching case. May is an older Ngunnawal woman living on Ngunnawal Country who intends to remain in her home owing to mobility limitations. The persona, her setting, and the place-based elements of her case (including her home and her connection to a patch of yam daisies) were developed under cultural oversight and approved for use within this framework.

A specific persona, rather than a generic user profile, serves a defined pedagogical purpose. Generic profiles invite assumption-based design, allowing students to project cultural imaginaries into the brief. A specific, carefully framed case supports empathetic, constraint-based thinking and accountable decision-making by requiring engagement with concrete circumstances. Students engage with May as a single teaching case, not as a representative of the Ngunnawal community, identity, or cultural knowledge.

3.2 Narrative Framework for AI-Assisted Reflection

The teaching module uses a hierarchical narrative structure: cultural anchor, user case, story arcs, and micro-stories within each arc.

Cultural anchors are publicly available principles about place and relationships, drawn from educational sources rather than from cultural oversight. An example is the principle that plants can carry memory and relational significance in connection with Country. Anchors orient students toward relational rather than purely functional readings and reduce stereotype drift by providing stable interpretive reference points.

The AI introduces the user case, then unfolds a sequence of story arcs that address thematic dimensions of May's life: connection to place, mobility, community relationships, and trust in technology. Within each arc, the AI presents micro-stories of approximately 80 to 200 words depicting a single everyday moment, for example, May's difficulty bending to tend the patch of yam daisies near her home, a routine that connects her to family memory.

After each micro-story, the AI prompts students with focused reflective questions about emotional priorities, environmental barriers, or implicit assumptions. The AI uses student responses to shape the next narrative segment, staying within the predefined anchors and approved frame. It does not generate cultural elaboration beyond what is given.

The conversational agent is built using the *LangChain* open-source framework [11] with content sourced from publicly available materials.

3.3 AI Governance: Boundary-Preserving Responses

The AI is configured with explicit boundary-preserving rules. The configuration encodes patterns for refusal, redirection, and explanation to ensure that the system does not fabricate cultural content, speculate about ceremony or law, or reward students for seeking culturally inappropriate details.

When a student requests cultural elaboration beyond the approved corpus, the AI affirms that some knowledge is not public, clarifies that the module uses only educationally available resources, and redirects the student toward reflection on why the request was made and what assumptions it reveals. Refusal functions both as ethical protection and as a teaching moment that surfaces the limits of design

knowledge. Table 1 summarises the division of what is generated by AI, what is templated, and what is manually authored.

Table 1. Division of labour

Element	Authored by	Generated at run-time	Reviewed under cultural oversight
Cultural anchors	Teaching team, public sources	No	No
Persona	Teaching team	No	Yes
Persona setting and place-based elements	Teaching team	No	Yes
Story arc themes	Teaching team	No	No
Micro-stories within arcs	AI generates within constraints	Yes, within approved frame	Framework reviewed; individual-generated stories not reviewed
Reflective prompts	AI tailors within team templates	Yes, within approved frame	Framework reviewed
Refusal and redirection patterns	Teaching team (oversight-informed)	No	Yes

This division means cultural oversight was consulted once, during framework development, to approve the static elements and the governance rules. The framework then runs asynchronously across student cohorts without reconsulting cultural oversight for each interaction. This is the operational basis of the load reduction described earlier. The framework does not eliminate consultation; it concentrates it during design and protects it from being re-extracted at each delivery.

4 METHOD

4.1 Participants

Fifty students enrolled in an undergraduate design studio were allocated to two parallel conditions: twenty-five to an AI-assisted version and twenty-five to a non-AI version. Both conditions used the same syllabus, assessment criteria, and learning outcomes. The only systematic difference was the presence or absence of AI-mediated narrative prompts.

4.2 Conditions

In the AI condition, narrative prompts were integrated into an asynchronous studio sequence. Students interacted with fictional scenarios via the AI agent, which asked follow-up questions, encouraged explicit articulation of assumptions, and redirected culturally inappropriate queries toward ethical and methodological reflection. In the non-AI condition, students worked with the same narrative content presented as static reading material and completed parallel reflective activities through written journal entries and structured peer discussion.

The comparison condition is not a "no-narrative" control. Both conditions receive the same narrative content. The difference lies in the medium of reflective engagement: dialogic and AI-mediated in one condition, written and peer-mediated in the other. This design allows observed differences to be attributed to the mode of reflective scaffolding rather than to the presence of narrative content.

4.3 Operational Definition

We analyse three constructs in students' work: empathy, relational thinking, and ethical awareness. Each construct is operationalised through observable features in reflective journals, design artefacts, and recorded AI interactions, rather than self-report alone.

Empathy is operationalised as how specifically and concretely a student responds to May's situation. Higher-empathy responses refer to particular details of her life (for example, the patch of yam daisies, the layout of her home, her routines, and her stated values) and treat her expressed preferences as constraints on design rather than problems to be fixed. Responses that refer only to generic figures such as "the user" or "older people," without concrete, contextual detail, are coded as lower empathy[12].

Relational thinking is operationalised as the number and kinds of relationships considered in framing and concept development. Higher-relational responses recognise parties beyond the primary user (for

example, family, community, more-than-human relations, Country), describe how different parties might benefit or contribute, and consider how design decisions may affect these relationships over time, including any accountability or governance arrangements. Responses that frame the task purely as meeting an individual user's needs, with little or no reference to broader relationships or responsibilities, are coded as lower-relational thinking[13].

Ethical awareness is operationalised as the extent to which a student explicitly reflects on assumptions, limits, and boundaries in their work. Higher-ethical responses name the student's own position (for example, aspects of their cultural background or experience that may shape how they see May), acknowledge where they do not have enough information and avoid speculating beyond it, identify cultural or other sensitive areas as outside the scope of the brief, and state what remains uncertain or unknown, in line with work on reflexivity and positionality in qualitative and design research. Responses that treat assumptions as facts, fail to acknowledge knowledge gaps, or ignore potential cultural boundaries are coded as indicating lower ethical awareness [14, 15].

The three constructs are related rather than strictly separate. Coding, therefore, allows multiple constructs to be assigned to the same excerpt, and any overlaps are retained for analysis rather than collapsed.

4.4 Data Collection and Analysis

Data sources include pre-course and exit questionnaires, student reflective journals, design artefacts (briefs, problem framings, concept portfolios), engagement indicators, AI interaction logs for the AI cohort, and short focus groups with volunteers from both conditions.

Questionnaire and engagement data are summarised using descriptive statistics, with non-parametric comparison between cohorts. The small sample ($n = 25$ per condition) means quantitative results are treated as supporting evidence rather than the primary basis for claims.

Journals, artefacts, focus group transcripts, and AI interaction logs are analysed using reflexive thematic analysis[16], anchored to the operational definitions in Section 4.3. Two coders work independently on a stratified sample, with disagreements resolved through reflexive discussion. Rigour is supported through triangulation across data sources and member reflection. Coding pays specific attention to language, indicating cultural overreach or recognition of cultural boundaries.

5 FINDINGS (OBSERVATIONS FROM FRAMEWORK DEVELOPMENT)

The framework has been developed, approved under cultural oversight, and integrated into the learning platform. Delivery is scheduled for the following semester, with data collection and analysis completed before the conference. Findings on student learning will be presented at the conference. What we report here are observations from development.

5.1 Cultural time and the approval process

Aboriginal cultural oversight is governed by relational accountability, not by project deadlines. Approval moves when the engagement is ready, not when a calendar says it should. This is not a delay to be managed; it is what taking oversight seriously requires, and any attempt to compress it would have contradicted the principles the framework claims to embed.

The implications run deeper than scheduling. Programs proposing AI-assisted Indigenous-informed pedagogy need to plan for this. Approval timelines cannot be reliably predicted from institutional planning frames, and the cost of doing the work properly arrives long before delivery.

This sharpens the cultural load argument. The load on Indigenous educators is not only produced by repeated requests for content. It is also produced by the labour of operating across two systems of time at once, one that treats duration as a commitment and one that treats it as a matter of engagement. The framework concentrates this labour during design but does not erase it.

5.2 Operational readiness

The boundary-preserving AI behaviours described earlier have been tested during development. Test prompts seeking cultural elaboration beyond the approved corpus consistently produced refusal responses aligned with the design rules. No students have yet interacted with the deployed module, so this is reportable as configuration evidence rather than learning evidence.

6 CONCLUSIONS

This study proposes and implements an AI-assisted narrative framework for asynchronous design education informed by Indigenous pedagogical principles of relationality, reflection, and responsibility, while constraining AI-generated content to a corpus developed and approved under cultural oversight. The contribution at this stage is conceptual and methodological, showing how stringent AI governance can support relational and reflective design reasoning without positioning the framework or its AI as a source of cultural authority. The framework was developed by non-Indigenous educators under Senior Elder oversight, which establishes the ethical legitimacy of this specific framework, persona, and corpus, but does not transfer cultural authority to the teaching team or generalise to other communities or contexts. Educators considering similar work should expect to undertake their own oversight process, paced by the relationships that make oversight possible rather than by institutional timelines. We submit this work at this stage to invite critical feedback on design, ethics, and governance before making stronger claims based on completed data. The forthcoming analysis will examine whether the framework supports relational and reflective design learning without increasing cultural load or reproducing extractive dynamics.

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RETHINKING DESIGN EDUCATION IN AN AI-ENABLED ERA: A COLLABORATIVE AUTOETHNOGRAPHIC APPROACH

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ABSTRACT

Artificial intelligence is rapidly transforming design practice, challenging educators to reconsider how design processes are taught and how future designers will work with emerging technologies. This paper presents an ongoing collaborative autoethnographic study undertaken by design academics at an Australian and a New Zealand University to examine how Generative AI (GenAI) is influencing the teaching of early-stage design processes, particularly discovery, problem framing, ideation, and early visualisation. Through a structured reflection framework, participants analyse their own teaching practices to identify opportunities, risks, and pedagogical priorities related to GenAI integration. Individual reflections are shared and collectively interpreted using Collaborative Autoethnography, enabling educators to co-construct insight grounded in studio practice. Reflexive Thematic Analysis guides the development of three pedagogical lenses; experiential learning, iterative problem solving, and critical reflection, through which educators' responses to GenAI adoption are interpreted. Rather than treating GenAI as a technical skill to be added to existing curricula, the study positions AI integration within the established foundations of studio-based pedagogy. The findings reveal a tension between professional efficiency and pedagogical intention, highlighting both the potential of GenAI to expand exploratory practices and the risks of premature convergence, fixation, and reduced engagement with foundational design thinking processes. The paper contributes insight into how design education can evolve to integrate GenAI while maintaining core commitments to iteration, reflection, and designer agency.

Keywords: Design education, design process, GenAI

1 INTRODUCTION

Generative AI (GenAI) is transforming education at every level, reshaping how knowledge is generated, delivered, and understood. Tools such as ChatGPT, Midjourney, and other generative systems are rapidly entering classrooms and studios, blurring boundaries between human cognition and machine capability. Educators across disciplines are now asking urgent questions: *how can we collaborate with GenAI in learning, what opportunities and risks does it present, how will it reshape professional roles, and how should pedagogy respond?* Such questions are particularly pressing in design education, where learning is grounded in creativity, iteration, and design thinking. AI has entered the design studio as both an opportunity and a provocation. While it expands designers' capacity to visualise, ideate, and experiment with speed and scale, it also challenges long-held assumptions about authorship, creativity, and human judgement. Design educators now navigate between experimentation and caution as they test emerging tools while seeking to preserve core "designerly" ways of knowing. This paper emerges from within that context. Drawing on the collective expertise of design educators and researchers, the study uses Collaborative Autoethnography (CAE) to reflect critically on how design education can evolve to prepare graduates for hybrid human-AI design practice. CAE positions educators' own teaching experiences, beliefs, and practices as legitimate sources of scholarly inquiry. The aim of this research is to explore how design educators can integrate GenAI meaningfully into teaching and curriculum design. Through structured reflection on their courses and areas of expertise, participants examine how GenAI is influencing different stages of the design process. The study seeks to identify

shared opportunities, challenges, and pedagogical priorities to support curriculum renewal and better prepare students to work critically, ethically, and collaboratively with AI.

2 BACKGROUNDS

2.1 Studio based pedagogy

Design education has a long tradition of employing the studio model as its core pedagogical approach [1], and it continues to function as the principal mode of teaching in contemporary design programmes [2]. The studio typically manifests as an open, practice-oriented learning environment that supports experimentation, feedback, and iterative development [3]. Central to the studio model is the notion of “learning by doing,” where students are immersed in processes that closely resemble professional design practice [3]. This approach can be framed pedagogically as active learning” [4] rather than passive instruction of technical skills. These students typically engage in problem-based learning [1], addressing ill-defined or open-ended design challenges [5]. Such projects necessitate iterative cycles of development closely reflecting established models for the design process where emerging design propositions are continually evaluated and refined. Schön’s concept of reflective practice developed during his research into architectural design studio education captures this process, emphasising reflection both in action and on action as a means of advancing design outcomes [6]. Through these iterative cycles, students exercise critical thinking by critiquing their own and others’ ideas, and by evaluating tools, techniques, and strategies to determine the most appropriate next steps in the design process [3]. Collectively, the qualities of *experiential learning*, *iterative problem solving*, and *critical reflection*, are foundational for educating future designers to navigate complex design processes.

2.2 Design process

The increasing use of digital and AI-based tools across design activities, from research and idea generation to prototyping and visualisation, has prompted renewed attention to how the traditional Double Diamond model [7, 8] is used and taught in design education. Recent frameworks such as the Stingray model [9] advances the Double Diamond in light of technological change, emphasising feasibility, viability, and awareness of bias alongside human-centred thinking. However, such early proposed models still require further clarification regarding how AI-based tools can tangibly integrated into the design process. Therefore, in this paper, we focus specifically on the early stages of the design process: Discover and Define and contribute practical insights into how educators can integrate AI tools meaningfully into the design process. These stages are critical in shaping how design problems are understood and framed, involving inspiration seeking, ideation, problem reframing, scenario setting, and early sketching through an iterative process. Rather than progressing sequentially, these activities loop and inform one another, establishing the conceptual foundation of a project and strongly influencing all subsequent design decisions; making them a key focus for examining how AI can be integrated into design education.

3 METHODOLOGIES

This study employs Collaborative Autoethnography (CAE) to examine shared experiences while maintaining individual reflexivity. As researchers [10] define it, CAE is “the study of self, collectively” (p. 11), where its strength lies in transforming individual reflection into collective insight, connecting lived experience with broader educational and disciplinary contexts. CAE was used to support both critical reflection and community building among researchers. This study also draws conceptually on the notion of the reflective practitioner [11] and the framework [12] for critical reflection in teaching. The concept of reflection-on-action [11] informs the examination of past and current AI teaching practices, while the use of multiple reflective lenses [12] supports questioning assumptions and deepening pedagogical insight. These perspectives emphasise reflexivity, interpretation, and the value of educators lived experience in making sense of complex and evolving teaching contexts. Thus, they position CAE as both a reflective and interpretive practice. Each educator’s narrative becomes a site for personal reflection and shared analysis, enabling the group to co-construct knowledge about the evolving relationship between GenAI and design education. Following prior applications of CAE in engineering education [13], this study adapts the approach to design context, treating educators lived experiences as a valuable form of pedagogical inquiry.

The authors are all educators and researchers from the design schools in an Australian and a New Zealand University. Each participant (P1, P2, P3 and P4) has a distinct design background, spanning

teaching, research, and professional practice, which ensures a rich spectrum of perspectives. Participants were invited to reflect on their teaching practice using a shared set of guiding questions, that were categorised into the four themes: (1) Context and Focus Area, (2) AI Tool-Specific Observation and Reflection, (3) Interpretation of GenAI challenges and opportunities, and (4) Responsible Educational Integration. These four topics, with their associated reflective prompts, were developed based on CAE [10], reflective practice [11] and critical reflection [12]. These topics helped the authors describe, observe, and interpret how GenAI is influencing the stage(s) of the design process they teach, and encourages reflection on both the current state of GenAI use and the future implications for design education. The study employs reflexive thematic analysis to identify shared meanings between reflections [10, 14]. The educators function as both participants and analysts, co-producing insight through reflection, discussion, and synthesis. Data was reviewed on a macro-level to gain a holistic view of emerging concepts, then on a micro-level to enable closer reading of individual cases [10]. Next, themes were constructed through group discussion and reflexive interpretation [14]. Reflections were initially guided by a framework, which provided a common structure for reflection, but then used flexibly by participants. Educators shared and reviewed each other's reflections, and themes were developed through identifying recurring patterns and insights across the cases. All reflections were based on participants' own teaching practice, with voluntary participation and no identifiable student data included.

4 RESULTS AND DISCUSSION

Across the four cases, educators reflect on how the use of GenAI is encountered within early stages of the design process. These encounters arise through different modes of engagement, including classroom teaching, observation across multiple design units and personal design practice. As such, the reflections capture how AI is experienced as part of everyday design education practice, rather than as a single or standardised implementation. While the focus was on early stage of the design process, the four educators chose different studio-based AI design activities to broaden the reflections on how AI intersects with established ways of thinking, making, and learning in design education. Namely, inspiration finding, scenario setting, early sketching, and problem framing and ideation. All educators position their reflections within studio-based pedagogy. Together, these reflections provide the contextual foundation for identifying shared pedagogical concerns and potentials. Explanation of each case along with reflections is given below.

4.1 Case summaries

P2 reflects on the use of text-to-image GenAI during inspiration finding and mood-board development. The focus is on how AI is encountered as a visual exploration and curation mechanism during early aesthetic definition, particularly in relation to form, material, and colour considerations. The reflection situates AI within inspiration finding rather than technical design skill development.

P3 focuses on the use of large language models during scenario setting and early conceptual ideation. This reflection examines how AI becomes involved in articulating future contexts and speculative narratives, positioning language as an early site of design work. The emphasis is on AI's role in supporting conceptual exploration during the formative stages of design thinking.

P4's reflection centres on AI-assisted sketching in early design development. P4 examines how AI intersects with established sketching practices that support ambiguity, exploration, and iteration. The focus is on how different types of sketches are encountered and used when AI-generated visualisation becomes part of the early design workflow.

P1 reflects on the use of both text-based and image-based AI tools during problem framing and early ideation. The reflection considers how AI supports interpretation, reframing, and inspiration at the outset of open-ended design briefs. The focus is on AI as a cognitive and visual support within early-stage design activity rather than as a solution generator.

Analysis of the four educator reflections reveals a strong shared awareness of preserving core pedagogical values of studio-based design education as artificial intelligence becomes increasingly present in early design activities. Drawing on the literature, *experiential learning*, *iterative problem solving*, and *critical reflection* were identified as key dimensions of studio-based design education [1,3,5,6]. Thus, these three dimensions define the themes for the thematic analysis of the educator reflections. While the reflections focus on different stages of the design process and different forms of AI, common concerns emerge regarding speed, fixation, authorship, and judgement. These concerns are

consistently framed in relation to how students learn to think and act as designers, instead of technical capability or tool proficiency.

4.2 Experiential Learning: Reconfiguring “Learning by Doing”

Experiential learning, understood as learning through active engagement and practical experimentation, remains a foundational principle across all four reflections. GenAI tools were frequently described as changing how students engage in experiential learning rather than eliminating it altogether. In several cases, AI accelerated the production of outputs, enabling students to explore ideas more rapidly and with greater breadth. This shift altered the nature of “doing” in the studio, moving it from manual production toward interaction, experimentation, and response. P2 reflects on the potential longer-term implications of this shift, noting that *“it may also inhibit creativity long term. Students’ capacity to imagine may suffer when they can prompt images.”* P2 also describes how generating inspirational imagery instead of searching for it enables students to articulate and test aesthetic intentions more fluently, but also requires sustained engagement in evaluating and refining outputs: *“For every image generated designers must think critically if the images represent their design intent, and to what extent, and how it could further meet their intent.”*

Similarly, P1 frames AI as a cognitive and visual support that allows students to spend more time engaging with briefs and ideas rather than struggling with initial decoding: *“Students often struggle at the very beginning of a design project, not because they lack ideas, but because they misunderstand the brief or overlook important details.”* However, educators also note that AI’s efficiency risks reducing productive struggle, an important component of experiential learning in studio education. P4 observes that when AI-assisted sketching is introduced too early, students may bypass exploratory sketching practices that traditionally support learning through trial, ambiguity, and failure: *“Traditional sketching requires time, effort, and repeated failure... AI’s efficiency risks removing these moments unless they are deliberately reintroduced through pedagogical design.”*

Across the reflections, experiential learning is not abandoned but reframed. “Doing” increasingly involves interacting with AI systems, experimenting with prompts, and evaluating generated outputs. As P3 notes, the pedagogical focus shifts away from simply obtaining outputs toward understanding how human–AI interaction shapes thinking: *“Rather than focusing on how to obtain better answers from ChatGPT, I encouraged students to examine how particular prompts shaped the direction, tone, and limits of the ideation space.”* Educators emphasise the need to design learning activities that preserve engagement, effort, and reflection, ensuring that prompt experimentation functions as experiential learning more than a shortcut to outcomes.

4.3 Iterative Problem Solving: Acceleration and Fixation

Iterative problem solving, characterised by cycles of idea generation, testing, and refinement, emerges as another shared pedagogical priority that is both supported and challenged by AI. All four educators describe AI as enabling rapid generation of alternatives, which can expand the exploratory phase of design when used deliberately. This aligns with existing research showing that AI can support early-stage design by expanding the exploration of the design space and enabling the generation of novel concept associations during ideation [15]. P3 notes that language-based AI can broaden conceptual space during scenario setting by producing multiple speculative propositions: *“ChatGPT supported this process by generating speculative propositions, reframing assumptions, and suggesting consequences that students had not initially considered.”* This expanded capacity for iteration is closely tied to how design choices are surfaced and examined. As P3 further reflects, *“Designing for future scenarios are constructed through choices about what to emphasise, what to question, and what to leave unresolved. ChatGPT, when taught carefully, becomes a medium through which these choices can be examined.”* Similarly, P1 observes that image-based AI allows students to quickly explore visual variations that might not emerge through imagination alone, noting that *“unexpected forms, material expressions, or atmospheres often appear, which can trigger new ideas or directions.”* At the same time, the reflections consistently identify risks of premature convergence and linear workflows. In studio practice, this was often addressed through structured activities where students generated multiple AI outputs, compared alternatives, and justified their selections through critique and discussion. While these activities primarily supported idea generation and exploration, they also encouraged students to engage more critically with AI outputs, treating them as a scaffold for critical thinking and design development rather than final solutions. High-fidelity outputs, whether visual or textual, can encourage students to settle too

quickly on initial ideas, shifting the design process from exploration to selection. P4 highlights this concern in early sketching: *“When persuasive sketches appear prematurely, they can disrupt the low-commitment nature of early ideation, encouraging students to evaluate and select ideas based on visual appeal rather than conceptual robustness.”* P1 raises a related concern in inspiration finding, noting the risk of design fixation when students are exposed to polished imagery early in the process, specifically the *“risk of design fixation arising from the provision of sophisticated high-fidelity imagery.”*

Across cases, educators note that the design process can become linear if AI outputs are treated as final answers instead of starting points for further exploration.

4.4 Critical Reflection and Designer Judgement

Critical reflection emerges as the most consistent and explicit concern across all four reflections. Educators repeatedly emphasise that GenAI integration heightens the importance of teaching students how to evaluate, interpret, and question outputs rather than accept them at face value.

P3 describes a deliberate pedagogical shift toward cultivating critical judgement, noting that *“some students treated the genAI outputs as authoritative, accepting its responses as plausible futures rather than provisional constructs.”* This emphasis on comparison and interrogation recurs across the reflections. P2 frames AI use as demanding heightened criticality due to the sheer volume and persuasiveness of generated imagery, noting the *“risk of design fixation arising from the provision of sophisticated high-fidelity imagery.”* P4 similarly stresses the importance of critical judgement when visually compelling outputs appear early, observing that such images can encourage *“students to evaluate and select ideas based on visual appeal rather than conceptual robustness.”* P1 adds a related perspective, noting that *“highly polished and realistic AI outputs can encourage students to settle too quickly on one idea.”* This concern links fixation not only to speed, but also to the apparent authority and completeness of AI-generated results.

Across the cases, critical reflection is not treated as an automatic outcome of AI use, but as a skill that must be explicitly taught and scaffolded. Educators express concern that without such awareness, students may over-rely on AI outputs, accept them as authoritative, or misunderstand their role in the design process.

Overall, the findings reveal a clear tension between professional efficiency and pedagogical intention in studio-based design education. While educators recognise the value of generative AI for speed and productivity in contemporary practice, they approach its integration cautiously in learning contexts, particularly for novice designers. The concern is not the presence of AI itself, but the possibility that efficiency may reduce engagement with foundational thinking processes central to experiential learning. Traditionally, studio pedagogy assumes that progressing through design tasks supports the development of design thinking through reflection-in-action [6]. Such iterative engagement with open-ended design challenges is central to studio practice [5] where learning grounded in experimentation, critique, and iterative engagement with ill-defined problems [3]. However, generative AI alters this relationship by enabling students to bypass exploratory stages and produce high-fidelity outputs rapidly. As a result, the link between process and understanding is no longer guaranteed, and may require more deliberate pedagogical structuring. This shift echoes established distinctions between professional practice and design education. In industry, designers rely heavily on digital tools such as CAD, yet educational programmes often delay CAD instruction until foundational visual and spatial thinking skills are established. Reflections in this study anticipate the need for similar interventions and careful sequencing when integrating AI within early stages of the design process, particularly within the Discover and Define phases of the Double Diamond model [7, 8]. While the Stingray model [9] acknowledges and even foregrounds AI-led early-stage design processes, it provides limited discussion of how these shifts should be scaffolded within studio-based design education. Our reflections contribute here providing some concrete guidance on integrating this model into studio education.

Finally, the study reinforces the continued importance of reflective practice within studio education. Reflection and critique must be deliberately structured elements of studio learning, supporting deeper engagement with design problems. The persuasive authority and fidelity of AI-generated outputs intensify the need for critical judgement, comparison, and interrogation. AI-generated outputs may also reflect cultural biases or dominant perspectives embedded in training data, which can influence design outcomes. This further reinforces the need for students to critically evaluate and question AI-generated content. If GenAI is used as a tool for exploration in design process, not as a source of fixed answers, it

can support deeper critical thinking by encouraging students to consider multiple interpretations and alternatives, while maintaining human-led design thinking.

5 CONCLUSIONS

This article examines how Generative AI is influencing the teaching of early-stage design processes, particularly discovery, problem framing, ideation, and early visualisation. Using a Collaborative Autoethnography approach, four educators critically analyse their own studio teaching practices to identify opportunities, risks, and emerging pedagogical priorities associated with integrating GenAI. The findings reveal a clear tension between the professional efficiencies afforded by GenAI and core pedagogical intentions within design education. While GenAI can expand exploratory practices and accelerate visualisation, it also carries risks of bypassing key exploratory stages, increasing the likelihood of premature convergence, fixation, and reduced engagement with foundational design thinking processes. Ultimately, the study suggests that the introduction of GenAI can distance/decouple the relationship between learning-by-doing and developing understanding of design thinking. Consequently, it highlights a greater need for deliberate and carefully structured pedagogical strategies may be required to sustain meaningful learning within GenAI supported studio education.

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IMPLEMENTATION OF A RECYCLING DESIGN WORKSHOP INSPIRED BY BIOMIMICRY

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ABSTRACT

Sustainable design and the use of recycled materials are essential for reducing environmental impact. Teaching these practices to future engineers and designers is crucial for promoting more responsible development. The objective of the workshop was to raise awareness and train students in the use of recycled materials through a design method based on the Biomimicry spiral, "From Biology to Design." This allowed first- and second-year Industrial Design Engineering students to propose products using materials donated to ELISAVA Material Depot, sourced from various activities and projects at the university.

The workshop consisted of three 3-hour sessions, during which the five stages of the proposed methodology were implemented. These sessions took place in a classroom and in the university's workshops. Materials used included wood and wood products, metal tubes, laminated plastics, fabric, and thread, among others. The proposed products included an organizer, a table/magazine rack, an eyeglass holder, a jewellery box, a coffee table, and a storage container. Among the results of this experience, we can highlight the knowledge and application of nature-based design methods; the dynamics of working to solve a specific problem under pressure and with limited time; the collaborative work and creativity displayed in an environment similar to professional practice, among others.

In the future, we intend to conduct more workshops under similar circumstances, but considering improvements focused on complexity, execution times, and scope. We believe that these types of learning experiences are very valuable for engineering and design students, as they promote more responsible and environmentally friendly practices.

Keywords: Sustainable design, recycled materials, biomimicry, ELISAVA material depot, educational innovation, higher education

1 INTRODUCTION

The overexploitation of natural resources began in the late 18th century with the Industrial Revolution and intensified with the onset of the Anthropocene (mid-20th century). Short-term economic gain has been prioritized over long-term sustainability, causing significant damage to our planet, particularly to the climate and biodiversity. Therefore, it is crucial to find new ways to contribute to environmental conservation by making better use of natural resources and even waste materials. In this regard, initiatives and strategies such as zero waste, recycling, and regenerative design have emerged in recent years. Among these, recycling processes, such as downcycling and upcycling, have significant potential for development and application. Both concepts aim to reduce environmental impact and decrease the consumption of natural resources, differing in the final value of the product. Therefore, training future engineers and designers in these practices is essential to raise awareness and foster more responsible development. To achieve this, nature-based design methodologies are of great support, especially those related to biomimicry [1], [2]. Biomimicry, which emerged at the end of the last century, learns from and imitates the strategies of living species to create sustainable solutions, valuing nature for its wisdom and not for what can be extracted from it [3].

Furthermore, these 3 days downcycling workshop had as its main objective to raise awareness and train Industrial Design Engineering students in the use of recycled materials through a design method based on the Biomimicry spiral, "From Biology to Design", also called "Biology to Design" [4]. This practice has significant pedagogical value and contributes positively to the training of designers and engineers [5]. It is important to mention that three previous implementations have been carried out with students from various creative disciplines on a private university campus in Mexico. These implementations used

methodologies based on the two spirals of Biomimicry: "From Biology to Design" and "Challenge to Biology" [6], [7]. While design and engineering methods exist for developing products with recycled materials [8], the authors considered it pertinent to rely on nature-based methodologies. This makes sense, given that both methodologies seek, among other things, to minimize the environmental impact from the manufacturing process through use, maintenance, and final disposal.

2 METHODOLOGIES

2.1 Objectives

The objectives of this downcycling design workshop were the following:

Sustainability Education: To teach students the importance of recycling and the environmental benefits of using recycled materials in product design

Design Innovation: To foster creativity and innovation, drawing inspiration from nature, to develop sustainable and functional products.

Hands-on Practice: Provide students with practical experience in the techniques and processes of developing and manufacturing products made with recycled materials.

Environmental Awareness: To increase future designers' awareness of the environmental impacts of their design decisions.

2.2 Participants

This workshop was attended by 13 Industrial Design Engineering students from ELISAVA, Barcelona: 9 first-year students and 4 second-year students, in five teams of two students and one team of three students (with first-year students). That is, the students formed teams freely and with members from the same year. The workshop was held in the afternoon to avoid disrupting students' classes. Participation was voluntary and by direct invitation from the Coordinator of the Industrial Design Engineering Degree. The only requirement for participation was basic knowledge of using tools and equipment for material transformation (primarily standardized materials). Participants were also asked to bring drawing materials and appropriate clothing for working in the ELISAVA workshops.

2.3 Methodology

The methodology, as mentioned, is based on the biomimetic design spiral "From Biology to Design." Figure 1 presents the original methodology in Spanish in the center, and around it, in a clockwise direction, we can see the corresponding adapted stage and its description (every effort was made to maintain the meaning and objective of the original stage of the biomimetic design spiral). The originally proposed implementation days for this workshop are also shown (day 1 = D1, day 2 = D2, day 3 = D3), three hours each day (9 in total), although some minor adjustments were made during implementation.

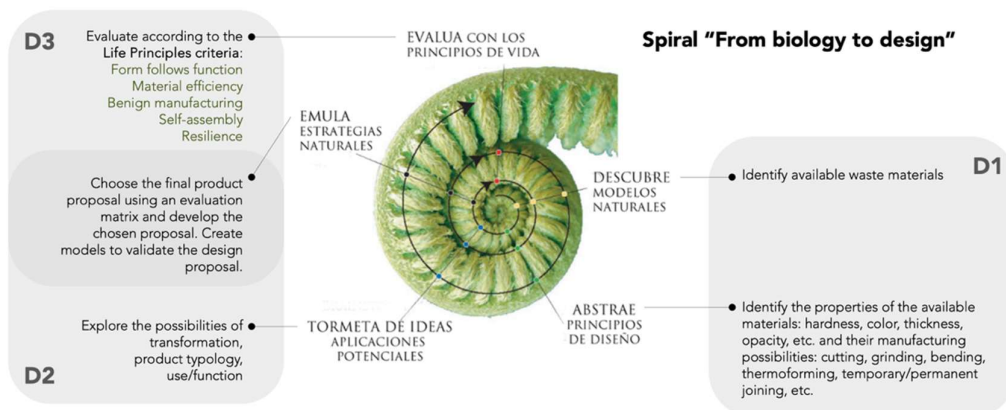


Figure 1. Design method based on the spiral "from biology to design"

Before implementing the methodology, an introduction was given, considering the instructor's presentation, a brief explanation of what circular economy and recycling design are, as well as the explanation of each step of the methodology.

The following details each stage of the methodology:

- **Discover.** *Identify available waste materials.* Figure 2 shows the selection of materials at ELISAVA Material Depot, a system and physical space inaugurated on the third floor of the ELISAVA Faculty of Design and Engineering in Barcelona, designed to promote the circular economy and the reuse of materials [9]. Day 1.



Figure 2. Students reviewing and selecting materials at ELISAVA Material Depot

- **Abstract.** *Identify the properties of the available materials: hardness, colour, thickness, opacity, etc. and its manufacturing possibilities: cutting, roughing, bending, thermoforming, joining, etc.* The selection and identification of material properties were carried out empirically due to the limited time available for this activity. In this regard, and if more time were available, methods offering a more scientific approach to this stage are recognized [8]. The materials chosen included wood and wood derivatives, cardboard, metal tubes, laminated plastics, fabrics and threads, among others. There was no specific procedure for classifying and preparing the recycled materials for use in the workshop. Day 1.
- **Brainstorming.** *Explore the possibilities of transformation, product typology, use/function.* This was done through text, sketches, and quick models, with minimal guidance and advice from the professor (see Figure 3). This stage was scheduled to begin on the second day of the workshop (as shown in Figure 1), but in practice it started at the end of the session on day 1. Days 1-2.



Figure 3. Students analysing the properties of materials and their potential for a new product

- **Emulate.** *Choose the final product proposal using an evaluation matrix. Make models for validation.* At this stage, the intention is for decisions to be made regarding the best design proposal based on an evaluation matrix, but some teams opted to create rapid models for the validation/evaluation of their ideas, before manufacturing the prototype. This stage was carried out mainly in the ELISAVA Prototype Workshop without feedback from the instructor. Support was provided only by the workshop staff, as tools and different equipment were used on-site, such as a jigsaw, laser cutter, milling machine, and sewing machine, among other equipment and tools. Figure 4 shows students working on their projects. Days 2-3.



Figure 4. Students working on their projects

- Evaluate.** Evaluate under the criteria of Principles of Life. To conduct this assessment, students were given an evaluation matrix with a scale of 0 to 5 (0 being deficient and 5 being outstanding) and colour-coded indicators (see Table 1). After completing the self-assessment, the teams shared their numerical scores and gave oral presentations of their prototypes. Figure 5 shows students from Teams 1, 2, 3, and 5 presenting their projects. Day 3.

Table 1. Evaluation matrix

	0	1	2	3	4	5
The form follows the function						
Use of the material						
Benign manufacturing						
Self-assembly						
Resilience						



Figure 5. Students presenting their projects

3 RESULTS AND DISCUSSION

As a result of this workshop, the products developed by the teams were the following:

Team 1: Wall organizer with adjustable shelves. Made with pine plywood and acrylic mirror, using a laser cutter.

Team 2: Magazine rack with side table. Made with pre-curved metal tubes, fabric and pine wood, mainly using a saw, milling machine and sewing machine.

Team 3: Double glasses holder. Made with polypropylene and Velcro, cut with a cutter and scissors.

Team 4: Jewellery box. Made using an existing chair leg and cotton thread, using a saw and handmade knots.

Team 5: Coffee table. Made with corrugated cardboard and MDF. Cut with a jigsaw.

Team 6: Storage container. Made with wood and various fabrics, using a saw, scissors, and knots.

The prototypes presented by the six teams are shown in Figure 6.



Figure 6. Prototypes presented by the teams

The choice of product type and functionality was neither questioned by the instructor nor justified in the prototype presentations. However, it can be observed that teams 1 and 2 (comprised of second-year students) developed products with more complex functionality and manufacturing processes than the other teams (3, 4, 5, and 6), which were made up of first-year students. This is easily explained by the fact that the process of acquiring knowledge and developing skills increases throughout university studies. During the first year, students typically work with simple, standardized materials and basic transformation methods.

Regarding the evaluation, each of the aspects to be evaluated is briefly explained below:

- **The form follows the function.** An important aspect was that the product had to have a high level of functionality, avoiding purely ornamental objects.
- **Use of the material.** Maximizing the use of available materials was also a non-negotiable condition for this exercise.
- **Benign manufacturing.** Another aspect to highlight, and one requested from the beginning of the workshop, was that the processes be as environmentally friendly as possible.
- **Self-assembly.** The objective was self-assembly, temporary or pressure-fit joints. The use of adhesives or permanent bonds between product components would be penalized.
- **Resilience.** Finally, the product was required to be resilient. This meant it could withstand use and handling, minor impacts, and even occasional drops. It also meant proposing simple designs, avoiding unnecessary complexity.

The self-evaluation of the proposed products, meanwhile, was based on the Principles of Life (observable in Figure 1 and Table 1). The highest score (23/25) was obtained by Team 2, the lowest by Team 4 (17/25), and the average was 20.33/25. Although this evaluation could have been carried out by the instructor, with greater experience and impartiality, the authors believe that self-evaluations strengthen students' critical thinking, as well as their environmental awareness. Furthermore, this workshop would not have been possible without the support of ELISAVA Material Depot, a project of ELISAVA, the Faculty of Design and Engineering in Barcelona, which aims to optimize materials management by centralizing donated materials from various university activities and projects [9].

4 CONCLUSIONS

Based on a downcycling design workshop, students became aware of the environmental impact of their design decisions and were encouraged to adopt more sustainable practices. Creativity and innovation were fostered, drawing inspiration from nature-based design methods.

Students gained hands-on design experience, generating solutions quickly with the support of agile prototyping using recycled materials. In this regard, it is important to highlight the value of trial and error through prototyping.

The most significant aspect of this workshop was that it fostered ecological awareness among the participating students. They learned the valuable lesson that it is possible to create new design solutions with a lower environmental impact and that methodologies exist to achieve this. In this regard, guidelines were established for creating products that are easy to disassemble and recycle at the end of their useful life. The workshop promoted downcycling, a design practice with great potential, due (unfortunately) to the increasing number of products and materials that can be reused after their useful life [10]. This can contribute to reducing the amount of waste in landfills, thus mitigating pollution and environmental degradation [11]. The workshop also addressed the design and business opportunities related to waste, scrap, and leftover materials from industrial waste.

By participating in projects that prioritize the use of recycled materials and eco-friendly design techniques, students develop crucial skills and knowledge for innovating in a world that increasingly demands sustainable solutions. While it is acknowledged that, due to time constraints, it was not possible

to compile a formal and systematic record of student feedback and reflections during the workshop, the observed indicators, such as their active participation, the questions they asked, and their problem-solving skills, suggest a positive impact in these areas. Undoubtedly, these types of learning experiences are extremely valuable for engineering and design students, as they not only foster more responsible and environmentally friendly practices but also prepare them to face current and future sustainability challenges.

5 FUTURE WORK

In the future, we plan to conduct more workshops based on this methodology, incorporating significant improvements such as more complex challenges, longer execution times, and a broader scope. Furthermore, we will implement more robust empirical research, including surveys and interviews with participants to more accurately assess the workshop's results and impact. As a potential further improvement, we are considering limiting the design solution to a specific type of product or problem to focus our efforts and achieve more concrete results.

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PROMPT, COMPARE, REFLECT, REPEAT: LEARNING RESPONSIBLE AI USE FOR PRODUCT DESIGN

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ABSTRACT

Artificial intelligence is rapidly reshaping product design practice and education, creating opportunities and risks for how future designers are trained. While AI tools can support ideation, documentation and decision-making, there is growing concern that uncritical use may weaken foundational design skills and reflective practice. This paper presents the development and initial evaluation of a participatory, workshop-based educational intervention centred on an AI-powered product design assistant tool. The approach aims to teach responsible and effective AI use by making students active participants in prompt construction, output evaluation and iterative refinement. The tool generates structured early-stage design documentation from user prompts, encouraging consideration of components, methodology, constraints and regulations. An exploratory workshop was conducted with Engineering Design students, combining instruction on prompt crafting with guided experimentation and reflection activities. Feedback indicates that participants found the tool useful for early-stage concept development and for understanding how input structure affects AI output. Features that enabled parameter and prompt manipulation were particularly valued, supporting critical comparison and reflective learning. Students highlighted limitations in technical depth, accuracy and verifiability, reinforcing the need for validation and careful task alignment. The findings suggest that participatory AI-building and prompt-design workshops can support AI literacy, critical judgement and responsible adoption in design education, positioning AI as a scaffold for learning rather than a substitute for design thinking.

Keywords: Studio pedagogy, artificial intelligence, formative assessment, engineering design

1 INTRODUCTION

The introduction of artificial intelligence into product design education represents a significant shift in how designers are trained for modern industry demands with collaborative AI design tools now offering notable potential to enhance designers' performances, efficiency and creativity [1]. AI tools may soon become essential components of the design process, from initial concept generation to final product optimisation, making it crucial for educational institutions to understand these technologies and appropriately incorporate them into the curricula. Design educators today face the challenge of not only teaching traditional design principles but also ensuring students understand how to effectively leverage AI capabilities while maintaining creative control and critical thinking skills. The goal of this project was to create a learning environment where students can explore AI's potential to enhance their design capabilities while also understanding its limitations and appropriate applications throughout different phases of the design process. This educational transformation requires careful consideration of which AI tools to introduce, when to introduce them in the design workflow, and how to balance AI assistance with fundamental design skills that remain essential for successful product development.

A dominant theme across educational literature is the capability of AI to support creative ideation and divergent thinking in product design. The paper ‘*How can AI support the creation of novel ideas in product design*’ [2] investigates the use of AI within structured ideation methods and reports that AI systems can increase the breadth and novelty of early-stage concepts when used as a stimulus or co-creator. Rather than replacing student creativity, AI is described as functioning as a generative partner that can propose unexpected combinations, analogies, and directions, thereby enriching ideation sessions. This aligns with studio-based pedagogical models where external prompts and provocations are already valued as creativity triggers.

As well as text-based AI systems, Dhimi et al. [3] explores the educational use of text-to-image systems and related generative tools for rapid visualisation. Comparative studies of AI image generation tools in

design learning contexts indicate that such systems enable students to externalise concepts quickly, explore stylistic variation, and iterate visual directions at a speed not previously possible. This capability is particularly relevant in early concept phases, where students often struggle to translate abstract ideas into visual form. This research has revealed that AI visualisation tools can lower the threshold for sketching and rendering, though concerns are raised that overreliance may weaken the development of foundational visual communication skills if not carefully scaffolded.

Beyond ideation, AI has been demonstrated to have meaningful contribution to later stages of the product design process, including detailed design and technical development. Marquez and Juan [4] reports that AI tools can assist with decisions concerning materials, finishes, configuration options, and parametric variations. Students using AI-supported workflows were able to explore a larger solution space within limited project timelines. Similarly, Lambert et al. [5] discusses an AI-supported pipeline that links concept generation to more production-oriented outputs, suggesting that AI systems can help bridge gaps between conceptual and technical stages of student projects. These studies position AI as a continuity tool across stages, supporting not only creativity but also synthesis and refinement.

Reynolds and Batley's [6] work on generative AI in final-year product design projects highlights that students can use AI tools to generate, refine and iterate design concepts. However, the "depth and completeness" did not align with the student's needs, and the ability to manipulate the output was limited.

Another strand of research examines AI prompt systems and conversational models as learning supports in engineering and product design tasks. The paper '*exploring the usability of AI prompts for mechanical engineering design development*' [7] evaluates how structured prompting strategies affect the usefulness of AI outputs in technical design contexts. Findings suggest that prompt literacy becomes an important meta-skill: students who learn to frame constraints, functions, and evaluation criteria clearly are more likely to obtain relevant and technically meaningful AI assistance. This introduces a new pedagogical dimension in which educators must teach design methods and effective AI interaction strategies.

The paper '*Impacts of generative ai on engineering and product design students' performance*' [8] reports mixed outcomes. Students perceive gains in efficiency, research support, and concept expansion, but both students and educators express concern about superficial learning and the risk of bypassing critical cognitive steps in the design process. AI can compress time spent on exploration and drafting, yet this same compression may reduce opportunities for reflective practice if assignments are not redesigned accordingly. The literature therefore stresses that performance gains are highly dependent on task framing and assessment design. Zhang et al. [9] highlights cautious optimism among lecturers, who recognise AI's potential to enhance workflow and expand creative exploration, but also worry about academic integrity, authorship ambiguity, and erosion of core skills such as sketching, model-making, and independent problem framing. The capability of AI to produce plausible design outputs raises questions about how originality and competence should be evaluated in studio assessment. This makes the argument for redesigned assessment formats that prioritise process evidence, iteration logs, and critical reflection over final artefacts alone.

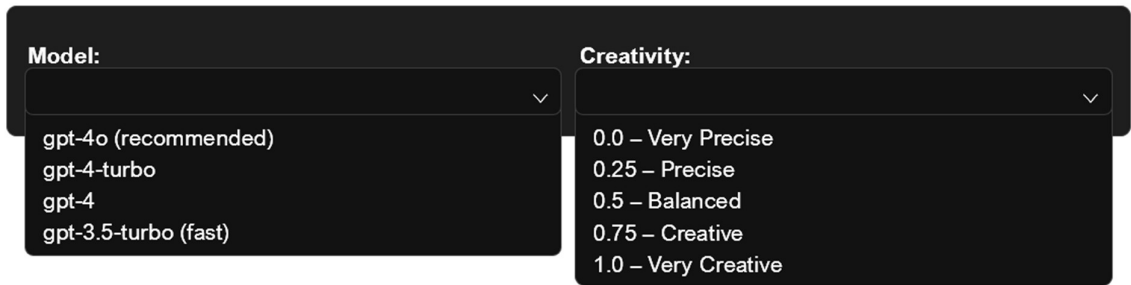
Across the literature, common challenges include the need for educator professional development to harness AI effectively, addressing ethical and accountability issues, and balancing AI support with design reasoning and critical thinking. Meta-analyses emphasise the need for more robust research methodologies and conceptual frameworks that capture AI's educational impacts, rather than reporting practice examples or isolated case studies [1]. Additionally, the broader education literature indicates that AI tools must be designed with user-centred considerations to ensure they support learner autonomy, engagement, and equitable access, particularly in resource-limited environments [10].

This paper details the creation of, and initial evaluation of a product design assistant tool and educational experience. The purpose of the tool is to allow students to understand the importance of the input they provide to AI tools and how this input changes the output. The educational experience teaches students about how to structure the input and how to analyse the output, but also, responsible use of AI for appropriate tasks.

2 METHODOLOGIES

As part of an EPSRC TERC funded project Digital Design Network Plus (D2N+), in response to Research Challenge One, 'Re-imagining the drone design process', an AI tool to support the early stages of the design process was developed. This tool enabled for the exploration of how AI could impact early

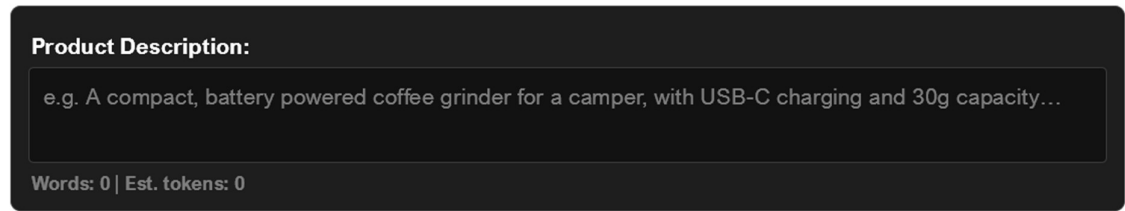
stages design and the broader digital design methodology. The tool was intended as an industry demonstrator; however, benefits were found in educating students on appropriate use of AI. The product design assistant tool functions as a lightweight AI-powered drafting tool that helps users generate structured product design documentation from prompts. After entering an OpenAI API key, the user can select an AI model and adjust a creativity setting to control how conservative (0.0) or inventive (1.0) the generated text will be (*Figure 1*). The user inputs data as a product description (*Figure 2*) and an instructional prompt (*Figure 3*). The instructional prompt works with the product description to return the desired output. For example, the regulations instruction prompt is “You are an expert in product regulations, standards, and compliance. Given a product description, highlight 5–7 key regulations, specifications, and standards that may apply (e.g., safety standards, environmental regulations, industry specifications). Be specific to relevant jurisdictions (e.g., UK, EU, US) and include any testing or certification requirements.” The interface is organised into practical design-document sections, product description, components, methodology, considerations, and regulations. When a user provides basic input about a product idea, the system generates written material for each of these sections, effectively turning a rough concept into more formal, structured design notes.



The image shows a dark-themed user interface with two dropdown menus. The first menu, labeled 'Model:', is open and shows four options: 'gpt-4o (recommended)', 'gpt-4-turbo', 'gpt-4', and 'gpt-3.5-turbo (fast)'. The second menu, labeled 'Creativity:', is also open and shows five options: '0.0 – Very Precise', '0.25 – Precise', '0.5 – Balanced', '0.75 – Creative', and '1.0 – Very Creative'. Both menus have a downward arrow icon at the top right of the list.

Figure 1. Model and level of creativity selection

The core functionality is therefore not detailed modelling or drawing, but guided text generation for design thinking and documentation. It helps translate early-stage ideas into clearer written form, encourages users to think across multiple dimensions of a product, and introduces categories that beginners might otherwise overlook. By prompting for components, methods, constraints, and regulatory factors, it nudges users toward a more complete and professional style of product planning which will have an influence on later stage design. This is particularly beneficial for novice designers and students because one of their biggest challenges is knowing what to consider and how to structure their thinking. Beginners often focus narrowly on what a product does, while missing materials, processes, safety, compliance, or lifecycle issues. This tool acts as a scaffold, demonstrating typical headings and considerations found in real design documentation. It can also reduce the intimidation of starting from a blank page by producing first drafts that students can refine, critique, and improve.



The image shows a dark-themed user interface with a text input field. The label 'Product Description:' is at the top left. The input field contains the text 'e.g. A compact, battery powered coffee grinder for a camper, with USB-C charging and 30g capacity...'. Below the input field, there is a status bar that reads 'Words: 0 | Est. tokens: 0'.

Figure 2. Product description input

In an educational setting, the tool can support learning by example. Students can compare their own ideas with the generated output and expand their reasoning. They can also compare the differences in output depending on their input, enabling better prompt crafting in the future. It also helps them learn the language of product design, how to describe function, justify choices, outline methods, and acknowledge constraints which is often as important as designing itself. Used thoughtfully, AI becomes less a shortcut and more a guided framework that accelerates understanding and builds confidence.

The product design assistant tool is also timely in the context of how the design and engineering industries are evolving. AI-assisted tools are becoming increasingly common in professional workflows, from concept development and documentation through to simulation and optimisation.

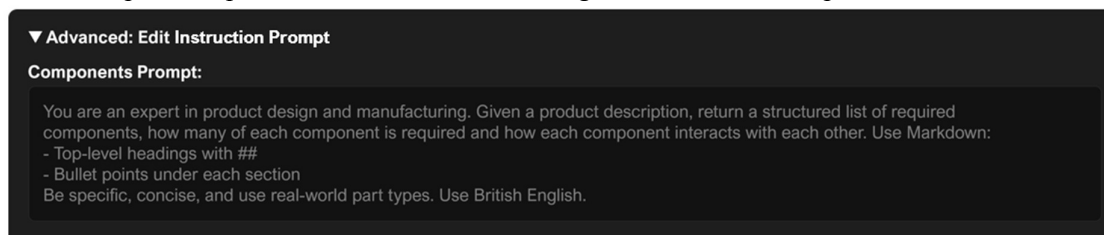


Figure 3. Instruction prompt default input for components

Many companies now expect graduates and junior designers to be comfortable working alongside AI systems, using them to accelerate research, generate drafts, explore alternatives, and structure technical information. A tool like this introduces students to that style of working in a focused, low-barrier way. By practising with AI-supported design documentation early on, learners develop prompt-writing, critical review, and refinement skills that are rapidly becoming part of standard professional competence.

2.1 Developing the educational experience

An initial exploratory workshop was created with the aim of developing an educational intervention on prompt crafting and the usefulness of AI to support product design. The tool was introduced to students for the first time during the workshop. The workshop was attended by students of the department of Design, Manufacturing and Engineering Management at the University of Strathclyde. The workshop included a presentation explaining the development of the tool and tips for crafting prompts for desired outputs. A practical activity included a worksheet that guided participants to design a prompt and reflect and develop their prompts and record differences in output.

Five students participated in the post workshop questionnaire to share their reflections on the usefulness of the tool. The survey comprised a combination of closed Likert-style questions and open-ended free-text questions. One student described themselves as a beginner on the use of AI and four with intermediate expertise. No students reported advanced or expert knowledge. Three male and two females participated. The mean age was 25 ranging from 20 to 32. Survey responses are reported as percentages due to the small sample size, and qualitative thematic interpretation for open-ended responses.

3 RESULTS

Participants reported that the ability to change models (80% useful to 20% neutral), ability to change creativity level (60% useful to 40% neutral) and edit default instruction prompts (80% useful to 20% neutral) were particularly valuable in enabling experimentation with system inputs and comparison of outputs. Students also found that the output categories of Components (100% useful) and Methodology (80% useful to 20% neutral) to be very useful, with Considerations (100% useful) and Regulations (60% useful, 20% neutral and 20% not useful) to be less useful.

The survey revealed a 50/50 split on if students would recommend the tools to others, and a 100% perspective that the output of the tool must be validated.

Participant 1 found that changing the creativity level from balanced (0.5) to creative (1.0) supported the types of creative exploration that would typically support demonstration of diverse ideation within a folio but perhaps was not realistic for real world production.

Participant 2 changed small details to influence considerations of design for manufacture and design for sustainability. This resulted in the tool returning rather complex language that was difficult to understand. However, this was changed by updating the instruction prompt to ask for a simpler response. Participant 3 used an existing project example and added more data to see how the output changed. As the input become more detailed, the output became more appropriate to the challenge.

Participant 4 increased the specificity of materials requirements for a product. However, found that the tool was not useful for this task. Their perception of the usefulness of the output did not change.

Participant 5 increased the level of detail on desired ergonomics for a product which changed the structure of the output to be more descriptive.

Each of the participants shared envisioned uses of the tool being developing an understanding for manufacturing or safety constraints, generating concepts for consideration and ensuring that ideas created align with technical requirements. Suggestions to improve the usefulness of the tool were to support presentation, layout and showcase of outputs, suggesting cost of the product, output in a report format and to evaluating designs against a known criterion.

Students were aware of challenges in the use of the tool being that outputs may not be accurate, lack of referencing to source material, difficulty verifying results, struggling to craft effective prompts and visualising the product using text-to-image or text-to-3DCAD.

4 DISCUSSIONS

From a pedagogical perspective, the structured output categories functioned as cognitive scaffolds, guiding novice designers to consider components, methods, constraints, and regulations that they might otherwise overlook. This aligns with studio pedagogy traditions in which learning is supported through structured prompts, critique, and iteration. Furthermore, the workshop design encouraged reflective practice, as students compared outputs, questioned validity, and refined prompts, positioning AI as a reflective interface rather than an authoritative source.

Participants valued the ability to adjust models, creativity levels, and instructional prompts. These features encouraged experimentation and comparison, shifting students from passive consumption to active evaluation. While generative AI is often criticised for promoting superficial engagement or automation bias [8, 9], the workshop structure appeared to counter this risk. Students iteratively refined prompts, compared responses, and unanimously emphasised the need to validate outputs. AI was therefore positioned as a fallible collaborator requiring judgement, rather than an authoritative source.

Prompt editing emerged as a significant learning mechanism. Small changes in specificity and constraint framing meaningfully altered outputs, reinforcing the importance of prompt literacy as an emerging design meta-skill, aligning with Vuletic and Ashcroft [7]. The act of crafting prompts required students to externalise assumptions about materials, ergonomics, sustainability, and regulation, mirroring early-stage problem framing in professional practice. The structured output categories further supported novice designers in broadening their consideration beyond function alone.

However, important boundary conditions were identified. One participant found limited usefulness when seeking detailed material specificity, highlighting the limitations of generative models for technically precise or database-dependent tasks. The tool appears most effective in early-stage conceptualisation and documentation drafting, with decreasing suitability for highly technical specification. This reinforces the need for task–tool alignment in AI-supported education.

Although individual features were rated positively, only half of participants would recommend the tool, suggesting ambivalence regarding reliability or depth. Categories such as Considerations and Regulations were perceived as less useful than Components and Methodology, possibly reflecting student preference for tangible outputs over compliance-focused content. This tension may indicate the need to more explicitly integrate systemic and regulatory thinking within assessment structures.

5 CONCLUSIONS

This paper introduced and piloted a participatory, workshop-based intervention centred on an AI-powered product design assistant to teach responsible and effective AI use in product design education. By making students active in prompt construction, parameter manipulation, and output critique, the intervention reframed AI as a scaffold for design thinking rather than a substitute for it. The tool's structured sections helped novices move from vague concepts to more complete early-stage design documentation, while the workshop activities foregrounded reflective practice and prompt literacy.

Initial results from the exploratory workshop suggest educational value alongside important caveats. Participants particularly valued the ability to edit system prompts and compare outputs, reporting usefulness in ideation and in understanding how input structure shapes AI responses. At the same time, they flagged limitations in technical depth, accuracy, and verifiability; perceived lower usefulness of Considerations and Regulations for immediate project needs; and a unanimous need to validate AI outputs. One participant's focus on detailed materials requirements highlighted the tool's current boundary conditions, pointing to the need for integrated domain knowledge.

These findings underscore the significance of participatory AI-building for cultivating AI literacy, critical judgement, and ethical awareness in design curricula. When students iteratively iterate prompts, challenge outputs, and document decisions, they practice the same forms of reasoning that underpin

professional competence linking creativity to constraints, justification, and compliance. For educators, the work motivates assessment designs that value process evidence alongside artefacts, aligning with responsible adoption of AI in studio practice.

Overall, the findings suggest that when AI tools are embedded within participatory and reflective studio activities, they can support AI literacy, critical judgement, and structured thinking. Future research should include larger cohorts, comparative conditions, and objective measures of learning outcomes. Taken together, the contribution is twofold: a practical teaching tool and a replicable pedagogical model in an AI-enabled future.

ACKNOWLEDGEMENTS

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COMPONENT SWAP ON VIRTUAL CATAPULTS FOR PROBLEM-SOLVING IN ENGINEERING EDUCATION

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ABSTRACT

This paper presents a web-based virtual catapult simulation to train the ‘component swap’ method in a quality management course, teaching Engineering students, especially those in engineering design and production engineering. In this method, components of two assemblies are systematically exchanged to analyse their effect on quality characteristics. While widely used in industrial problem solving in ‘real’ production setups, existing training with realistic applications, e.g. physical catapults, paper aeroplanes are resource intensive, sensitive to operator effects and constrained by logistical and accessibility barriers – often limited in teacher-centric education or training.

The virtual catapult replicates the original scenario with interchangeable components, automated data generation and configurable difficulty levels. A browser-based interface allows students to run experiments, visualise data and draw evidence-based conclusions, while gamification elements reward efficient identification of causal components. The design supports inclusive use by enabling participation independent of location and allowing adaptation to different learning needs.

A first comparative study with mechanical engineering students indicates that the virtual training substantially reduces time and operator-induced variation, while maintaining self-reported learning outcomes and motivation. The primary contribution of this work is a transparent, openly available methodological tool for teaching systematic component swap, complemented by preliminary evidence of its usability and perceived educational value in engineering education.

Keywords: Virtual simulation, web-based training, gamification, inclusive learning, accessibility, data simulation, component swap, problem-solving

1 INTRODUCTION

Effective problem-solving relies on the systematic use of appropriate methodologies. Training in these methods is essential for both design and production engineers [1]. The Ishikawa and 5-Whys methods are commonly used in root cause analysis, but practical approaches also play an important role [2]. One of the most effective methods for isolating a failure in assemblies is to systematically swap components between a functioning and a non-functioning product [3][4]. This approach, also known as Shainin’s ‘component search’ [5], is firmly established in industrial problem-solving processes and is therefore an important element of many problem-solving training programmes [6][7][8]. This is particularly relevant for design and development engineers, who must systematically analyse the impact of design choices on product quality characteristics. The component swap method is taught in quality management classes for mechanical engineering students at the DHBW Cooperative State University Ravensburg.

State-of-the-art training in quality management methods is characterised by practical case studies, business simulations and integration into holistic frameworks such as Six Sigma or 8D [9]. In education, catapults (see Figure 1) are often used as training aids, offering a process that enhances understanding [10]. Catapults serve as experimental objects that generate data with natural variation. They are easy to understand, have an intuitive functionality and can be easily adjusted to new conditions. This allows learners to analyse statistical relationships and investigate the influence of various components on relevant quality characteristics.

Such trainings sessions are effective because they combine technical and soft-skill development, immerse learners in realistic scenarios and foster interpersonal competencies needed for process improvement. On the other hand, catapult-based training faces several limitations, including high

resource requirements and limited scalability. Additional drawbacks include unwanted process and hardware variation, potential safety risks and barriers to participation due to logistics and accessibility. These factors reduce overall learning effectiveness and efficiency. In this context, training efficiency is understood as the relationship between the achieved learning objectives and the time and resources required to deliver the training.



Figure 1. Catapult in problem-solving trainings

This paper addresses the following methodological research question: How can the training of a problem-solving process using the component swap method be improved by using a virtual simulation? To answer this question, a virtual catapult tool was developed and a preliminary evaluation comparing the virtual and physical setups was conducted. In doing so, the virtual catapult is used to explore how simulation can improve engineering education.

2 LITERATURE REVIEW

Virtual reality simulations and laboratories using digital twins are increasingly utilised in engineering education to provide students with hands-on experience in a safe, scalable environment [11][12]. Bai-Lin Li et al. [13] and Tisza et al. [14] showed that interactive virtual substation simulation training systems can significantly improve students' practical competence and engagement in engineering programmes. In practice, some virtual simulations related to quality training can be found, such as a moulding machine [15], a catapult [16] and a trebuchet [17]. These simulations focus on changing settings to optimise outcomes but not on identifying faulty components.

However, there is no virtual assembly tool for training the component swap method available. A review of the current scientific literature also reveals that implementations of component-swap training using virtual assemblies are not described or systematically evaluated.

This gap highlights an opportunity to contribute new insights into the design, application and instructional effectiveness of virtual catapult simulations for quality management education. Our work addresses this gap by introducing a parametric, web-based virtual catapult for evidence-based training in problem solving using component swap. The subsequent evaluation involves a comparison between training using a physical catapult and that using a virtual.

3 TRAINING USING PHYSICAL CATAPULTS

The current hands-on training for mechanical engineering students uses a scenario in which a customer has rejected two of three catapults due to projectile range being out of specification. The student group starts a structured problem-solving process following the 8D method. To verify the customer complaint, data is generated by firing the catapults and measuring flight distance. Unseen, the catapults have been manipulated e.g. weight of the projectile (ball) or length of the elastic band before usage. The results confirm the customer complaint (see Figure 2).

The problem-solving continues with applying a cause-effect diagram that lists potential causes such as wrong setup, ball weight or elastic band properties. These causes now need to be confirmed or rejected using problem-solving methods such as the component swap. Important prerequisites for component swap — such as the availability of functional and non-functional assemblies, ease of disassembly, and simple retesting are performed. Following the component swap approach [3] functional and non-functional assemblies (see example in Figure 2) are selected, disassembled and reassembled. If no change is observed, this indicates that the cause lies in the components rather than in the assembly

process. Next, components are swapped pairwise (in Figure 2: catapult arm, projectile (ball) and elastic band) and assemblies are tested again. The graphical analysis confirms the causal component (in figure 2 elastic band). Further steps like the ‘5-Why’ method or ‘regression analysis’ are conducted to identify the underlying root cause. Finally, corrective actions are implemented and all catapults are successfully tested within defined specifications.

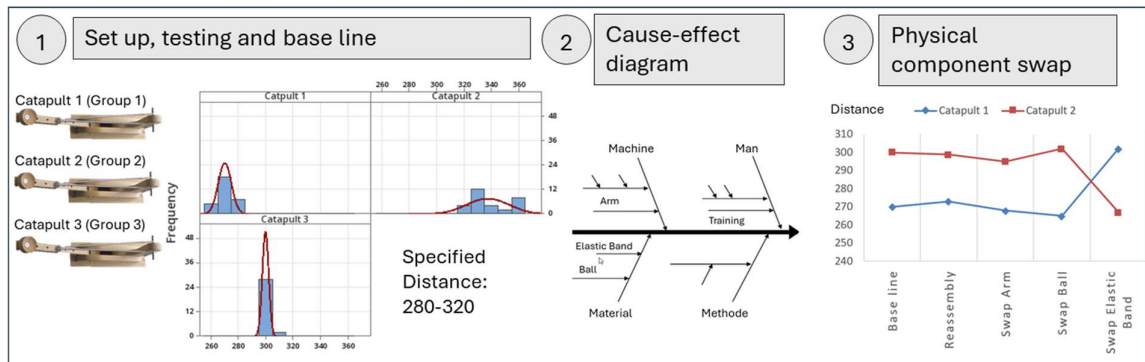


Figure 2. training with real catapults

While students appreciate the hands-on nature of the training, this approach exhibits several disadvantages:

- The generation of data for statistical analysis is very time-consuming, especially generating data after every component swap making the training less efficient.
- Training is restricted between nine to 15 students in physical presence, making it difficult to scale. Remote access or online training is not possible. Gamification is not well developed, as all students work in one shared problem-solving process, even when splitting up in teams.
- Flight distance is strongly affected by the students operating the catapult (around 20% compared to catapult-to-catapult variation). Together with additional factors such as wear of catapult components, training effectiveness is reduced.
- Difficulty of the problem – in terms of the number of manipulated components - is not adaptable to individual learning needs and may not fully address the needs of neurodivergent students.

These disadvantages highlight the need for simulation-based solutions that improve efficiency, scalability and accessibility while providing a safe, motivating environment for training the ‘component swap’ in engineering education, also under demanding course conditions, e.g. number of students, educational backgrounds, team compositions and dynamics.

4 VIRTUAL CATAPULTS: TRAINING CONCEPT AND BACKGROUND

The virtualisation must preserve the basic concept of the existing problem-solving scenario, using catapults as data generators. At the same time, it should add features such as gamification and multiple difficulty levels. The developed solution is a platform-independent simulation that realistically represents the physical behaviour of a catapult and virtually replaces the previous experimental setup. First, the new training concept is outlined, followed by technical details of the simulation.

4.1 Training concept and process

In the virtual catapult training, the scenario remains unchanged, but instead of firing physical catapults, students use the web interface *virtualcatapult-problemsolving.twie.website* to generate data. After selecting the difficulty of the problem, students explore the baseline by clicking “new measurement”, which generates a baseline dataset. Using a cause-effect diagram, potential root causes are developed and prioritised, similar to the current training. Suspicious components can then be swapped pairwise via drag-and-drop. With minimal additional time and effort, a new dataset is generated and can be analysed in the next step, confirming or rejecting the causal component (see Figure 3). Once the root cause is confirmed, further steps can be taken to solve the problem.

The scenario can be repeated as often as desired to increase learning success. In addition, the difficulty level can be gradually increased. To enhance motivation and competition, the number of components

swapped and the resulting number of attempts are recorded and used as a gamification element.

4.2 Technical background and data generation

A central challenge in the technical implementation of the data simulation is not only to provide deterministic values, but also to reflect the variation of real processes. This is essential for quality management education, as students need to learn to distinguish between systematic and random variation.

Two main approaches for generating data were considered: engine-based and formula-based. While physical systems are well-suited for modelling collisions and complex interactions, they introduce unnecessary overhead and complexity for this specific use case. Instead, the focus was placed on the precise and reproducible calculation of projectile trajectories using defined input parameters. Direct mathematical modelling enables efficient control and high transparency of the simulation process, ensuring that results are both accurate and easily adjustable for training purposes.

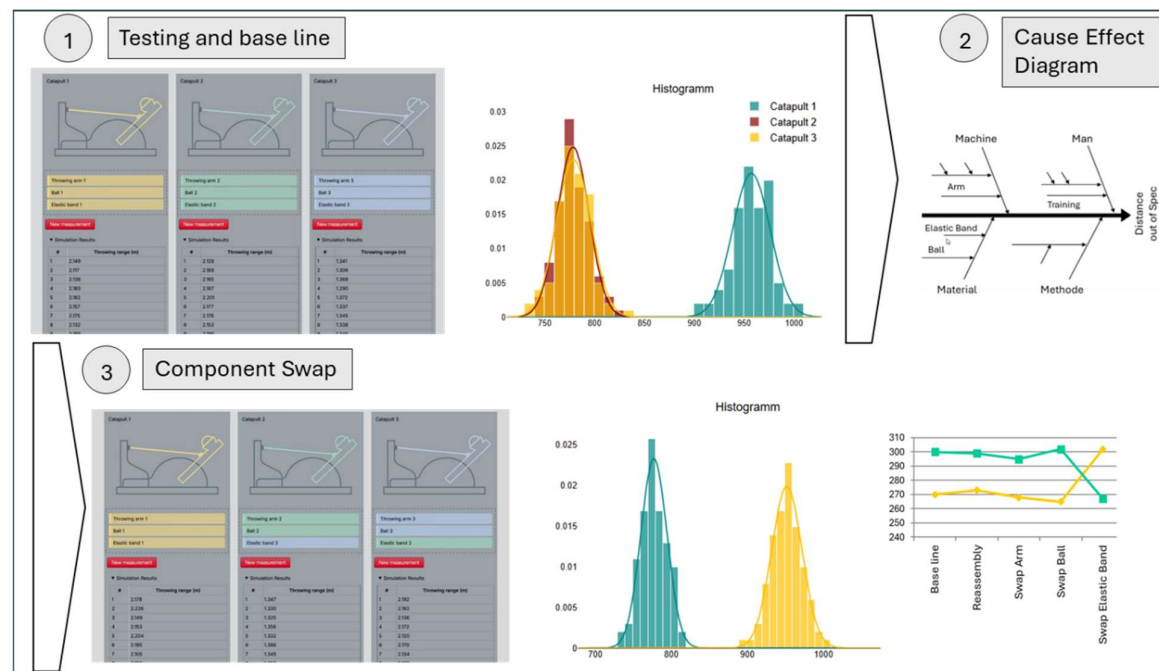


Figure 3. training with virtual catapults at a low difficulty level

Building on this formula-based modelling, the trajectory of the projectile is calculated using standard equations of projectile motion. The initial velocity is derived from the conservation of energy: the potential energy stored in the stretched rubber band is transformed into the kinetic rotational energy of the throwing arm. This initial velocity is then inserted into the equation for the x-coordinate, allowing the precise determination of the projectile's landing position and distance. Due to the fact that repeated application of the formula yields exactly the same distance, which does not reflect real-world conditions, variation is added to the simulation results. To achieve a realistic, natural variation, the 'Box-Muller' transformation was implemented. This method transforms two uniformly distributed random variables into normally distributed variables [18].

This enables the simulation of realistic measurement noise around the calculated ideal values, which was successfully validated by histogram analyses. The difficulty level is implemented by changing the number of causal components and the amount of variation in the dataset.

For intuitive usability, the web application utilises responsive design principles. A CSS grid layout ensures usability across devices, including desktops, tablets and smartphones. The user interface is organised into configuration areas for selecting difficulty levels and output areas where the generated measurement series are visualised in tabular form. This structure provides the technical foundation for digitally replicating real training scenarios in quality management. The application is implemented using standard web technologies like HTML, CSS and JavaScript. All code is provided as open source on the referenced homepage, supporting transparency and further development.

5 EVALUATIONS

To evaluate the virtual catapult simulation two training sessions were conducted, one with physical catapults (n=12 students) and one with virtual catapults (n=12 students), allowing a direct comparison. All students were second-year mechanical engineering students specialising in design and were randomly assigned to the two sessions. It was the first time they were challenged with the catapult problem. During both sessions, the same problem was stated and the problem-solving training followed 8D. Catapult operating time was recorded and after the session the students were asked in a survey about how they experienced the training. The results of the survey show that the perceived learning outcome was at a comparable level for both training formats (see Figure 4).

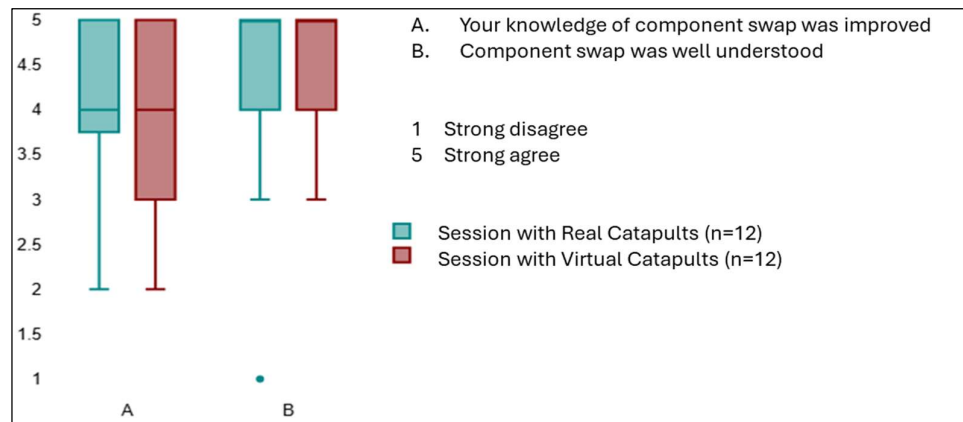


Figure 4. Boxplot of survey results from two training sessions

The evaluation of the virtual catapult demonstrated how the training of the component swap method is improved:

- Efficiency increased: Since no catapults were operated during the virtual simulation more than one hour of the five hours total training time was saved (20%).
- Training is scalable to larger groups, enables remote participation and improves accessibility. Gamification is supported, as students report their number of attempts.
- Flight distance is no longer affected by physical operation, making the effects of the components easier to understand.
- The difficulty of the problem can now be adjusted in each run, and the scenario can thus be adapted to individual learning needs.

Due to the small sample size, these findings are considered preliminary. Nevertheless, they provide valuable insights for further development and larger-scale studies.

6 CONCLUSION AND OUTLOOK

This paper introduced a web-based virtual catapult simulation developed to train the ‘component swap’ method as part of structured problem-solving in quality management. Building on the limitations of hands-on training sessions with physical catapults, the virtual approach provides an easily accessible environment that retains the core didactic strengths of the physical scenario while improving efficiency, scalability and flexibility. The simulation is accessible via *virtualcatapult-problemsolving.twie.website*, and the code is provided as open source, supporting transparency, reuse and further development by the community. An initial pilot evaluation with students showed reduced training time, removal of operator-induced variation and high levels of motivation through gamification. However, the shorter duration of the simulation meets the learning outcomes and competencies as in the cohort with physical training. Future work will focus on a more systematic evaluation with larger and more diverse student groups to quantitatively assess learning outcomes, transfer effects and long-term retention compared to traditional training. As a methodological extension, additional quality tools should be integrated. For example, using the simulation to conduct a prior Design FMEA or to develop Poka-Yoke solutions could provide substantial added value, especially for design students, and would represent an interesting extension of the concept. The technical development of the simulation should be expanded to include advanced features such as adjustable experiment settings for comprehensive training in quality management

methods, including Design of Experiments (DOE). Further enhancements could encompass additional error sources such as incorrect assembly, incorrect set-up and environmental influences. Finally, integration into blended learning concepts and remote lab settings will be explored to further strengthen the role of virtual assemblies and the ‘component swap’ method across different application domains in evidence-based engineering education.

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DESIGNING TO THRIVE – EXAMINING PERCEPTIONS AND EMBEDDING PRACTICE TO SUPPORT HUMAN FLOURISHING IN PRODUCT DESIGN STUDENTS AND EDUCATORS

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ABSTRACT

Human Flourishing - as defined by American psychologist, Martin Seligman – combines occupational and physical domains of human functioning such as meaning, purpose, personal growth and perceptions of happiness, joy, altruism and creativity [1]. ‘Proactive’ aspects of creating wellbeing and human flourishing are not often embedded directly into courses, rather being picked up ‘reactively’ in universities through Student Services, which although excellent, are disconnected from daily teaching. Creative burnout is unfortunately very common in the design profession, therefore understanding and taking ownership of personal flourishing is a critical skill for students and teaching team alike. However, do we all know what flourishing looks like for ourselves as educators, or how it manifests in our students? And do students understand the same about us as educators?

This paper examines two facets of human flourishing as it relates to engineering and product design education. Firstly, the results of a student-focused survey relating to subjective flourishing and the disconnect in its manifestation between student and educator. Secondly, how human flourishing and especially kindness - a key facet to support flourishing - can be embedded as an overarching framework within a module to create a greater depth of understanding of a design problem, and ultimately, of student (and client) flourishing needs. How can we teach, and design to thrive as individuals and a collective, not just survive?

Keywords: Human flourishing, positive psychology, pedagogy, product design, engineering

1 INTRODUCTION

The concept of wellbeing in scientific literature has changed considerably in the last thirty years – prior to the late 1990’s, there was a distinct focus on negative elements such as distress, mental illness, hardship and trauma [2]. Wellbeing is now understood as a multidimensional concept involving fitness in intellectual, social, psychological, financial, spiritual, occupational and physical domains of human functioning flourishing, such as meaning, purpose, personal growth and perceptions of happiness, joy, altruism and creativity [1, 3]

The development of Positive Psychology builds on the fields of earlier humanistic psychology – such as Maslow’s Hierarchy of Needs, which dictates that a number of fundamental elements (physiological needs, safety, social and self-esteem) need to be established before someone can reach the top of the pyramid – that of growth and self-actualisation [4]. It has been argued that ‘self-actualisation’- the top of the Maslow Pyramid, could be very much the same as everyday creativity – or at the very least that one can help facilitate the other [5]. Rogers (1952) also commented that creativity is about the tendency to actualise oneself [6]. This in theory could be highly beneficial to those teaching, and on, creative courses such as product design and engineering, but all steps before that of self-actualisation would need to be established to provide a solid foundation for creativity.

Positive Psychology also considers the wider application of wellbeing to organisations and communities [7]. Three pillars of Positive Psychology have been suggested; Positive Subjective Experiences (happiness, fulfilment, joy, satisfaction, flow, optimism), Positive individual traits (character, courage, talents, interpersonal competence) and Positive Institutions (families, schools, organisations and societies) [8]. This makes wellbeing an essential component to study and develop in educational settings, as the wellbeing of an individual will affect the wider community and vice versa. There are many

elements across each of the Pillars that can be developed and supported in higher education to enable the individual – both student and educator alike - to ‘flourish’ and increase their personal, and professional wellbeing – including fulfilment, optimism and interpersonal interactions. Ensuring that educators / lecturers *and* students are not only surviving, but flourishing in their roles ensures that both the individual and the entire organisational environment can perform optimally [9, 10]

Over the last decade, the university sector has experienced significant and wide-ranging change [11]. In a recent report from Morrish (2019) involving 59 institutions in the UK from 2009 – 2016, rising stress levels, occupational health referrals and counselling visits were found, along with declining levels of mental health and wellbeing among university lecturers [12].

Student wellbeing is also of high concern, with students reporting increasing levels of psychological distress and demands, likely exacerbated as a result of the CV-19 pandemic [13, 14]. Whilst student wellbeing is in general decline, reports have stated how the perceived difficulty and stress on an engineering-based degree can cause significant declines in mental health [16].

Academic staff also refer to the practical and emotional demands on their workload and wellbeing, created by the responsibility for supporting students - especially as student wellbeing in educational frameworks has also been suggested by Kahu, Nelson and Picton to be ‘at the heart’ of an interface between their emotional, cognitive and behavioural connections to their study [15, 17]. But the pressure of balancing the needs of students with other demands and expectations of a lecturer’s role is also present, and concerning it is reported that often pastoral support given to students is not valued or recognised institutionally [15]. Staff reported that these challenges were compounded, as student wellbeing was expected to be prioritised over and above lecturer wellbeing - despite lecturer wellbeing being associated with being better mentally, emotionally and practically equipped to respond to student needs [15].

This bi-directional relationship between student and lecturer wellbeing is critical to not only understand but to positively foster to create a flourishing university environment. It was with this in mind that the following interventions were conducted at the University of Sussex in the academic years of 2023-2024, 2024-2025 and 2025-2026.

2 FLOURISHING – EXAMINING PERCEPTION DIFFERENCES

Wellbeing, as described above, has a multitude of facets which combine to give each individual a subjective overview and understanding of their current position. As some of the facets are situational or out of the control of the individual, there is also the issue that subjective wellbeing can change very suddenly, for example, with a looming deadline, an illness, or an argument with another. However, the concept of ‘flourishing’ as described by Seligman helps an individual to establish a general understanding of their average position in sectors of ‘PERMA’ - Positive Emotions, Engagement, Relationships, Meaning and Accomplishments [10,18]. The online PERMA digital profiler can help individuals to ‘score’ their subjective wellbeing accurately – high scores across the 5 pillars show ‘flourishing’, middle scores show ‘surviving’, whilst low scores demonstrate ‘languishing’ [19]. Even without using the profiler though, we can reflect on the pillars and determine where we likely sit on the languishing/surviving/flourishing scale, which was demonstrated in the open ‘flourishing’ study with students and lecturers below. Subjective wellbeing is of course, personal, but with only an outline of the PERMA framework, could students clearly articulate what ‘flourishing’ looked like for them?

2.1 The student surveys

An anonymous survey was sent out to all undergraduate students from the School of Engineering and Informatics by two student volunteers in Spring 2024 with the following prompt: “Humans can flourish in many different ways; emotionally, mentally, spiritually, physically and socially, with each area being both separate and completely interlinked. We would like to explore what flourishing means to you, as a student here at Sussex. **In which ways would you define and recognise flourishing in yourselves?**” The survey was completed by 47 students. Given the nature of the open question, the responses varied in detail with some students expressing multiple ways of flourishing, which was a key part of the study – to allow respondents to define the term for themselves. Perception of definition was being also being explored. All responses were considered, totalling 71 entries and key words/phrases were interpreted from the answers.

It was perhaps not surprising that the most common response by students to the open question was ‘good grades’, or variants of this phrase (10 out of 42 respondents), followed by ‘achievement / fulfilment’ or

variants of this phrase (8 out of 42 respondents) - with most respondents indicating achievement of personal goals being a key measure of their own flourishing. But since these are personal, and not always communicated to the lecturers, there could be difference in its interpretation and integration into the teaching and learning environment. Looking at the other top answers across respondents, some are intrinsically embedded in the teaching and learning set-up, such as 'learning new things' (5 respondents) and providing 'guidance/feedback' (4 respondents). Others might not always be integrated into teaching and learning activities, such as building 'confidence' (3 respondents) and being 'creative' (3 respondents). One may argue that other similar responses could have been grouped together thus demonstrating a higher importance via a higher count, e.g. 'study-life balance' and 'mental-physical wellbeing'. If merged, there would indeed be an indication of higher importance within the student community.

After gathering the information on themselves, we also wanted to know if the students could identify 'flourishing' in others – so a second question was asked: **“In which ways would you define and recognise flourishing in your lecturers?”**

The highest responses include key words/phrases such as 'passion', 'understanding', and 'engaging' (12 combined responses) relating mostly to the delivery of lecture content. The respondents also mentioned multiple inter-personal skills such as 'friendly', 'enthusiasm', and 'approachable' (4 combined responses). While there were also multiple responses that included variants of 'knowledge' and 'understanding' of the topics, it is no surprise that the respondents emphasised the soft skills in their lecturers as ways of demonstrating that they are flourishing in their lecturing roles. What was clear however, was how students saw their lecturers as 'lecturers' – and measured their 'flourishing' mostly against this identity/ job role alone.

2.2 The staff surveys

In January 2024, the authors ran a session at the University of Sussex Teaching and Learning Conference entitled 'Human Flourishing', which introduced the concepts of Seligman and asked the staff the same first question given to the students – **“In which ways would you define and recognise flourishing in yourselves?”** These responses were captured live, and anonymously on a Padlet board shown on the main screen. Responses included “feeling my work has impact”, “feeling part of a community”, “supporting others to flourish”, “learning new things”, “having a work/life balance”, “finding meaningfulness”, “being compassionate with myself” ... many similar themes were shown.

The responses from the students to how they saw flourishing in their lecturers (as discussed above) were then shown on screen. Whilst there is an overlap between 'passion / understanding / engagement' from the student's perspective and 'supporting others to flourish' from the lecturer's perspective, the general disconnect between subjective flourishing (as an individual human) and observed flourishing (students saw only the 'lecturer') was obvious, and quite shocking to those in attendance.

Similarly, the second question was asked to those in the room - **“In which ways would you define and recognise flourishing in your students?”** Again, the responses were captured live, anonymously and on screen via Padlet. Responses included “engagement”, “growth in confidence”, “building communities of learning”, “self-motivation”, “excitement”, “trying their best”, “helping peers”, “reflecting”, “being curious” and “being independent”. Once more, the results from how students saw flourishing in themselves (as above) were then displayed on screen – again, with a very clear disconnect between subjective flourishing and observed flourishing. The top answer from how the students see flourishing in themselves of 'good grades' was not mentioned once in the 60 responses from the teaching and lecturing staff in attendance.

These disconnects were then discussed as a group – ultimately leading to a collective agreement that we would not be able to develop university-wide flourishing unless there was a clear, and common language and understanding of how that actually manifested to ourselves and in others. If we were not talking the same language, we would never be able to succeed.

2.3 Forming a bi-directional link – embedding 'flourishing' in a taught design module

One way to build a common language between students and lecturers was trialled in the module 'Thinking Big – the 5 Senses' which features a multi-layered, open brief. Around 30 students were asked to create a brand / sector relevant product that enhances a sensory interaction, working specifically with one of six pre-selected brands and in response to the social landscape of the CV-19 pandemic. In 2024, another layer was added – student designers were asked to design a product that also 'enhanced the

measurable subjective wellbeing of the user, specifically within the framework of human flourishing'. A one-hour lecture/workshop on Seligman's flourishing and PERMA was given to the designers, focusing initially on the concepts of subjective wellbeing (i.e. how do you recognise flourishing in yourself?). After short discussions in class, the results and disparity between the previously surveyed student's subjective flourishing and lecturer observed perceptions of student flourishing were displayed on screen. Once more, the disparity between responses was discussed.

This module however, required the students to actually understand how flourishing manifested in their specific target markets - and required them to embed physical elements into their design that could be shown to increase measurable perceptions of subjective wellbeing using the PERMA framework, e.g. self-empowerment through personalised but community embedded exercise. By deepening their empathic understanding of flourishing in others through the design process, students reported that their awareness of how to see flourishing in real-life (and in others) had been sharpened, along with a deepened sense of how wellbeing could be developed for users of products. Each final product proposal was mapped by each group onto the PERMA framework to showcase understanding of which pillars were their focus, and how they could (in theory) be tested for effectiveness. This project was rerun in Spring 2025 and Spring 2026 with similar results – helping to bridge the language / observation / understanding gap of flourishing seen above.

3 KINDNESS AS A PRACTICE FRAMEWORK TO SUPPORT FLOURISHING

'Kindness' is a key aspect of how flourishing can be manifested, but using kindness as an overarching constraint on design projects also gives deeper insight into the myriad problems that designers face. Applying the word 'kindness' to all project questions (and subsequent decisions) allows scope to improve enthusiasm, well-being/flourishing, empathy, altruism and meaningfulness in the designers themselves as well as with target users. Each enquiry in the research and development stage can be reframed to include 'kindness' as a lens. Such a framework simplifies some decision making on the basis of something being either 'kind or unkind' (as defined and measured below).

The following framework was used with a second-year class of 32 students in the Design for Industry module at University of Sussex. Students were encouraged to use the 'Kindness Framework' as a founding set of constraints for two industry set design briefs during the academic year of 2024-25 (again rerun in 2025-2026 with a cohort of 30 students).

3.1 The Kindness Framework

The Kindness Framework, (as developed by co-author G. Ellis) can be split into different sectors. Firstly, we can look at kindness focussed on the designer themselves, e.g. stress levels inside /outside the studio, natural pace of working, organisation skills, planning, expectations, feedback, communication and general wellbeing. If these elements are systematically understood by the designer, structured and built into the timeline of a project then we consistently see higher behavioural and emotional stability over an individual that ignored them. This is particularly true of student designers at times of high stress and looming deadlines. For example, 'am I being kind to myself by working until 3am? Or would it be kinder to myself to go to sleep at midnight and wake a little earlier?'. Or 'am I being kind to myself with my planned workload, or should I allow myself more time to complete tasks?'

Second is kindness to all other users, through the lens of empathy. This is already an academic stalwart that is highly researched, studied and practiced. Nevertheless, it was observed throughout the module in question (and comparing it to previous student project approaches) a slight language change by prefixing 'kindness' encouraged a more considered bias to disciplines like Human Centred Design, ergonomics, haptics, readability and comprehension, usability. This second sector also includes collaborators - we should also grant kindness to all those involved in the making real of any design - the engineers, fabricators, testers and investors for example. For example, 'how is the project presented? With clarity and precision? Without ambiguity and empathy for specialisms and common languages? Am I being kind to all to ensure that can work together most effectively?'

Lastly, the Kindness Framework considers the impact design has on the Earth, endeavouring to reduce the harm we do in any form. By employing 'kindness', decisions can be vetoed on whether they meet whatever performance / environmental criteria is set by the brief or from research (such as repair, recycling, reuse, producer responsibility). This has been demonstrated in practice by companies such as Patagonia stating in 2022 that the 'Earth is our only stakeholder' for decision making. For example, 'is

this the kindest material choice for the planet? Is it exploiting the Earth in any way, or is it working regeneratively?’

This trial of the Kindness Framework was shown to positively help students with establishing clear priorities across each sector – initially, what is the Kindness priority for themselves? How can they ensure they are supporting their own wellbeing through kind decisions? Secondly, how can they apply kindness in the eyes of empathy and compassion, and lastly, is this kind to the Earth? Results from this initial embedding showed a lower number of students self-identifying as being overwhelmed (sector 1) when compared to previous cohorts, along with highly empathic project results (sector 2) and a class-wide high consideration of environmental issues relating to their project proposals (sector 3).

4 CONCLUSIONS

It is clear, and deeply concerning that subjective wellbeing continues to decline in both students and educators, and whilst the authors acknowledge that a multitude of external / uncontrollable elements (such as financial strains, job insecurities, personal life) contribute highly to the wellbeing of an individual, there are multiple avenues that can be explored to increase positive aspects within the university landscape. Ensuring the same language is used between parties is key, along with empathic understanding of the ‘human’ and not just the ‘role’ they play. The decoupling of grades from the student’s perception of ‘success’ would undoubtedly allow them to see personal flourishing in a wider respect, and in a similar way to how lecturers view ‘student flourishing’, e.g. skill development, creativity, exploration etc. With a traditional grades-based system however, this is difficult to achieve. What is essential is the embedding and exploration of wellbeing and flourishing concepts within courses themselves and not seeing the subject of languishing as an issue to be dealt with reactively by an already overloaded Student Support after a student’s wellbeing has declined.

These interventions have shown how proactively teaching YR2 student designers to apply the concepts of positive psychology / Kindness Framework to themselves and their design work builds a foundation onto which the more complex PERMA framework can be applied in YR3. Further study would be needed to explore how the introduction of wellbeing and flourishing concepts to YR1 students could perhaps further affect their university experience and work in a positive way. What has been already shown however is how the tools and definitions of kindness and flourishing creates more resilient student designers with a wider number of deeper, richer, more empathic work (when compared to previous, prior intervention year projects) – and due to the bi-directional influence on subjective wellbeing, allows both student and educator alike, to thrive.

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EDUCATING FOR CRISIS PREPAREDNESS THROUGH DESIGN STORYTELLING

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ABSTRACT

Preparing and designing for crises is an essential cross-disciplinary skill. This demand teaching methods that unite students from different fields and equip them with systematic tools to imagine, plan, and act to improve citizen preparedness. Across a series of workshops, we tested the well-established ‘personas and scenarios’ method with both design and non-design students to support storytelling, situational forecasting, and empathy with potential users. This article presents a pedagogical reflection on a case study that explores the use of personas and scenarios as tools for actionable storytelling in design education. It examines how effective this approach is in contexts that involve the interaction of people, technology, and crisis situations. We present methods, results, discuss student feedback, and argue that this approach can be adapted to a wide range of disciplines working with disaster preparedness and technology innovation.

Keywords: Design methods, design education, design storytelling, crisis preparedness, forecasting

1 INTRODUCTION AND BACKGROUND

The ongoing *polycrisis* of natural and man-made disasters demands that we, as educators, prepare future generations and equip them to empower people and communities in the face of disasters [1-3]. From a citizen’s perspective, navigating uncertainty requires understanding how people think, feel, and act, what past experiences they draw on, and which resources they can access during a crisis. Such resources may include technology, individual skills, and relational assets like social capital. To imagine different crisis scenarios and simulate how situations might unfold toward potential solutions, we need to explore and test various scenario-based formats in a learning environment. Using personas and scenarios in the way specified by Cooper [4] can be seen as a form of ‘proxy’ or surrogate user-representation, where a persona is established to represent a user profile based on our knowledge about a demographic segment. Followingly, a persona is a profile representing a particular group of people, such as a group of customers or system users, a market segment, a subset of employees, or any other stakeholder group. Using personas is also an effective way to anonymize data while retaining inherent complexity, and for communicating and discussing human experiences with interdisciplinary teams for problem-solving, design or forecasting.

1.1 Epistemological viewpoints on personas and scenarios and forecasting

Situated within qualitative epistemology [cf. 5], personas and scenarios remain contested because their accuracy cannot be verified and they rely on perceived credibility rather than just empirical facts [see for example 6]. Their intentionally fictitious nature also prevents scientific falsification, and even when supported by data, they can never be conclusively validated. These critiques highlight tensions between realist and socially – and narratively – constructed epistemologies. Their capacity to enhance designers’ empathy is likewise debated, as personas may unintentionally reinforce bias, misrepresent user groups, or reduce real-world engagement and testing. While acknowledging these limitations, we focus on their effective use in educational settings [cf. 7], particularly for development of design narratives and forecasting. Here, ‘future forecasting’ refers to using research-based insights to anticipate and shape emerging conditions through qualitative and quantitative signals rather than fixed predictions. Futuring methods, including visual tools that map temporal relationships, facilitate reflection on long-term sociopolitical and ecological implications. Because design lacks a standardised trend-forecasting methodology, multidisciplinary collaboration and scenario planning remain essential for developing resilient and adaptable future visions. [8-10]. Design educators highlight scenarios as valuable for

training students to design future products and services, while other researchers note their usefulness in preparing crisis managers. Moats et.al. (2008) [11] similarly emphasise the role of technology and scenario planning in supporting local decision-making and crisis management. In design education specifically, scenario building is identified as a core method for teaching students to ‘design futures’ and for fostering civic engagement [12-14]. Perspective-taking is fundamental to design – especially human-centred design – because it helps reduce bias and supports the identification of the ‘right problem’. Well-executed human-centred approaches are associated with improved productivity, quality, user acceptance, error reduction, and lower development costs [15-17]. Designers may involve end-users directly or represent them indirectly through personas, which help scope user segments early in a process. Co-creating personas can also strengthen organisational learning and inclusiveness [18]. Ultimately, anticipating how people will behave, interact with a design, and experience future contexts is central to all design activity. Storytelling is integral to constructing user scenarios, which Cooper [4] describes as an extension of persona creation. Cooper frames this as a form of role-play in which designers adopt the perspectives of their personas to empathise with them and narrate their encounters with a system, service, artefact or other future conditions. These stories may extend from basic interactions to broader descriptions of future ‘preferred situations’, in Simon’s terms [19]. In this case study, we show how combining personas with scenario development helps students construct stories about possible future situations, particularly those involving people, technology, and natural or human-made crises.

2 RESEARCH METHOD

This study aims to offer a replicable example for teaching, accompanied by qualitative pedagogical reflections within the context of interdisciplinary crisis preparedness education, rather than presenting a quantitatively driven, evidence-based assessment of impact. Our study is hence a descriptive case study presenting an approach developed for – and tested in – an educational setting involving both designers and non-designers, hereafter referred to as the Workshops (WS). Because crisis preparedness relies on interdisciplinary collaboration, we applied this approach with a mixed group of students [20, 21]. The cases described consist of four workshops: **WS 1** (2024), involving 20 international full-time Erasmus Mundus students in Portugal with varied backgrounds; **WS 2** (2024), involving 22 international full-time Master’s students in Portugal; **WS 3** (2025), involving 24 full-time Master’s students in service, technology, and interaction design in Norway; and **WS 4** (2026), involving 20 international full-time Erasmus Mundus Master’s students in Norway. After each WS, students completed an anonymous online survey containing both fixed-response items and open-ended questions for qualitative feedback. Based on these cases, we present our experiences teaching design and non-design students how persona creation and scenario development can be used to forecast crisis situations from a human perspective. We outline our storytelling approach, describe the workshop structure, and conclude with lessons learned regarding tool relevance, student responses, and areas for improvement.

2.1 Storytelling about crisis scenarios

Across four half-day workshops with students we used personas and scenarios to support actionable storytelling. The students learned to create plausible narratives by adopting a character with specific abilities and resources, identifying a challenge, proposing an improvement, and explaining how it becomes possible through context and available technology. Focused on crisis scenarios, the workshops introduced four variables: **crises, people, disabilities, and technology**. Crises – natural or human-made, such as hurricanes, wildfires, earthquakes, floods, crime, terrorism, cyberattacks, pandemics, or conflict – may be short- or long-term and can be understood through three phases: pre-crisis, active crisis, and recovery [22, 23]. Although the workshops focused on situations requiring immediate individual response, students were free to explore interventions across all crisis phases. Together with the students, we also identified groups likely to be affected – such as local residents, children, the elderly, tourists, non-native speakers, refugees, and displaced or homeless individuals [24]. The aim was to expose students to the potential diversity of people impacted by crises and their differing needs, fostering empathy for individuals whose circumstances differ from their own. Because vulnerability is central to humanitarian response, we integrated varying vulnerability levels into the exercises. This reflects growing expectations that public and private services support at-risk individuals through inclusive ‘Leave No One Behind’ approaches. Awareness of vulnerability is therefore essential for designers and related professionals both in education and future practice. [25]. Accordingly, we specified that the

people students should consider may have temporary or permanent disabilities, ranging from behavioural and emotional conditions to sensory impairments, physical disabilities, brain injuries, respiratory disorders, and developmental disabilities such as ADHD, cerebral palsy, autism spectrum disorders, or learning disabilities. Building on the range of crises and user characteristics, we then introduced *technology* as another element, using the modern smartphone as a familiar and accessible example. By highlighting its diverse input, output, and sensing capabilities, we encouraged students to recognise the technological resources available to their personas before developing their scenarios.

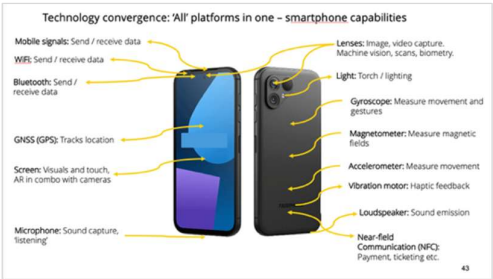


Figure 1. An illustrated overview of smartphone hardware capabilities as described and used in the workshops

Students worked in groups to identify a crisis scenario based on their own lived experiences, preferably one they had directly or indirectly encountered. After selecting a crisis, they chose a target user segment and created a feasible, credible persona. Using this persona, they then developed a realistic scenario set within the chosen crisis and described – through visual and verbal storytelling – how a smartphone and its capabilities could support the persona in that situation. The workshops were structured as rapid design processes aimed at producing design narratives, with defined time frames for each task: **Step 1, 10 minutes:** *Share stories from your home place, or memory, of a crisis event. This can be natural or man-made catastrophe. Decide on using one of the situations shared in the group as a starting point.* **Step 2, 20 minutes:** *Decide which segment of the population (from demographic variables) you want to focus on in your design. Create a persona based on this segment. Include at least one disability as a part of the characteristics of the persona.* **Step 3, 20 minutes:** *Identify and brainstorm how the smartphone can be of use for the persona in this crisis-situation. Write and draw together a story describing this scenario and how the persona can use the smartphone in the crisis.* Between steps 1 and 2, groups briefly presented their work, and after step 3 they shared their final stories. Because each step had strict time limits, students relied mainly on existing knowledge in the group to create credible personas, scenarios, and narratives. Although they could search online or use AI tools, the short timeframe encouraged them to draw primarily on shared insights. This distinguishes this method from standard persona and scenario development, which typically relies on extensive research and diverse datasets. We refer to our adapted approach as ‘rapid design for storytelling and empathy’. After each workshop, students completed a short anonymous online survey. A total of 49 responses were collected. The purpose of this feedback was to support ongoing evaluation of the class in order to enhance the student experience and foster an interactive learning environment in which students could share their perspectives. The responses are used to inform pedagogical reflection and guide improvements of teaching practices. However, it is important to note that this feedback is not intended to serve as scientific evidence of the method’s impact on student learning. Assessing outcomes such as increased empathy, reflection, or depth of learning would require additional approaches beyond a single, one-time survey. The students rated the exercises highly for their usefulness and for helping them empathise with the people in their stories. They also expressed interest in applying these methods in their future work. Scores were somewhat lower regarding how much the exercises prompted reflection on their role as designers, and the more general claim that they ‘learned a lot’ received slightly lower ratings as well. In the qualitative comments, students were asked what worked well, what could be improved, and whether they had additional feedback. Table 1 presents some selected responses.

Table 1. Displaying some of the written answers from the survey

What worked well?	What could be improved?	Any other comments or feedback
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<i>The fact that we can exchange ideas about possible solutions for the segment we want to reach</i>	<i>it could be longer and involve some research</i>	<i>This class has made me more interested in service design</i>
<i>The explanation about all the functions on the smartphone was really helpful! Some of them are not that well known</i>	<i>More time to explore the background of the persona</i>	<i>I really liked the theory part of the workshop</i>
<i>hands on creation of designing personas</i>	<i>Explain more Why and how it relates to humanitarian action.</i>	<i>thank you !!! it was very rewarding</i>

3 RESULTS: DESIGN OUTCOMES AND REFLECTIONS

WS 1, 2, and 4 included diverse international cohorts of non-design students, while WS 3 consisted mainly of students with design training, alongside a smaller group without such backgrounds. Across all workshops, participants drew on crisis experiences from varied geographical and personal contexts.



Figure 2. Students developing scenarios during workshop 4

All students produced high-quality outcomes that were diverse, realistic, and well presented. The results from the first WS exceeded our expectations given the short time available, and this performance was repeated in the subsequent WSs. Students were highly engaged in sharing knowledge and used scenario-based storytelling to explore innovative ways smartphones could support disaster victims. Below, we present two synthesized, example stories.

3.1 Example story 1

Fátima is 30 and lives in a refugee camp with her young children. She's an artisan, selling the items she crafts to others in the camp. After losing part of her hearing in an explosion while fleeing her home, she relies on her smartphone. She posts daily stories and markets her work through social media, and her phone keeps her connected in other ways too: it flashes and vibrates if her baby wakes up out of sight, and it alerts her to nearby military incidents. When talking with customers who speak other languages, she uses her phone to translate messages. Most news and updates about camp life also reach her through her phone, making it an essential tool for staying informed and keeping her family safe.

3.2 Example story 2

Miquelina is 84 and lives alone in the Aveiro region of Portugal. Thanks to a local police program, she's learned how to use her smartphone and smart bracelet if a wildfire breaks out. One day, a fire creeps toward her area, and her phone flashes and speaks a warning. She unlocks it with face recognition, which quietly tells emergency services she's home, safe for now, and aware of the alert. If the situation gets worse, Miquelina can simply press her phone's main button three times. That triggers a distress signal, shares her location, and opens a video and audio link to emergency operators, automatically launching a rescue mission. If she doesn't trigger it but the fire escalates, her initial biometric confirmation ensures she's placed on the evacuation list, so responders know where she is without having to search for her.

As shown, the students were able to produce realistic, life-like stories about their persona Fátima and Miquelina, and how a smartphone can support life in a refugee camp, and in an ongoing wildfire.

3.3 The focus on technology, relational and contextual factors

Observations from the workshops suggest that using the smartphone as a technological frame offered a familiar technological basis for building scenarios. Students, regardless of background, understood how smartphones function and could draw on their own and others' experiences. Although phones provided

a practical anchor, many stories centred on the relational aspects of crises. Students often began by asking whom their personas would contact first, and who they had turned to the last time they needed information or guidance. They assumed that communication with another person would be essential for emergency decision-making. Connecting scenarios to familiar contexts and memories of crisis events also made the storytelling concrete and detailed. A diverse classroom proved essential for meaningful learning about preparedness. When students came from varied disciplinary, geographic, cultural, and gender backgrounds, they contributed a broader range of crisis examples and firsthand insights into how people and communities think, feel, and act during difficult situations. Such diversity also encouraged consideration of crises from multiple socio-economic perspectives, enriching the overall learning experience [26]. In our experience from the workshops, the technological component of the smartphone functioned like a catalyst for discussions and development of stories of crisis preparedness while still retaining a focus on people and their relations and communities as the main factors. The role of the smartphone as an enabler for, and mediator of, social relations and connections was evident in all the resulting design stories. This focus on relational aspects – and accordingly design [27] – was at the centre of all future scenarios, ranging from narratives of crisis in the form of refugee situations, displacement, earthquakes, floods and wildfires.

4 DISCUSSIONS

Actionable knowledge differs from traditional scientific scholarship by explicitly connecting theory and practice [28]. Although design practice routinely involves this type of knowledge, personas and scenarios can help make it accessible to non-design students. Many are familiar with analysing data but find it less intuitive to translate data into stories and proposals for improvement. Even so, we observed that interdisciplinary and diverse groups generated stronger and more relevant ideas, while the more homogeneous group of mainly design students of the same nationality in the third workshop showed slightly lower engagement and less varied storytelling, though our sample is too small for firm conclusions. While intentionally ‘breaking the rules’ of best-practice persona and scenario development – by giving strict time limits – we found the method remained well-suited for rapid design exercises in educational contexts, serving seven purposes: 1) Sharing experiences within participant groups. 2) Establishing a situation and context for the story. 3) Identifying stakeholders to design for, including demographic factors and potential disabilities. 4) Building empathy and awareness of people in specific emergencies. 5) Proposing design interventions that show how technology can help. 6) Using storytelling to forecast improved future solutions and increase awareness and preparedness for crises, and: 7) Encouraging reflection within groups and across groups through sharing results and stories. In sum, we believe the approach can contribute meaningfully to disaster preparedness.

4.1 Limitations and conclusion

These workshops functioned as bottom-up exercises in imagining and visualising future situations, with students pooling existing knowledge to generate propositional insights. The resulting stories about human-technology interactions in crises were realistic but not evaluated for feasibility, cost, privacy, or other second-order constraints. We acknowledge potential priming effects from the workshop framing predefined contexts, and participants’ memories or biases. However, the aim was not factual accuracy but the creation of imaginative, future-oriented concepts to support vulnerable users. Overall, the ‘rapid design’ workshops were productive and engaging, as reflected in student feedback, and effectively introduced storytelling as a design method in crisis-preparedness education.

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MENTAL IMAGERY VIVIDNESS AND ITS IMPACT ON LEARNING ATTAINMENT IN DESIGN EDUCATION

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ABSTRACT

Recent research has determined that a diverse experience of mental imagery exists between individuals, even amongst those working in design. Designers, including those within engineering and product design, can experience mental imagery in varying levels of vividness across all sense modalities, from visual to emotional, and little is known about how this cognitive diversity impacts on their design process, or on their educational success. This paper poses the question: Does higher mental imagery vividness lead to better performance in a design module? By recruiting students from two engineering design classes to complete a psychometric questionnaire measuring multisensory imagery vividness and comparing these responses to final class grades, correlations have been determined between success in a design class and multisensory mental imagery vividness. The findings of this study confirm that the hypothesis posed is incorrect, with any correlations found showing that the higher a student scores their imagery vividness, the worse their final class grade is. These results pose further questions about the need for consideration of cognitive diversity in design education and how we can create more inclusive learning environments in engineering design.

Keywords: Mental imagery, design cognition, engineering design, education, inclusivity

1 INTRODUCTION

The experience of mental imagery, the perception of an image within one's mind, is often considered integral to a designer's cognition [1] and beneficial for designers across fields [2]. The experience of mental imagery allows those working in creative fields access to internal thoughts, emotions and senses [3]. Imagery is commonly believed to occur more vividly in creative individuals [4] and there is evidence that utilising the experience during the design process can improve outcomes [5]. One example of this is evidence indicating that utilising mental imagery to visualise a user while generating solutions can increase empathy and support user-centred design [5]. However, mental imagery is reported as being underutilised by experienced designers [6], with many claiming indifference to the phenomenon in their design work, potentially due to the casual nature of the experience [7,8]. Additionally, prior research shows the assumption that designers inherently experience vivid mental imagery is not accurate, and for those it does hold true for, it is an experience unique to the individual, with diverse elements, processes and dimensions [9,10,11]. Understanding the scope of this cognitive diversity could improve student engagement, as well as engagement in settings such as codesign for healthcare due to an improved understanding of the requirement for personalised learning and design environments [12]. Commonly, mental imagery is discussed solely in terms of visual imagery, the experience of visualising an image within the mind. Visual mental imagery is considered useful in design working, with it actively assisting creative output in designers that experience the phenomenon [13]. However, mental imagery is experienced across varying modalities that cover different senses: olfactory, auditory, gustatory, tactile, and kinaesthetic [14,15]. Emotion mental imagery manifests in a similar manner with emotion imagery sharing traits akin to physical emotion perception, as is the case with other sense modalities [10;16]. Further to the diverse modality experiences, there are various dimensions of mental imagery that impact on a designer's cognition, such as rotational ability [17], or visuospatial imagery ability [18]. Often, mental imagery is discussed in terms of the "strength" of the image, referred to as the vividness of mental imagery [19]. The vividness of mental imagery ranges from aphantasia, the complete lack of imagery, to hyperphantasia, imagery described as being as vivid as real life [11]. Aphantasia is thought to impact around 1-3% of the population and hyperphantasia around 3-7%, with the remaining population experiencing mental imagery in-between, on a scale of sorts [11]. Further, individuals have

been found to experience different mental imagery modalities in varying levels of vividness, with it being possible to experience mental imagery in one sense but not another or to experience every sense at different levels of vividness [15].

Complicating mental imagery research into the diverse experience is the subjectiveness of the phenomenon [20,21], with it being difficult to measure due to it occurring entirely within an individual's mind and there being a limitation on objective measurement options. Currently, mental imagery is regularly measured through psychometric self-response questionnaires that attempt to measure the vividness of mental imagery through self-responding to scenario-style questions [22]. The Plymouth Sensory Imagery Questionnaire (PSIQ) [23] is a self-response questionnaire that measures mental imagery vividness across seven modalities: appearance, sound, smell, taste, touching, bodily sensation, and feeling. It presents individuals with five scenarios for each of the seven categories and asks them to rate their mental image on a zero to ten measurement scale, with zero representing no mental imagery, and ten an image as vivid as real life perception.

It has been found that there is a gap in existing research to investigate the diversity of mental imagery experiences within the field of engineering design [10], and in particular engineering design education. Compared with experienced designers, novice engineering designers have fewer external cognitive influences due to their limited design experience and knowledge. Studying engineers at the outset of their careers is therefore justified, as the impact of prior knowledge is comparatively low. It is hypothesised, based on existing research that the mental imagery experience is inherently useful in designers [11] that higher reported levels of mental imagery vividness across modalities, as measured by a pre-existing psychometric questionnaire, will lead to higher attainment levels in an engineering design module. The paper aims to confirm this hypothesis by comparing mental imagery vividness reports to grade attainment of engineering design students in specified design modules to find any potential correlations.

2 METHODOLOGIES

Participants were invited from University of Strathclyde's Department of Design, Manufacturing and Engineering Management (DMEM) undertaking The Design Emotion and Experience module (Module 1) or The Design Form and Aesthetics module (Module 2). During both modules students undertake an individual design project considering the full design process. Mental imagery vividness was measured in the study with a variation of the PSIQ [23]. Alterations were made to the PSIQ to remove smell and taste after a pilot study revealed negligible results from the inclusion of these questions. The PSIQ is measured on a scale of zero to ten. For this study, this measurement scale was interpreted as possible aphantasia (scores less than one), very low imagery vividness (scores one to two), low imagery vividness (scores two to four), moderate imagery vividness (scores four to six), high imagery vividness (six to eight), very high imagery vividness (scores eight to nine), and possible hyperphantasia (scores above nine). The PSIQ was provided to students as an online questionnaire, with an average response time of seven minutes and six seconds. The PSIQ results were compared with module grades, out of 100, allowing for equal comparisons. The results have been analysed by statistical analysis, and the calculation of Pearson Correlation Coefficients (PCC) between PSIQ results and module grades.

3 RESULTS

3.1 Overall PSIQ

There were 1,050 responses in total from the 42 participants, with 775 from the Module 1 cohort, and 275 from Module 2. Overall, 0.76% of the responses were measured as aphantasia, while 14.38% were measured as hyperphantasia. Of the Module 1 cohort, 35.48% of responses were very high imagery vividness, 29.03% were high, and 35.48% were moderate, while of the Module 2 students, 54.55% of responses were very high, 18.18% were high, and 27.27% were moderate (Figure 1). Overall, 40.48% of responses were very high, 26.19% were high, and 33.33% were moderate level imagery vividness (Figure 1).

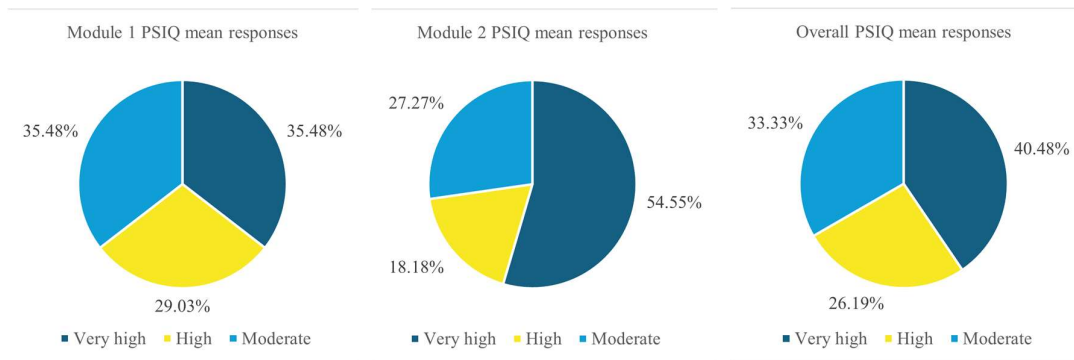


Figure 1. PSIQ mean responses by cohort and overall

Statistical analysis was performed on the PSIQ responses by calculating and comparing means, modes, medians, ranges and standard deviations of both modules and overall (Table 1). Means were similar between both modules and the overall, with 6.92 for Module 1, 6.99 for Module 2, and 6.94 overall. Both modules returned high overall means, with the exception of the feeling modality for both Module 1 and overall, both of which resulted in means of moderate level imagery vividness. The modes were calculated as very high vividness with a small number of exceptions: appearance for Module 1 and appearance overall were both possible hyperphantasia level vividness and touching for Module 1 and feeling for Module 1 were both moderate level vividness. The medians calculated were also mostly high vividness, with overall median for Module 1 7.00, for Module 2 8.00, and all 42 participants total 7.00. The only exception was for the feeling modality for Module 1 which resulted in a median of 6.00, or moderate level vividness. For the ranges, all results were large ranges 6.00 to 10.00 for Module 1, 8.00 to 10.00 for Module 2, and 8.00 to 10.00 for the overall results.

Table 1. Statistical analysis results by cohort and overall

	Appearance	Sound	Touching	Body	Feeling	Mean	Mode	Median	Range	SD
Module 1	7.92	7.00	6.75	6.70	6.23	6.92	8.00	7.00	10.00	2.32
Module 2	7.36	6.56	7.18	6.91	6.91	6.99	8.00	8.00	10.00	2.28
Mean (total M1&2)	7.78	6.89	6.86	6.76	6.40	6.94	8.00	7.00	10.00	2.31
Mode (total M1&2)	10.00	9.00	8.00	8.00	8.00					
Median (total M1&2)	8.00	7.00	7.00	7.00	7.00					
Range (total M1&2)	8.00	10.00	10.00	10.00	10.00					
SD (total M1&2)	2.01	2.44	2.16	2.22	2.46					

The standard deviations calculated were mostly between 2.00 and 2.56, with the exception of the appearance modality for Module 1 which resulted in a standard deviation of 1.89, and the sound modality for Module 2 in which the standard deviation was calculated at 2.84. The PCCs calculated, found in Table 2, were found to be all positive when considering the 42 participants together. This included two weak correlations for appearance versus feeling and sound versus feeling, and three strong correlations for sound versus touching, sound versus bodily sensation, and touching versus bodily sensation.

Table 2. PCC calculations by cohort and overall

Module 1	Sound	Touching	Body	Feeling	Module 2	Sound	Touching	Body	Feeling
Appearance	0.4243	0.4120	0.2011	0.1985	Appearance	0.5007	0.2164	0.4896	-0.1907
Sound		0.5502	0.5497	0.0836	Sound		0.8493	0.8370	0.2561
Touching			0.7208	0.2037	Touching			0.8463	0.2741
Body				0.3167	Body				0.1603

Overall	Sound	Touching	Body	Feeling
Appearance	0.4551	0.3349	0.2559	0.0814
Sound		0.6194	0.6084	0.1076
Touching			0.7487	0.2314
Body				0.2925

3.2 Module versus PSIQ comparisons

Further PCCs were calculated to find correlations between the PSIQ responses and the grades for each module, and the overall cohort of participants. These were calculated for each modality mean versus the overall grades, as well as the overall PSIQ means versus the overall grades. All Module 1 correlations, as per Table 3, were found to be negative with the strongest negative the feeling modality versus overall grades at -0.4035 and the weakest the sound modality at -0.1419 (although it should be noted this is not a negligible correlation). With the Module 2 correlations, all correlations were negative but were slightly weaker than Module 1 with feeling the strongest at -0.3811 and appearance the weakest at -0.0003 (Table 3). Overall, all correlations found between the PSIQ responses and the overall module grades for all 42 participants were negative, with strength ranging from -0.4088 for the feeling modality to -0.1156 for the sound modality (Table 3). The largest difference was in appearance with -0.3655 for Module 1 to -0.0003 for Module 2, with an overall PCC of -0.2696, while the feeling modality returned the strongest negative correlation across both modalities and overall.

Table 3. Statistical analysis results by cohort and overall

<i>Pearson</i>	Module 1	Module 2	Total
<i>Appearance</i>	-0.3655	-0.0003	-0.2696
<i>Sound</i>	-0.1419	-0.1287	-0.1156
<i>Touching</i>	-0.2280	-0.2231	-0.2318
<i>Body</i>	-0.1715	-0.1924	-0.1776
<i>Feeling</i>	-0.4035	-0.3811	-0.4088
<i>Overall</i>	-0.3796	-0.2390	-0.3440

4 MENTAL IMAGERY IN DESIGN EDUCATION

4.1 PSIQ

The level of vividness across the entire participant pool was high on average, with an overall mean of 6.94. It is commonly understood that designers and creative individuals often experience high vividness of mental imagery [1], and that appears to extend to the novice engineering designers in this study. An interesting area of future work would be investigating the reasons for this occurrence. The mean results are similar across all modules and overall, with one suggested explanation that participants' work in design may allow them a better understanding of their own mental imagery experience, although it is hard to conclusively give a reason without further exploration. For participant mean results, there are no extremes of 0.00 or 10.00, and only one participant's responses resulted in a mean of under 5.00 (still within the moderate level). Considering the mean results (Table 1 and Figure 2), participant results appear clustered into the moderate to very high-level vividness space, an unsurprising result for a group of engineering designers given prior research on the topic [1,10]. A result of note is the lower mean scores for the feeling modality for the Module 1 cohort and the total cohort, which is surprising given the high focus on emotion within the course teachings. It has been highlighted when considering the individual responses to questions, that the questions themselves may have an impact on responses. For example, one question in the feeling modality is "in love," which is a highly subjective emotion that will be impacted by an individual's own experiences.

For the Module 2 cohort, 54.55% of results were measured very high-level vividness, while 35.47% of the Module 1 cohort responded very high. This discrepancy could be explained by the Module 2 participants being further along in their education as it has been found that experienced designers are able to visualise faster [19]. Over 50% of Module 1 participants results of imagery vividness was within the high and very high categorisations, alongside over 70% of Module 2, corroborating the strong mental imagery vividness on average result. Of the total 1,050 responses, only 0.76% were aphantasia-level results, while 14.38% were hyperphantasia-level. Considering it is believed that aphantasia affects approximately 1-3% of the population, while hyperphantasia affects around 5-7% [11], it is expected that the levels of hyperphantasia will be reported higher in a study, although the jump to 14.38% here is above average. While this is a high number, the overall mean scores show that the level of possible hyperphantasia is closer to the expected average, with these results confirming that individual experience of mental imagery is complex and unique within a person's cognition.

Of the statistical analysis, there is consistency amongst the mode, median and range results, although there is a clear presentation of diversity in the mental imagery experience. This is clear with the high ranges, with participants responding at all levels of the imagery vividness scale, both within themselves and between participants. The standard deviations are all above 2.00 which is high and shows a large

variation from the mean, despite also being consistent across modality and cohorts. For the PSIQ PCCs, while there are numerous weak correlations that have been disregarded due to a lack of conclusive correlations, the remainder are largely positive across all results. The feeling modality is an anomaly with more variation observed in the correlations. In particular, the appearance versus feeling modality correlations revealed a great deal of variation, with the Module 1 cohort's PCC calculated as 0.1985, and the Module 2 cohort as -0.1907, resulting in the overall PCC calculated as 0.0814. Further investigation into these results would be interesting as there are clear distinctions between cohorts.

4.2 Comparative results

PCCs were calculated for each of the modality means and overall means, both by separate cohort and overall. The weak correlations indicate more clustered data rather than true correlations so have been deemed negligible and removed from analysis. These results do not give a definitive answer to the hypothesis so are irrelevant within the scope of this research. Of the remaining results, all correlations found between PSIQ results and class grades were negative, with no positive correlations uncovered. This indicates that the hypothesis was incorrect and that higher levels of imagery vividness in novice engineering designers often leads to lower performances in a design-based module. Considering the common assumption that creative individuals often have more "useful" imagery [1], this is an unexpected result and further exploration of why would be advantageous.

Of the two separate modules, overall, the results from the Module 2 cohort were weaker than the Module 1 cohort, and the total. This is with the exception of the bodily sensation modality, although the differences are almost negligible. Potential impacts on these results are: the year group and length of study so far; the module project the participants have been assigned; their individual academic performance; their university course, faculty or institution itself; or their mental imagery experience itself. Further investigation into multisensory mental imagery would also be useful, for example, to consider why the correlations for the sound modality in particular are weaker than other modalities. One reason could be that sound imagery is not as regularly utilised during a design project, while appearance, touching and bodily sensation are often essential when creating products that have a user-interaction element. Additionally, prior research has found that there is direct impact from the questions, with individuals having unique experiences of the scenarios presented. For example, the sound of a cat meowing might be more familiar and therefore an "easier" imagery experience to consider for someone who lives with a cat, than for someone who has not regularly been around a cat. This is especially true for feeling mental imagery, with emotion being subjective to an individual's own emotional cognition.

5 CONCLUSIONS

This paper presented a correlation study with hypothesis that higher levels of mental imagery vividness would lead to better performance in a design module. It considered the question in the context of engineering design education by presenting student engineering designers with a mental imagery vividness questionnaire (the PSIQ) and comparing their responses to their class grades in a design-based module. The hypothesis was proven incorrect through statistical analysis undertaken on the results, which presented conclusively negative correlations between the PSIQ results and class grades investigated. The result here confirms that, on average, higher levels of mental imagery vividness in engineering design students results in lower grades in certain design-based module. The purpose of this paper is to share the correlations found between mental imagery vividness reports and grade attainment, with the results providing initial evidence of the importance of consideration of mental imagery experience diversity in education, and beyond. While simply asking pre-set questions that measure mental imagery vividness is not enough to fully understand the extent of the diverse experience and further development of more appropriate methods for measuring the mental imagery experience would be beneficial, the work begins the conversation about how and why this should be considered in learning environments. This work is a first step towards a goal of defining the mental imagery experience in engineering design students and understanding the diverse experiences and their impact on engineering design education. In addition, it encourages conversation on whether the correlations uncovered could extend to learning environments within codesign settings, such as in healthcare design projects that require educational considerations for patients, carers, and healthcare professionals new to design environments, and how this cognitive diversity could be accounted for within these more complex settings.

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SIMULATION WITH OR WITHOUT DEPTH? DIDACTIC OPPORTUNITIES AND BOUNDARIES OF FEA USE IN EARLY ENGINEERING EDUCATION

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ABSTRACT

The use of Finite Element Analysis (FEA) has long been established as a core component of engineering education. Due to the increasing availability of CAD-embedded workflows, FEA is now accessible at a significantly lower threshold, leading to its growing application even in early stages of training, often without the methodological depth required for robust dimensioning or optimisation and validation. At the same time, FEA offers high didactic potential: the visualisation of abstract quantities such as deformation, stress, or load paths on 3D models can make theoretical content more tangible and support diverse learning approaches.

This paper investigates the purposeful use of FEA in early phases of engineering education, with a focus on diversity-sensitive learning through visualisation. A survey conducted among teachers at Austrian HTLs (secondary higher vocational schools) serves as a case study to assess the current state of practice. The aim is to derive action-oriented guidelines for the responsible implementation of FEA in teaching: when does FEA provide value as a tool for visualisation and conceptual understanding, where are its limits in terms of informative validity, and how can it contribute to inclusive didactic strategies?

Findings suggest that FEA should primarily be used as a tool for visualisation and conceptual understanding in early training phases. Validation-focused simulations (e.g., for dimensioning or optimisation) are better suited to advanced stages. Furthermore, the diversity-sensitive added value of visualisation, as a bridge between various learning paths, is elaborated and illustrated through concrete examples.

Keywords: Simulation-based learning, Finite Element Analysis (FEA), Engineering education, Didactic approaches, Intuitive usability

1 INTRODUCTION

Since the proliferation of 3D modelling in the 1980s and its continuous integration from the mid-1990s onward, digital product models have become the foundation for downstream CAX applications and thus for modern virtual product development. Around 2005, CAD-embedded FEA marked a key milestone by making simulations more accessible. [1] This transition broadened access to what was previously the domain of experts. Today, users are often only a few clicks away from color-coded simulation results. [2]

While this low-threshold accessibility presents opportunities, it also carries risks. Robust simulation results are not solely a product of software workflow completion. They require thoughtful modelling decisions, plausibility checks, validation, and the ability to correctly interpret outcomes in an engineering context. [3, 4] Nevertheless, the visualisation potential of FEA provides significant didactic value: displacements, stresses, or load paths¹ can be vividly presented on a 3D model, rendering abstract content more accessible and addressing diverse learning needs. [2, 3, 5–7]

This paper examines how FEA can be used responsibly in early engineering education and translates these insights into practical guidance: when does FEA add value as a visual-cognitive scaffold, where

¹ This paper focuses on structural mechanical investigations using FEA. Other application domains such as heat conduction and heat transfer, acoustics, and vibration analysis are not explicitly addressed or discussed, in order to maintain a clear scope and focus.

do its limits lie, and which didactic contributions can realistically be expected? A survey of teachers at Austrian HTLs² serves as a case study of current practice. Drawing on these findings, we propose a three-level model that differentiates visualisation-oriented use from validation-capable analysis and outlines appropriate framing for each. In this paper, diversity is operationalised as heterogeneity in learners' prior knowledge, mathematical confidence, spatial reasoning, and preferred problem-solving styles, and is used primarily as an interpretive lens for discussing how FEA-based visualisations may scaffold learning through accessible representations.

In addition, the scope of this paper is limited to the didactic use of structural-mechanical FEA for depicting and discussing resulting mechanical loading. It does not address stress assessment for safe design, nor does it cover lifetime or fatigue calculations; thus, the presented use cases focus on visualisation and conceptual interpretation rather than design verification or safety-relevant dimensioning. Furthermore, the paper does not explicitly investigate gamification or exploration-oriented engineering learning techniques in conjunction with simulation tools; however, such approaches appear promising and constitute a worthwhile direction for future research and development.

2 STATE OF THE ART

The literature on teaching FEA in structural mechanics consistently highlights a tension between rapid, low-threshold tool access and the methodological depth needed for trustworthy engineering decisions [2, 9]. Multiple authors report that students can quickly generate persuasive contour plots, yet this accessibility may foster overconfidence when modelling assumptions and boundary conditions remain implicit [2, 10]. Learning gains are described as strongest when simulation is embedded in a triangulation of hand calculations, FEA, and structured reflection on deviations, thereby making assumptions and limitations explicit [11]. Likewise, project- and problem-based formats are effective primarily when tasks require justification of modelling choices, comparison of solution paths, and documented plausibility/verification checks rather than mere workflow completion [4]. Interactive and visualisation-centred approaches can strengthen conceptual understanding of deformation and stress patterns and draw attention toward interpretation [6, 12], but authors emphasise that visualisation alone does not establish verification-oriented practice. Accordingly, several contributions stress the need to cultivate engineering judgement, recognising non-physical constraints, interpreting stress concentrations/singularities, and performing mesh- and sensitivity-related checks [2, 9]. Course assessment and design-project integration studies further show that competence gaps persist unless verification and interpretation are explicitly required in assessment and reporting [13, 14]. Curriculum-reform work therefore argues for coherent task chains linking structural testing/physics concepts and interpretation, supporting staged competence development rather than one-shot software training [15].

2.1 Methodological Depth as a Prerequisite for Reliable Simulation

As shown in [3], in FEA teaching and application, two fundamental approaches can be distinguished:

- The pragmatic approach is oriented toward the software workflow and primarily communicates the process steps leading to a result. Methodological background knowledge is often assumed or addressed only selectively. Competence is therefore frequently equated with tool proficiency and functional scope.
- In contrast, the theory-oriented approach emphasises FE model theory, including integration methods and solver know-how, element selection, discretisation, and abstraction of real load cases. However, in many curricula, the connection between these theoretical foundations and concrete software implementation remains abstract. [2, 4]

While both approaches serve legitimate objectives, they yield different types of results: the pragmatic approach allows for quick visualisations and preliminary insights, whereas engineering-reliable simulations require deeper methodological understanding. This distinction is critical: limited

² An Austrian HTL is a federally regulated vocational secondary school that provides a five-year, job-oriented engineering education combining general education, theoretical instruction, and extensive practical training. HTLs aim to equip students aged roughly 14-19 with solid technical, methodological, and entrepreneurial competencies, preparing them both for immediate professional practice and for further tertiary studies. Graduates complete A-level examinations and their qualification is classified as short-cycle tertiary education (ISCED level 5), with strong alignment to industrial practice through industry-experienced teaching staff. [8].

methodological depth can serve a didactic purpose through visualisation but must not be mistaken for reliable evidence in validation, sizing, or optimisation contexts.

2.2 Learning Diversity

In early training phases, the heterogeneity of learners is typically high. Students vary in terms of prior knowledge, mathematical confidence, spatial reasoning, and preferred problem-solving styles (e.g., exploratory vs. analytical). [16, 17] Visualisations can act as didactic bridges in such settings by reducing the cognitive effort required to translate between formal description and intuitive meaning, supporting causal reasoning and system structuring [18].

For simulation use in education, several key aspects emerge:

- Multiple learning styles can be addressed simultaneously (visual, exploratory, analytical).
- Varied levels of prior knowledge and tool proficiency, both among learners and instructors.
- Simulation as an opportunity to enable differentiated learning paths, where not all students need to reach the same depth; what matters is a transparent framing of the simulation's informative value.

3 RESEARCH DESIGN: SURVEY CONTENT AND EMPIRICAL INSIGHTS

A prior study [3] discussed the tension between low-threshold, tool-driven simulation and methodologically grounded FEA in engineering education. The present paper focuses explicitly on early education phases. Rather than comprehensive instruction in validation-capable FEA, the focus lies on how FEA can be employed meaningfully for educational purposes while ensuring clarity about its limitations. The core hypothesis is that applying and visualising theoretical content via FEA can support comprehension of mechanical principles. In the context of the present study, this assumption is examined primarily through teacher-reported practice and perceived didactic value.

To ground the discussion empirically, a targeted survey was conducted among teachers at Austrian HTLs (Section 3.1). The goal was to assess the current state of FEA integration in teaching and to collect practical insights that inform the action guidelines developed in Section 4.

3.1 Survey Objective and Study Design

The study was carried out as an online survey during a Ministry-organised teacher training program for CAD/FEA teachers at HTLs. A total of 52 participants responded ($n = 52$). The questionnaire included closed questions for quantitative data and open questions to capture experiences, motivations, and perceived limitations. Results were analysed using descriptive statistics and thematic categorisation.

The survey³ addressed the following topics:

- Frequency of use, as well as year levels and subjects where FEA is implemented
- Tools used, including CAD-embedded vs. standalone FEA software
- Objectives of use, distinguishing between visualisation/understanding and analysis/optimisation
- Barriers and support needs for teachers

3.2 Key Findings

FEA is already widely applied among the surveyed teachers despite not being explicitly anchored in curricula: 96% of respondents reported using FEA in teaching, indicating that adoption is largely driven by individual initiative. The degree of integration varies considerably, ranging from sporadic use to consistent application, and is most commonly concentrated in senior year levels. The dominant instructional purpose is visualisation to support understanding of theoretical concepts; teachers mainly use simulation to make mechanical phenomena visible and to foster conceptual learning, for instance by illustrating stress distributions, deformation under load, modal shapes, and natural frequencies. In contrast, using FEA for reliable calculation, sizing, or optimisation plays only a minor role in regular instruction and is typically limited to diploma projects or particularly engaged students with close teacher support. Regarding the tool landscape, CAD-embedded FEA clearly constitutes the primary entry point and is widely used in classrooms: integrated modules are frequently mentioned, and their ease of access and low-threshold workflows appear to facilitate broad uptake, whereas standalone tools are used less often and by a smaller subset of teachers. Reported barriers are dominated by time pressure and curriculum constraints; additionally, respondents highlight challenges related to methodological

³ The entire survey, including the evaluation, can be found at TU Graz Repository: <https://doi.org/10.3217/cs5pp-x4y71>

depth, including insufficient foundational knowledge among both students and teachers. At the same time, there is strong demand for support: more than 80% expressed interest in further training, and 84% explicitly requested supporting materials.

3.3 Summary of Survey Results

FEA is already established in school practice, primarily as a visualisation and understanding tool. Time and curricular constraints, as well as a lack of methodological depth, are cited as key limitations. The strong demand for professional development and teaching resources suggests that while educators recognise the value of FEA, they require guidance and frameworks for responsible use. These insights inform the staged implementation model and recommendations presented in Section 4.

4 RECOMMENDATIONS AND OUTCOMES

4.1 Use-Depth Relation of FEA in Early Engineering Education

A tiered model for FEA use in education, inspired by the approaches of VDI 2211⁴ and illustrated in Figure 1, can be derived, distinguishing three levels of application based on the required technical depth:

- **Level A** refers to established FEA for robust engineering analysis (e.g., verification, design, optimisation). This requires high methodological expertise, including model formulation, numerical effects, and result validation. Such competencies are typically developed in advanced or university-level education.
- **Level B** represents a transitional level, typically encountered in student projects or thesis work, but only under clear teacher guidance and explicit instruction. Results must be discussed jointly as assumption-dependent and highly sensitive to modelling choices (e.g., loads, boundary conditions, contacts, mesh). Outputs therefore require close supervision and should be interpreted using structured reflection prompts.
- **Level C** focuses on FEA as a tool for visualisation and conceptual understanding. The emphasis is not on numerical accuracy, but on making mechanical behaviour tangible. Didactic benefits can be achieved even with minimal methodological depth.

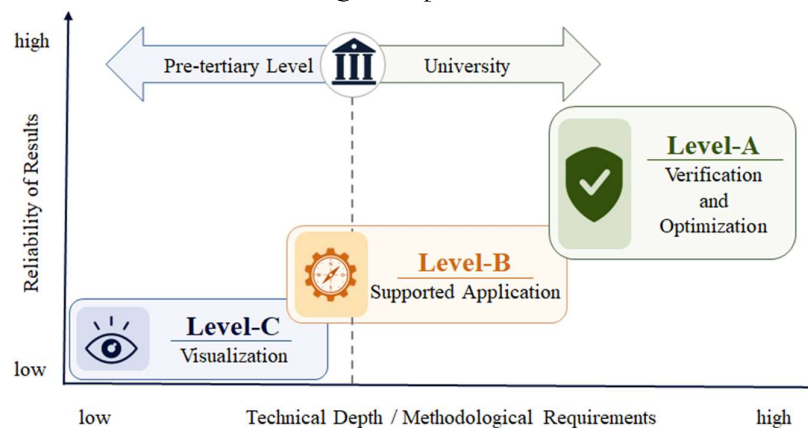


Figure 1. Three-level model for the responsible use of FEA in engineering education

4.2 Diversity Perspective: Why Visualisation Can Function as a Didactic Lever

Visualisation contributes didactically through three core mechanisms:

- **Conceptualisation and localisation:** Abstract quantities are linked to physical locations on components, aiding term formation and interpretation. Students annotate hotspots and link them to bending moment distribution.
- **Bridge between formalism and intuition:** Visualisation facilitates translation between formal input (e.g., equations, loads, boundaries) and physical meaning, lowering cognitive barriers. Given a hand calculation, students predict the deformation pattern before running the simulation.

⁴ Following the ABC concept of VDI 2211, calculation and evaluation methods can be organised into three levels (C-B-A) that trade rapid availability against statement quality, ranging from quick common-method decision aids (C) to specialist, high-effort analyses used when high certainty is required (A). [19].

- Exploration and comparison: CAD-embedded environments allow rapid variation of parameters, enabling cause-effect relationships to be discussed via contrasts ("if-then"). One-parameter sweep: students explain/predict trends.

Figure 2 illustrates this through the comparison of an analytical model and an FEA result.⁵ Visualisation is not a replacement for theory, but a didactic bridge that enables structured interpretation (load-boundary-response) and pattern recognition (e.g., symmetry, hotspots, edge effects). Dynamic visualisations (e.g., animation) further enhance conceptual clarity.

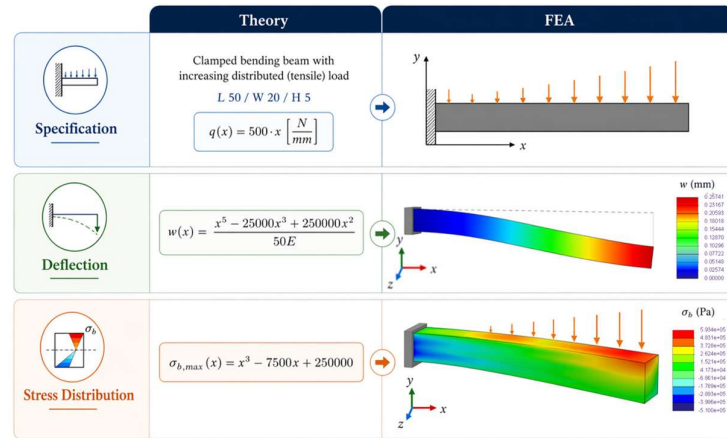


Figure 2. Application examples illustrating the use of FEA as a didactic tool for visualisation and conceptual understanding

4.3 Limitations

The empirical findings are based on a case study with HTL instructors in an FEA-relevant context. Accordingly, the very high reported adoption rate (96%) may be specific to this setting and may not generalise to other subjects, school types, or education levels. In addition, diversity is used as an interpretive framework for discussing heterogeneity in learners and teaching practices, but no direct learner data were collected (e.g., learning outcomes, self-efficacy, subgroup comparisons), which limits empirical claims about diversity-related effects.

A further limitation concerns stress interpretation and comparability across instructional approaches: in FEA, stresses are represented as local, element-based quantities that can exhibit peaks (e.g., at singularities or strong gradients), whereas school-level mechanics often relies on simplified or nominal stress measures derived from idealised assumptions. Without sufficient theoretical grounding and explicit instructional framing, particularly in more pragmatic/visualisation-oriented uses, this mismatch can encourage misinterpretation (e.g., treating local peaks as directly comparable to simplified metrics).

5 CONCLUSION AND FUTURE WORK

This paper addresses the central tension between "click-based simulation" and "simulation with depth". FEA is already widely used in HTLs, mainly as a tool for visualisation and understanding. Especially in early education stages, its value lies in rendering abstract phenomena tangible and providing visual entry points for diverse learners.

The proposed three-level model provides a practical framework for balancing benefit and limitation while preventing misinterpretation. As a next step, the educational impact of visualisation-based FEA use should be quantitatively assessed, e.g., through pre/post testing or controlled comparisons of learning outcomes. Additionally, the development of standardised teaching materials and professional development offerings is planned.

⁵ A further limitation concerns the comparability of stress results: in FEA software, stresses are computed as local, element-based quantities derived from the underlying continuum model. In contrast, classical mechanics teaching typically derives stresses from simplified nominal stress concepts. If this conceptual difference is not made explicit, FEA plots may be misread as directly comparable to analytical nominal stresses.

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INCLUSIVE DESIGN PRACTICE - INCREASING ADOPTION BY ENGINEERING STUDENTS

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ABSTRACT

Engineering businesses report diversity, equity and inclusion within design ranks low, in a Royal Academy of Engineering survey of relevance and preparedness. At the University of Southampton, we prepare graduates from engineering UG programmes to have an interest in inclusive design. They are encouraged to empathise with a range of perspectives and issues in pursuing their group design work. To what effect? We do not currently see final year engineering students widely adopting inclusive design principles and practice, so what can we do? We benefit most from seeking to emulate good practice in our taught content derived from standards and expert practice, notably the Cambridge University Inclusive Design Toolkit. A few student groups, in their final year group design project, report an approach that addresses a good range of the eight aspects of inclusive design consolidated here, mainly from EN 17161:2019 Design for All and the Inclusive Design Toolkit. To extend the adoption of good practice we can build on what is delivered to most engineering disciplines in their first and second year, following recommendations here to develop; sensitivity to the need for inclusive design (from wider examples which are likely to resonate), knowledge of good inclusive design practice (from holistic evaluation exercises), design judgement (from user evaluation and empathy tools) and commitment to applying inclusive design (from interim assessment incorporating design risks to aid early prioritisation). We could also benefit from creating manageable opportunities for stakeholder feedback in planning and implementing students' design process, to verify and validate our continuous improvement.

Keywords: Inclusive, engineering, design, education

1 INTRODUCTION

There is a significant challenge in ensuring that inclusive design practice is properly recognised, valued, and prepared for in graduate engineering education, so that engineering organisations can rely on the capabilities of graduate engineers in these increasingly important areas.

The results from a 2023 survey of *ethics in the engineering profession* [1] showed that diversity, equity and inclusion (DEI) ranked highly in terms of relevance to engineering business and professional engineering institutions and such organisations rated their preparedness as 'high'. However, 'diversity, equity and inclusion **within design**' ranked low in survey respondent's judgement of relevance and their preparedness. "While companies were aware of this issue in a general context, many did not see the relevance to their particular product or service" [1]. Good practice is increased by awareness of ethical issues through mandatory training. "A minimum requirement for ethics-related CPD content, and signposting to available resources, would be helpful" [1]. Ahead of the need for CPD, in the University of Southampton's School of Engineering in the UK, we aim to train graduate engineers' capability and preparedness to design inclusively. We aim to address; Physical Needs (aspects including mobility and dexterity), Sensory Needs (aspects including audibility, visual clarity, and the need for tactile feedback), and Cognitive Needs (considering memory, attention spans and an ability to learn new things).

If in our experience final year engineering students are not fully adopting inclusive design principles, we should ask: what more can we do? Perhaps we ourselves are drawing on limited experience, testing how well designs meet a range of psychological and physiological needs appears difficult.

Through our engineering teaching we aim to meet the expectations for inclusive design embedded in professional formation towards achieving professional competence, in the UK expressed in the UK-SPEC [2]. In this paper we examine how effective that provision appears to be, by analysing students' reported practice in their final-year group design projects, identifying gaps and opportunities for improvement.

2 EXPECTATIONS FOR INCLUSIVENESS IN ENGINEERING DESIGN

The UK Equality Act (2010), requires service providers to avoid discrimination based on age and other protected characteristics, emphasising the importance of adopting inclusive design. BS EN 17161:2019 reports that European States have committed to applying Universal Design in the development of new goods, products, facilities, technologies and services to ensure full, equal and unrestricted access for all. This Design for All approach intends that all products and services can be easily accessed (approached & perceived), understood (comprehended and choices decided); and used (acted with or reacted to). [3]

2.1 Engineering – professional practice and the undergraduate formation aim

Accredited engineering degrees prepare students to become registered professionals who are required to demonstrate ‘awareness of diversity and inclusion issues [2]. The UK body, the Engineering Council’s Statement of Ethical Principles has an expectation that professional engineers will promote equality, diversity and inclusion [4]. However, the standard for professional engineering competence, UK-SPEC, only applies to registered engineers and thus has a limited reach for effecting cultural change [1].

Chartered Engineers “shall prepare, present and agree design recommendations... taking account of cost, quality, safety, reliability, **accessibility**, appearance, fitness for purpose...” [2]. When forming professional engineering capabilities, the learning aims for undergraduates studying an accredited degree (AHEP 4) include the competence to, “design solutions for complex problems that meet... **diversity, inclusion...**” and to, “...recognise the responsibilities, benefits and importance of supporting equality, diversity and inclusion.” To evaluate our teaching of engineering design in UG degree programmes, we can first establish aspects of existing guidance for inclusive design.

2.2 Existing guidance on inclusive engineering design

Established guidance on the scope of inclusive design appears in several standards. However, BS 7000-6:2005 ‘Guide to managing inclusive design’ [5] does not break down specific aspects of inclusive design practice. BS EN 17161:2019 Design for All, is more helpfully prescriptive; “Inclusive design recognises diversity by addressing the ability and preferences, for example, of people who:

- have impaired vision and/or hearing (including colour blindness, etc.);
- are from different cultures (with different languages, values and/or customs);
- have language and/or speech impairments (resulting in difficulties with reading & comprehension);
- have physical limitations (reductions in strength, movement and/or co-ordination, etc.);
- are different ages, have varying cognitive abilities and have different requirements for gender” [3].

These standards both reference the Cambridge University Inclusive Design Toolkit [6] which suggests five categories of user capability should be considered when designing or assessing a product:

- **Vision**; the ability to use the colour and brightness of light to detect objects and discriminate between surfaces and details.
- **Hearing**; the ability to discriminate tones or speech from ambient noise and to tell where sounds are coming from.
- **Thinking**; the ability to process information, hold attention, store & retrieve memories and select appropriate responses and actions.
- **Reach & Dexterity**; the abilities of the arms to reach to different places around the body, perform fine finger manipulation, pick up and carry objects and grasp and squeeze objects.
- **Mobility**; the ability to move around, climb steps and balance.

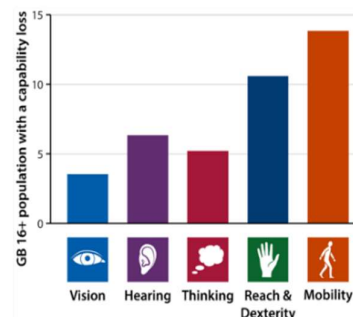


Figure 1. Capability loss in five categories among the Great British adult population [6]

The Cambridge University Engineering Design Centre propose assessing the demand placed on a user by the design in each of the five areas above, to compare with the capability of a sample user [6]. An ideal design should place a demand in each area lower than the lowest capability of a range of users, in the anticipated range of conditions e.g. ambient light/sound levels can compromise a user’s ability to read/hear. To extend the range of users whose capability exceeds the lower limit, designers can [5]:

- provide multiple means of information presentation and user interaction;
- provide solutions with fixed or adjustable parameters (personalisation);
- minimise complexity and eliminate unnecessary limits or constraints on user interactions;
- provide compatibility with assistive technologies.

Detailed design process outputs are available in Table C1 in EN 17161:2019 Design for All [3] including results from ‘Evaluation from the perspective of the widest range of users. “It is important that inspection is carried out by people with expertise and experience in accessibility and usability... to identify major issues...” [3]. In evaluating designs against user requirements, Useability/Human Factors Engineering methods can enhance consideration of use scenarios with hazards using risk management. This applies for example, in medical devices where ISO EN 62366-1:2015 [7] informs the process, for example to tackle the root cause of use errors, noting, “nearly every evaluation finds use errors...” Consolidating elements of inclusive design below helps to confirm where we are teaching best practice.

2.3 Engineering Design – consolidated aspects of inclusive design

Drawing mainly on the Inclusive Design Toolkit [6] and Centre for Excellence in Universal Design’s 7 Principles of Universal Design [8], we can create a consolidated list of five partially overlapping inclusive design aspects to benchmark our teaching. Physical accessibility is sub-divided into four parts:

1. **Physical Accessibility:** Does the design provide ‘dignified access’, equivalent utility for users with physical limitations, e.g. multiple forms of interaction, and no segregated ‘disabled’ provision?
Does the design demand capability less than the range of anticipated users’ capability in terms of,
 - a. Vision, considering the size, shape, contrast, colour and placement of form, graphics and text,
 - b. Hearing, considering volume, pitch, clarity and location of sounds versus background noise,
 - c. Reach and Dexterity, considering forces, movements, precision and types of grips required in use, noting demands increase reaching above the head or below the waist and with repetition,
 - d. Mobility, considering whether the product requires the user to move around and provides suitable features to assist with any climbing, with balance and with support for mobility aids?
2. **Cognitive & Neurodiverse Suitability:** Does the design demand less than the range of anticipated users’ capabilities in sensory processing; memory, attention, pace and prior experience e.g. through limiting complexity, making layout/form match conventions for function, reducing ‘visual noise’, simplifying acoustic effects, separating interactions and making them reversible with feedback?
3. **Equitable Use & Safety:** Are functional, privacy, security and safety features equally effective for all body types e.g. male & female, or different heights/reaches/(grip)strengths, also are hazards and errors minimised and do features cater for a range of environmental conditions and use of aids?
4. **Information Inclusion:** Is all interface and safety information available in multiple formats (audio, tactile, high contrast) to suit those with different literacy levels or vision/hearing impairments?
5. **Responsiveness to Diversity:** Is the design responsive to language and cultural differences, speech impairments, age differences, medical conditions, perhaps with multiple forms of interaction or the ability to be personalised to meet individual user needs?

We can then consider how much of this consolidated inclusive design guidance is conveyed in our teaching, and how much capability do engineering students report adopting in final year design projects?

3 TEACHING INCLUSIVE DESIGN – INTENDED LEARNING

At the University of Southampton, aligned with a general EDI Vision, 'To foster a culture of respect, inclusivity & open-mindedness', first year UG engineering students are introduced to,

- a) values, including EDI; designing seeking equitable use in terms of age, disability, cultural/socio-economic background, race, pregnancy, religion/belief, gender & sexual orientation, in the context of under-served and changing markets e.g. an ageing demographic with capability loss, Figure 1,
- b) performance specification e.g. including anthropometric data informing ergonomic performance.

In groups students apply performance specification in a design project, with an opportunity to reflect and review evidence of their learning in a portfolio. The design brief varies by engineering discipline.

Some briefs e.g. to design a hydro-turbine, do not overtly suit applying aspects of inclusive design.

In the second year most UG engineering students are introduced to systems design in which IDEO Method Cards are referenced, seeking to introduce to them methods which would support inclusive design; anthropometric analysis, error analysis, cross-cultural comparisons, rapid ethnography, extreme user interviews, cultural probes, role playing, behaviour sampling, experience prototyping and use of empathy tools (‘to experience processes as though you have the abilities of different users’) [9].

An example Design Specification template for second year mechatronic design, build & test projects, prompts consideration of ergonomics and some project groups do add aspects of inclusive design.

Further study of inclusive design in the third year then depends on discipline specific modules. Mechanical Engineering students are introduced to human factors, design following anthropometric

assessment to achieve ergonomic performance, manual handling, further empathy tools e.g. simulation glasses, the inclusive design toolkit [6] and four characteristics of accessible design: Perceptibility Operability, Simplicity and Forgiveness (minimising the occurrence and consequences of errors). Good practice in inclusive design of user interfaces is illustrated with ‘Dos and don’ts on designing for accessibility’ [10] and examples of perception with colour vision deficiency. An example of co-design with older adults shows how to better understand needs and preferences e.g. for large, easy-to-read fonts, simple interfaces, ramps, wide doorways, grab bars, clear instructions, patience and communication. Other engineering disciplines may have more or less opportunity for learning before those continuing to a fourth-year group design project can choose to apply aspects of inclusive design in practice.

4 EVIDENCE OF ACTUAL INCLUSIVE DESIGN LEARNING

This study focuses on evidence for the effectiveness of learning in UG engineering degree programmes in the University of Southampton. In the fourth-year final design project, students should be able to apply aspects of inclusive design in a relatively large and challenging group design project (GDP). They respond to a brief proposed by an academic supervisor with some scope to develop performance specifications from researching stakeholder needs. Given the competing priorities within these projects, students’ reported choices provide the most reliable available evidence of the extent to which they are incorporating inclusive design in their engineering practice and therefore indicate their likely capability at graduation. Within the group project interim report template, the following prompt question is asked: *“What aspects of equality, diversity and inclusivity have you identified that should be considered with respect to your design and/or project management? This includes the areas/aspects where you will consider inclusive design practices.”*

62 groups of 5-6 students in the fourth (final) year of their UG engineering degree in 2025-26 responded with free text in their interim report submitted after the first 2 months of their 7-month GDP. This is the stage when their design performance specification should incorporate stakeholder input and their engineering design should be clearly established as a concept. Group membership is aligned with the major technology discipline in the project, predominantly Aeronautical Engineering (32%) and Mechanical Engineering (50%), fewer Civil Engineering projects (13%), Marine or Acoustical Engineering (each 2%). Though the technology focus varies, it would be rare for the scope of the design project to preclude a reasonable expectation for the students to address inclusive design aspects.

The proportion of responses which aligned with each of the eight consolidated aspects of inclusive design (section 2.3) is taken to indicate the student group’s collective adoption of these aspects in their design practice. The percentages are suggested here as a reasonable measure of the level of the cohort ‘s capability and preparedness to apply their learning in engineering design. The level of students’ collective adoption of each aspect of inclusive design practice is low, as shown in Figure 2. Within each group the number of aspects adopted is also typically low. While some groups embrace the potential of their design project to incorporate inclusive design, many appear not to do so.

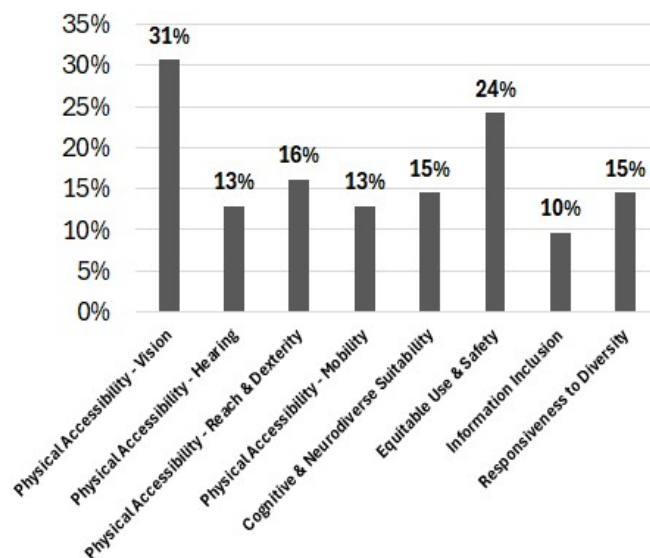


Figure 2. Inclusive design aspects evident in GDP interim reports

35% of groups responded only by noting aspects of equality, diversity and inclusivity that should be considered with respect to project management, with no aspects of inclusive engineering design reported as being included in their design specification and initial embodiment of design concepts.

34% of groups responded identifying only one aspect of inclusive design, typically, as shown in Figure 2, design for impaired vision in their design’s user interface, or design for equitable use and safety.

The widest range of aspects, adopted by a Maritime Engineering group, shows that it is possible to reflect most aspects of inclusive design after 2 months work. Their interim report included (extracts):

- Manual tasks (lifting, pushing, pulling) for normal operation must suit a range of strength levels.
- Actions taken to facilitate ease of movement around the vessel should include clear routes with improved visibility, highlighted steps or trip hazards, handrails and clear instructions.
- The operation of the lifeboat and its associated equipment must eliminate any bias towards casualty survivor rate. Recovery and movement of survivors on board the vessel must be accessible to all.
- Signage should be clear... warnings should use audio (siren) and visual (flashing beacon) signals...
- Survivor seating must accommodate 2.5% females to 95% males, inc. children & pregnant women.

An Aeronautical Engineering group also showed that responses to a good range of aspects is possible:

- Wind tunnel operation indicators should use both visual and audible warnings to alert deaf and blind people in any dangerous areas, ... issued with sufficient time before tunnel operation to allow physically impaired people in dangerous areas to either vacate or alert tunnel operators.
- All documentation (operation, H&S, software) should be easily translatable with clear instructions. Intense colours and clear symbols must be used to convey the message across relevant languages.
- Modular components must be light or physically undemanding, enabling the widest future usage.

Although only one source of evidence, generally low levels of adoption of practices addressing the eight consolidated aspects of inclusive design (2.3) across the 62 final year group design projects, suggests, with notable exceptions, there is potential to improve this part of learning and teaching for UG students.

5 RECOMMENDATIONS FOR POTENTIAL IMPROVEMENTS

For the University of Southampton to realise greater potential in inclusive design practice there appear to be five opportunities to address the gaps in UG students' apparent capabilities (Section 4), through developing learning content and learning methods. Adapting Davis and Feinerman's learning aims which can be applied to engineering ethics [11], the learning content and method should first seek to improve students' **sensitivity** (the awareness and recognition of inclusive design challenges) and increase their **knowledge** (resources such as codes, standards, theories, and/or decision-making tools). Then the method should enhance students' **judgement** (the analysis and reasoning required to make and justify choices) and finally reinforce students' **commitment** (the motivation to act based on learning).

5.1 Recommendations for Developments in Learning Content and Methods

1. Ensure knowledge, particularly of the less widely adopted aspects of inclusive design (Figure 2) is suitably enhanced with illustrations of good design practice in response to hearing impairment, limited reach & dexterity, limited mobility, limited cognitive ability, neurodivergent conditions, information exclusion and characteristics of diversity – so the realisation that design responses are needed for all 8 aspects is relatable to technological solutions resonating with students' interests.
2. Include in workshop-style activity, students performing an evaluation of an example design for its demand versus different user groups' capability in the eight aspects, by plotting assessment of demand vs. capability, as illustrated in the Inclusive Design Toolkit [6]. A group of students can be given different user profiles in terms of age, physical or mental impairment and compare their evaluation results, thereby practicing recognition and empathy for others' ease of use. Empathy tools such as the Cambridge Inclusive Design Toolkit's Simulation Gloves and Simulation Glasses and Impairment Simulator Software (demonstrating the effects of vision and hearing impairments on image and sound files) could be explored, or the effects reproduced by other means.
3. Include in processes for establishing performance specifications, prompts to consider the eight aspects of inclusive design for relevant user groups, validated with available (proxy) users (e.g. academics). Include inclusive design aspects in reviews of design performance vs. specification.
4. In design risk assessments, prompt for including potential failures to suitably address the 8 aspects of inclusive design. Seek to show how designers can identify potential failures to design inclusively alongside all other aspects of design performance, and prioritise responses to severe or likely detrimental consequences, even in the case of novel designs with unprecedented use scenarios.
5. Include in formal assessment of designs, expert/stakeholder and peer evaluation of inclusive design performance at an interim stage when improvements can still be implemented within the current design process. Evaluation at a final assessment stage, should consolidate the recognition of the priority of addressing inclusive design and integrating it as a relevant capability to commit to.

Through conferring on such recommendations with stakeholders in the development of engineering education, we aim to develop inclusive design practices in our teaching methods and monitor the results, including how well future students' practice aligns with the consolidated aspects of inclusive design.

6 CONCLUSIONS

Though engineering businesses report diversity, equity and inclusion within design ranks low in relevance and their preparedness, we can at the University of Southampton prepare graduates from engineering UG programmes to have a real interest in inclusive design. Students are already encouraged to empathise with a range of perspectives and issues in pursuing their group design work from their first year. However, we do not currently see final year engineering students, deeply or widely adopting inclusive design principles. We can further emulate good practice in our taught content by revisiting standards and expert practice, notably that in the Cambridge University Inclusive Design Toolkit [6].

A few student groups, in their final year group design interim project report, note an approach that addresses most of the eight aspects of inclusive design consolidated in section 2.3. To extend that limited adoption of good practice, we can build on what is delivered to most engineering disciplines in their first and second year, following the recommendations in section 5.1 to develop; **sensitivity to the need for inclusive design** (from wider examples likely to resonate with students), **knowledge of good inclusive design practice** (from evaluation exercises for the eight aspects), **design judgement** (from proxy user evaluation and empathy tools) and **commitment to applying inclusive design** (from interim assessment incorporating design risks at stages in design where improvements can be realised).

Through implementing such recommendations, we, amongst others teaching engineering design and tutoring related projects, can make our modelling of desirable behaviours more evident. We can then seek feedback from stakeholders in our education process to evaluate the effects of this approach, seeking to continuously improve our influence on student learning and subsequent professional practice.

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BEYOND HUMAN INCLUSION: AI AND THE EXPANSION OF CREATIVE PARTICIPATION IN DESIGN

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ABSTRACT

Artificial Intelligence (AI) is increasingly embedded in designers' creative workflows, reshaping not only how design is produced but how participation in the creative process is configured. What began as computational support for ideation and efficiency is progressively transforming the distribution of agency within design practice. This paper examines how the meaning of inclusion evolves in response to AI integration for creative empowerment, reframing it as creative participation across human, artificial, and more-than-human actors. The study combines the *three waves* paradigm of human–AI creative relationships with the Inclusive Design Research Centre (IDRC) framework as complementary analytical lenses. This reading traces how the role of AI evolves from a tool augmenting human cognitive access (First Wave), to a collaborative partner enabling hybrid co-creation (Second Wave), and toward an embodied agent within distributed multi-intelligence ecosystems (Third Wave)—revealing a parallel expansion of creative participation from individual augmentation to relational negotiation and systemic coexistence. The paper introduces the concept of relational creative agency and discusses implications for design education, highlighting the need to cultivate orchestration, trust calibration, systems thinking, and ethical reasoning for emerging multi-intelligence design contexts.

Keywords: Human-AI co-creation, creative participation, inclusive design, distributed creativity, design education

1 INTRODUCTION

Artificial Intelligence (AI) is increasingly embedded in designers' creative workflows, where it is widely used to support ideation, exploration, and the generation of creative outputs. What initially emerged as a productivity aid is rapidly becoming a structural component of contemporary design practice, profoundly reshaping the relationship between designers and the creative process [1]. Recent scholarship suggests that the inclusion of AI agents in creative processes is fundamentally reshaping how designers think, act, and contribute to design activity. Research on hybrid intelligence conceptualises human–AI collaboration as a complementary system in which artificial agents generate outcomes that exceed individual human intentions [2]. Empirical studies of computational co-creativity further show that AI systems dynamically participate in creative exchanges, influencing direction, interpretation, and meaning making during interaction [3]. From a socio-technical perspective, this shift challenges the traditional view of technology as a passive tool. Theories of material and technological agency argue that artefacts actively shape human practice [4], while Giaccardi and Redström [5] describe emerging intelligent systems as “co-performers,” thereby questioning the anthropocentric assumptions that have historically underpinned design. These developments suggest that the growing inclusion of AI in creative processes is not merely a technological shift but a conceptual one. If multiple intelligences can now actively contribute to design outcomes, how might we reframe the concept of inclusiveness in the creative process? As designers increasingly adopt AI in the creative process, the traditional framework of inclusive design, primarily concerned with human diversity, requires reconsideration. The paper argues that AI integration is transforming inclusion from a human-centred accessibility paradigm toward a relational form of creative participation distributed across human, artificial, and environmental actors. The paper also discusses the implications of this shift for design education.

2 SIGNALS OF CHANGE: THE EXPANDING SCOPE OF INCLUSION IN DESIGN

Once primarily concerned with human-centred accessibility, inclusive design is increasingly being reframed through socio-political, systemic, and ecological lenses. Early formulations such as *Universal Design* [6] and capability-based *Inclusive Design frameworks* [7] focused on reducing functional exclusion in the use of products, services, and environments by accommodating diverse human abilities across the population. These approaches established inclusion as a measurable response to human variability yet largely retained an anthropocentric and product-oriented focus. Expanding this view, the *Inclusive Design Research Centre (IDRC)* reframed inclusion as an ecosystem property grounded in human uniqueness and systemic adaptability [8]. Subsequent developments, including *Design Justice* [9], reframed inclusion as a matter of redistributing power within the design processes, emphasising community leadership, intersectionality, and structural equity. More recent regenerative and more-than-human design perspectives [10] further challenge the anthropocentric assumptions underlying even progressive inclusive models by recognising ecological systems, living materials, and AI agents as legitimate participants in design. Within this expanded horizon, *Biodiversity Inclusive Design* has emerged as a critical synthesis integrating justice-oriented design with a bio-relational ontology attentive to multispecies agency and material vitality [11], reframing design as a relational practice across human-nonhuman assemblages. Parallel to these developments, the growing adoption of AI in creative practices is prompting renewed reflection on who participates in the creative act. AI systems increasingly challenge the assumption that agency resides solely with human users [5], reframing technological artefacts as co-performers within design processes. Empirical studies show that designers must now negotiate hybrid forms of agency as AI systems move beyond passive tool use toward more active participation [12]. Co-design research similarly expands inclusion beyond stakeholder diversity toward an ontological reconsideration of who - or what - counts in design [13]. These signals may inform us about a decisive transformation: inclusive design is no longer confined to accommodating human difference but is becoming processual, systemic, and post-anthropocentric - reconfigured around relational networks of human, artificial, and more-than-human agencies.

3 DEFINING THE ANALYTICAL FRAMEWORK

In this paper, we analyse how the increasing use of GenAI in the creative process is reshaping the concept of inclusion in design. The study combines the *three waves paradigms* of human-AI relationships for creative empowerment [1] with the IDRC Inclusive Design framework as complementary analytical lenses [8]. While the *three waves* model traces how roles and agency evolve across human-AI creative configurations, it remains primarily descriptive. The IDRC framework, by contrast, provides a systemic theory of inclusion but does not explicitly account for artificial agents as actors in the creative process. Their integration is therefore analytically generative: the *three waves* model reveals how creative agency shifts, while the IDRC dimensions enable a systematic assessment of how these shifts progressively redefine participation within AI-empowered creative ecosystems.

3.1 The evolving role of AI in the designers' creative process

The *three waves* paradigm addresses the evolving relationship between GenAI and the designer's creative process. These waves serve as a starting point for reflecting on how AI is introduced into the design process to support creative empowerment. From AI being a practical tool for performing tasks in the creative process (first wave), the relationship has evolved toward a collaborative process between humans and AI, where AI can be seen as an active co-creator rather than merely a tool (second wave). This relationship will further evolve, seeing AI as an isolated agent interacting with humans, machines, and the environment within a distributed creative process (third wave). Within this conceptualisation, the focus of inclusion shifts from access to designed outcomes toward creative participation in the design process. As human-AI relationships evolve, creative participation itself is redefined, reshaping who takes part, with what roles, and with what forms of agency.

3.2 The IDRC Framework as a lens on creative participation

To systematically examine how the concept of creative participation evolves across the three waves paradigm, the authors adopt the three core dimensions of Inclusive Design articulated by the Inclusive Design Research Centre (IDRC) [8]:

- **Recognise and design for human uniqueness and variability**, moving beyond “one-size-fits-all” solutions toward highly differentiated responses to individual needs.
- **Use inclusive and transparent co-design processes** involving people with diverse perspectives - particularly edge users - as active contributors throughout development.
- **Design within complex adaptive systems**, acknowledging that design decisions operate within interconnected socio-technical contexts and should transform exclusionary dynamics into system-level benefits.

The IDRC framework was selected for three reasons. First, it offers a guiding approach suited to a digitally transformed and highly interconnected society, framing inclusion as a systemic and adaptive property aligned with the distributed dynamics of AI-mediated creativity. Second, it frames diversity as an epistemic resource rather than a deviation from the norm, supporting a cognitively open view of participation. Third, its grounding in HCI, disability studies, and socio-technical systems theory provides a robust basis for analysing the shift from person-centred inclusion toward systemic forms of creative participation.

4 THE EVOLUTION OF CREATIVE PARTICIPATION ACROSS THE THREE WAVES

The analysis reveals a progressive expansion of creative participation within AI-empowered creative practice. Across the waves, AI does not simply enhance efficiency but gradually transforms who participates in creativity, how participation is structured, and toward what systemic purposes creative processes are oriented. This evolution directly affects the constellation of cognitive, motivational, and socio-technical factors that underpin creative potential in design. This structured reading reveals not only increasing technological sophistication but also a progressive redefinition of inclusion within the creative process, moving from human-centred access toward hybrid and ultimately distributed creative participation. Although analytically presented as sequential, the three waves cannot be clearly separated in practice: their boundaries are blurred, and they frequently overlap and co-evolve over time, simultaneously embodying multiple dimensions of creative participation. For detailed empirical examples illustrating each wave, readers are referred to Bruno et al. [1].

4.1 First wave - AI as a tool: augmenting cognitive access

The first dimension of the IDRC framework - recognise and design for human uniqueness - provides a critical lens for interpreting the first wave of human–AI interaction. In this phase, AI primarily operates as a computational tool that helps designers move beyond standardised “one-size-fits-all” solutions toward more differentiated and tailored responses. By enabling the analysis of large and diverse datasets, AI increases the system’s capacity to recognise human variability and support more fine-grained personalisation within the creative process. In this wave, AI augments designers’ efficiency throughout the creative process, supporting activities such as large-scale information gathering, pattern recognition, clustering, and rapid generation of alternatives from extensive datasets. Cognitive technologies can rapidly synthesise unstructured data and surface insights that would otherwise remain difficult to detect [14], thereby expanding designers’ access to creative knowledge. From a participation perspective, the designer remains the primary creative agent but increasingly operates as a meta-designer, configuring parameters and strategically leveraging computational variability. AI functions as an extension of human cognition - a prosthesis that reduces informational and cognitive barriers and enables broader access to complex creative resources. However, the interaction remains largely instrumental and unidirectional. Designers use AI to accelerate workflows and maintain creative momentum, but the system does not yet meaningfully reshape the dialogic structure of ideation. Inclusion, therefore, primarily expands at the level of **augmented cognitive access**, rather than through a redistribution of creative participation. At the level of creativity factors, this wave primarily strengthens **domain knowledge activation, memory retrieval, pattern recognition, and analogical reasoning**. By offloading repetitive analytical and generative tasks, AI reduces cognitive overload [14] and allows human attention to concentrate on higher-order interpretive and critical activities. Creative control remains predominantly human-led: designers define parameters, interpret outputs, and curate final solutions [15]. In summary, creative participation in the first wave is **infrastructural and human centred**. AI accommodates differences in human cognitive capacity and enables more finely tuned personalisation, yet it does not fundamentally

redistribute agency within the creative process. The centre of creativity remains firmly human, even as it becomes computationally amplified.

4.2 Second wave - AI as a partner: orchestrating hybrid creative participation

The second dimension of the IDRC framework - *use inclusive and transparent co-design processes* - provides a critical lens for interpreting the second wave of human–AI interaction. In this wave, AI evolves from an efficient tool into an active collaborative partner, transforming the creative process into a dialogic and bidirectional exchange. Rather than merely supporting isolated tasks, AI increasingly participates in ideation by generating suggestions, proposing analogies and metaphors, and offering real-time feedback that shapes the direction of creative exploration. From a participation perspective, this wave marks a shift from instrumental use toward negotiated agency. Human–AI interaction becomes symbiotic: both actors contribute to and influence the creative trajectory. AI systems can stimulate divergent thinking, support visualisation, and introduce alternative framings that contribute fresh perspectives and expand designers' cognitive horizons. As a result, imagination, perspective-shifting, and idea generation become progressively distributed across human and artificial actors. Conceptually, this transition strongly reinforces the IDRC dimension of inclusive co-design processes. Inclusion moves beyond accommodating individual variability toward restructuring the creative process itself as a multi-agent collaborative system. The focus shifts from equality of access to **cognitive diversity**, as non-human forms of reasoning enter the ideation space and actively challenge designer assumptions. AI's generative unpredictability plays a particularly important role in this phase. By introducing elements of surprise and reframing, AI can disrupt cognitive fixation, stimulate divergent thinking and expand imaginative exploration [16]. Creativity, therefore, becomes more explicitly relational and processual, emerging from continuous feedback loops between human and artificial agents. At the level of creativity factors, the emphasis expands toward **idea co-generation, perspective shifting, creative flow activation, and feedback negotiation**. Designers are required to actively manage the dynamics of collaboration, balancing openness to machine contributions with critical oversight. Accordingly, the designer's role evolves toward orchestrating the dialogue with AI [17], calibrating trust, and critically evaluating machine-generated outputs [18]. Agency becomes partially shared: creativity increasingly emerges from negotiated human–AI interaction loops rather than from individual cognition alone. In summary, creative participation in the second wave becomes **hybrid and co-evolving**. AI is no longer merely accommodating human cognitive differences but actively reshaping who participates in creativity and how creative authority is distributed. Inclusion thus shifts from an infrastructural condition toward a relational one, reflecting the emergence of multi-intelligence co-production within the design process.

4.3 Third wave - AI as embodied agent: enabling multi-intelligence coexistence

The third dimension of the IDRC framework - *designing in a complex adaptive system* - provides the critical lens for interpreting the speculative third wave of human–AI interaction. In this phase, AI is no longer understood primarily as a tool or even as a discrete collaborator, but as an **embodied creative agent operating within ecosystems of distributed intelligence**. Creativity is no longer located within individual minds; rather, it emerges from dynamic interactions among humans, artificial systems, and environmental actors. From a participation perspective, this wave marks a fundamental systemic shift. Intelligence becomes distributed across multi-agent ecologies, requiring designers to move beyond creating isolated artefacts toward **designing conditions that enable emergent outcomes**. Drawing on theories of distributed cognition [18] and more-than-human design [10][13], the creative process becomes relational, situated, and environmentally embedded. Conceptually, this wave most strongly amplifies the IDRC dimension of designing within a complex system to achieve a broader, beneficial impact. Inclusion expands beyond human participants to encompass biodiversity, ecological systems, and more-than-human stakeholders who are increasingly treated as legitimate “clients” of the design process. AI operates as an infrastructural mediator, integrating physical, social, and ecological data streams, rendering environmental signals perceptible in creative decision-making and supporting more-than-human design approaches oriented toward sustainability challenges. Access to creative knowledge, therefore, becomes multi-layered and context aware. Rather than drawing solely on human-generated datasets, AI systems increasingly synthesise environmental, behavioural, and systemic information. Participation correspondingly extends beyond the human–AI dyad toward complex multi-agent ecosystems, where creative outcomes are shaped by ongoing interactions among heterogeneous actors

[18][19]. At the level of creativity factors, this wave foregrounds **distributed cognition, situated and embodied intelligence, systems thinking, and relational sense-making**. Creativity evolves from an individual or hybrid capability into an emergent property of the system itself. Accordingly, **creative agencies become systemically distributed**. Designers shift from sole creators or arbiters toward orchestrators and stewards of multi-intelligence ecologies [19]. Their responsibility increasingly involves cultivating resilient relationships across human, artificial, and ecological domains and transforming potentially exclusionary dynamics into virtuous cycles of systemic co-performance. In summary, creative participation in the third wave reaches a systemic threshold. Inclusion is no longer primarily infrastructural or relational but ontological: it concerns which forms of life, intelligence, and knowledge are recognised as legitimate participants in the creative process. This shift introduces profound ethical and educational challenges, positioning designers as key actors in shaping more resilient, sustainable, and coexistent socio-technical futures. A concrete example comes from Neri Oxman's *Material Ecology* practice (MIT Media Lab), in which computational algorithms, biological organisms (silkworms, bees), and environmental data streams co-produce design outcomes that no single agent could predetermine [20]. As a designer, she acts as a steward of multi-intelligence ecology.

5 FROM AUGMENTING COGNITIVE ACCESS TO ENABLING COEXISTENCE

The trajectory traced across the *three waves* does not simply describe a technological progression; it reveals a deeper transformation in how participation, agency, and responsibility are configured within design. What begins as the augmentation of human capability progressively destabilises the anthropocentric foundations of creative practice. Inclusion, historically framed as the accommodation of human difference, becomes insufficient to account for the emerging conditions of AI-mediated creativity. Across the waves, the centre of gravity shifts markedly - from optimising the individual designer's performance, to hybrid co-performance between human and artificial agents, and ultimately toward systemic configurations in which creativity emerges from entangled relations among humans, machines, and environments. Creativity can no longer be fully understood as an attribute of an individual subject; rather, it increasingly manifests as a property of a relational field. This progression challenges the very grammar of inclusion. Traditional models presuppose a boundary, a norm, and the act of admitting the Other into an already-defined system. The configurations observed across the three waves suggest a more profound reconfiguration: not simply the expansion of participation, but the redistribution of creative agency itself. The critical question shifts **from who is included to how agency is negotiated and sustained across heterogeneous intelligences**. From this perspective, the contribution of this paper lies in reframing the discourse from inclusive design toward **relational creative agency** - a condition in which creativity is understood as co-emergent, distributed, and ethically situated within multi-intelligence ecosystems. In this emerging landscape, AI is neither a neutral tool nor a rival intelligence, but an infrastructural mediator that reshapes the conditions under which creative participation becomes possible. The implications for design education are substantial. Teaching AI merely as a productivity enhancer is no longer sufficient. Nor is it adequate to frame human-AI collaboration primarily in terms of efficiency gains. Concretely, foundational studios can introduce *reflective AI auditing* - where students document and critically evaluate the AI's role at each ideation stage - to develop critical AI literacy and reflective use of generative tools; intermediate studios can deploy adversarial *co-creation workshops* with structured peer critique to cultivate human-AI co-creation, dialogic orchestration, trust calibration, and orchestration skills; and advanced projects can adopt *more-than-human design briefs* and *speculative ethics assessments* to address the systemic, ecological, and ethical dimensions of distributed intelligence while cultivating systems thinking and ethical reasoning.

Ultimately, the integration of AI into creative practice confronts design with a pivotal choice. AI can reinforce technocentric logics of optimization and control, or it can support the emergence of a mature technosphere capable of coexisting responsibly within the biosphere. The *three waves paradigm* suggests that the future of design will depend less on computational power alone and more on cultivating relational intelligence, systemic responsibility, and the willingness to reconceptualise creativity itself as a shared, planetary condition.

6 CONCLUSIONS

This study proposes a structured interpretation of how creative participation evolves across the three waves of human-AI interaction, mobilising the IDRC dimensions as an analytical lens. Through this

comparative reading, the paper highlights a progressive shift from human-centred augmentation to hybrid co-creation and, ultimately, toward distributed multi-intelligence ecosystems. The analysis remains primarily conceptual and interpretive. Further empirical research is needed to examine how these dynamics unfold in situated design and educational contexts, and how designers and students navigate emerging multi-intelligence environments. Despite these limitations, the three waves model provides a useful scaffold for anticipating how AI may reshape creative participation and for supporting educators in preparing designers to act responsibly within increasingly complex socio-technical and ecological systems.

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FACILITATING MULTIDISCIPLINARYITY WHEN DESIGNING HEALTHCARE SERVICES WITH DIVERSE STAKEHOLDERS

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ABSTRACT

This paper examines how disciplinary diversity enriches learning and innovation in design education through healthcare-based design research projects. Three multidisciplinary service design projects brought together students from engineering, business, design, medicine, nursing, pharmacy, and dentistry to address complex, real-world challenges: improving access and awareness at a community health centre; redesigning user and staff experiences in a congested hospital reception area; and improving medication transfer processes between hospital pharmacies and wards to reduce errors and increase efficiency. An iterative research and design process engaged healthcare stakeholders through observations, interviews, and co-creation activities. Using a qualitative case-study approach, student reflections, tutor observations, and project outputs were analysed to identify key themes in multidisciplinary collaboration. Findings reveal both benefits and tensions arising from disciplinary, cultural, and linguistic diversity. Complementary expertise supported systems thinking, empathy, and solution development, while challenges emerged around communication, ambiguity in open-ended briefs, unequal contributions, and assessment fairness. Service design tools—particularly journey mapping, collaborative digital platforms, and low-fidelity prototyping—functioned as boundary objects that facilitated shared understanding among diverse stakeholders. However, differences in prior design skills and the use of AI-generated representations introduced additional pedagogical and assessment complexities. The paper concludes that multidisciplinary healthcare design projects provide a powerful learning environment for developing critical capabilities such as navigating ambiguity, engaging stakeholders, and reflective collaboration. It highlights the need for clearer process orientation, targeted communication support, and robust assessment frameworks, offering practical insights for educators designing inclusive, real-world healthcare design learning experiences.

Keywords: Interdisciplinary design teams, service design, design for healthcare

1 INTRODUCTION

Design education is increasingly focused on preparing graduates to address complex healthcare challenges that cut across clinical practice, service delivery, technology, organisational systems, and patient experience. Healthcare design problems are rarely contained within a single discipline; instead, they require collaboration between designers, engineers, healthcare professionals, and managers to balance human-centred care, regulatory constraints, operational workflows, and technical feasibility. In response, design education has increasingly adopted multidisciplinary, project-based approaches that immerse students in real healthcare contexts, enabling direct engagement with patients, frontline staff, and senior decision-makers [1].

Research in healthcare design education demonstrates that multidisciplinary projects improve students' ability to frame ill-defined problems, surface latent needs, and negotiate competing stakeholder priorities [1,2]. Programmes incorporating service design methods—such as journey mapping, stakeholder co-creation, and service blueprints—have proven particularly effective in healthcare contexts, where such tools support shared understanding and alignment across diverse professional groups [3]. Within educational settings, these methods act as boundary objects, enabling students to translate ethnographic insights into service-level interventions while navigating the complexity of healthcare systems [4].

However, prior work also highlights persistent challenges in multidisciplinary healthcare design education. Differences in professional language, disciplinary norms, tolerance for ambiguity, and levels of prior design skill can hinder collaboration, particularly when clinically trained students encounter exploratory and iterative design processes [5]. Assessment fairness and facilitation workload further complicate these projects, especially when they involve external healthcare partners and live service constraints [6]. Despite these challenges, healthcare remains a powerful pedagogical context for developing systems thinking, empathy, and reflective collaboration [7].

Within this context, the present paper examines three multidisciplinary healthcare-based design research projects conducted within a postgraduate design-for-healthcare programme. It investigates how disciplinary diversity influences collaboration, the use of design tools, stakeholder engagement, and learning outcomes. By analysing both the benefits and tensions that emerge in authentic healthcare projects, the paper contributes practical insights for educators designing multidisciplinary learning experiences intended to prepare graduates to co-create inclusive, and feasible healthcare services.

2 METHOD

Three interdisciplinary team projects on an MSc in design for healthcare are evaluated. All students were divided across the three projects which ran over two modules. The first six weeks was spent on uncovering needs in a healthcare setting (module 1) and the second six weeks involved ideating solutions to those needs (module 2). The students, all co-located spent two to three days over three weeks conducting the primary research which involved observations of service users and staff interacting with the processes along with interviews with management and staff. Outside of this time the students were conducting secondary research and analysing their findings. Mid stage reviews were conducted at both the research and ideation phase of the project with the collaboration partner. Students submitted a project process book for each stage of the project which included one to two paragraphs of their reflections on the process. All field visits were facilitated by one of two design tutors as well as the studio classes. The Tutor field notes also contributed to observations of the students' progress. Table 1 provides further details on the project and the disciplinary backgrounds of the students and participants.

Table 1. Case study descriptions and research approaches

	Project	Disciplinary and country of origin of team members	Disciplinary background of research participants
1	To improve access and user experience at a health centre with services including GP visits, occupational therapy, physiotherapy, speech therapy and dental care. The students focused on access to the site with signage, website, and social media. Space was also reimaged.	Team of six with: 1 nursing - Africa 1 Pharmaceutical engineering, - China 1 Mechanical engineering - Brazil 1 Hospital and Health Systems management - India 1 Industrial engineer - Ireland 1 marketing consultancy - Ireland	Community Healthcare Network Manager, Staff officer, Receptionist Nurses, Physiotherapist Speech therapist Occupational therapist, Smoking cessation consultant
2	To improve the user experience for users navigating the reception area of a local hospital with a focus on: privacy, congestion, a multitude of functions and balancing customer facing tasks with other administration. The students focused on new space layout, redirecting service flows, signage and a new café space	Team of 4 with: 1 nursing - Ireland 1 Product Design - Ireland 1 Dentistry - India 1 Biotechnology - India	Nurse and Quality and Patient Safety Facilitator Nurse manager Hospital CEO Senior hospital manager Receptionists Porter Nurses
3	To improve the pharmaceutical processes and journey of delivering medicines from the hospital pharmacy to the wards and delivery to the patient. The students focused on solutions to prevent error in prescription transcribing, error prevention and	Team of 4 with: 2 Pharmacy - India 1 clinical Pharmacy- India 1 Dentistry - Africa	Hospital senior manager Chief pharmacist Senior pharmacist Pharmaceutical technician Porter Ward Nurse Nurse manager

	dedicated medicine management at the patient bedside		
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3 FINDINGS

Eight themes were identified in relation to interdisciplinary collaboration with multiple stakeholders:

Language and cultural differences

Language and cultural barriers were challenges to varying degrees amongst the students. This had a number of positive and negative impacts. During the research phase of the project in particular the students most impacted tended to rely on other team members to conduct the primary research such as approaching people and conducting interviews when on location doing the field research. The projects also relied heavily on the tutoring staff to manage the partnerships, direct the primary research along with fluent English-speaking students to take the lead on communication.

“I was able to support Alex, you know, where he was lacking in a language challenge or a cultural challenge of that type of understanding.” Team1

While this maximized efficiency with shared data, it created an inequality around the student workload and made grading difficult for staff as the submission was an individual assignment. Presentations back to the partners were also challenging and these students relied on visuals and models to explain both the research and ideas. On one project the client was pitching for funding and requested to have a fluent English speaker to present on behalf of the project which elevated that student’s profile while potentially disadvantaging the other non-native English-speaking students. One advantage of the diversity of the teams was that they worked closely and supported one another.

“I know she struggled a little bit to communicate as well, so we kind of did empathise with her that it's like coming from her background would be very difficult.” Team1

Confidence in speaking was another aspect of the ability to communicate and by the end of the project through other students support this student became more able to communicate in English.

Complementary expertise from diverse disciplines

Placing the students in teams meant that they could learn from each other’s diverse knowledge and skills.

“But then, likewise, vice versa, I've probably learned how to approach work and projects, you know, from an engineering background also.” Team1

The pharmacy team were a group of healthcare professionals but really valued the sharing of the expertise of each other.

“A is a pharmacist, there were a lot of things that I didn't know from that end, like I would understand things from the doctor and nurse's end but like he provided so much insight. B as well-being a dentist like it was nice to have a group of diverse professions.” Team 3

While the healthcare professional’s expertise was really valued during the research phase the solution generation phase was a steep learning curve for them and they in turn relied heavily on the design and engineering disciplines on the teams.

“Like C has the product design and she's like amazing, it's really nice to see. And I think the mixture of the group is nice to see people with skills like that.” Team 2

The teams were encouraged to brainstorm together and that drew upon different experiences, approaches and modes of thinking in a complimentary manner.

“When we did the group brainstorm where we all had our sheets and then passed them on and then you've got clinical experience that I don't have so that's like a really nice perspective and then you can sort of bounce ideas off each other and kind of debate it out, like sort of say like, oh, what if this, why would this be bad? And then like by sort of saying all the way something won't work, you can kind of come to an idea that might help or not.” Team 2

Ambiguity of open briefs & need for clearer orientation / process mapping at the outset

During the ideation phase it became clear that the students with healthcare backgrounds struggled with ambiguity and the openness of the brief. Their disciplines had trained them to be systematic logical thinkers where one solution was sought for quickly to solve a problem. This was at odds with the design approach of exploration and iteration and the alteration of divergent and convergent thinking. They were not used to challenging the status quo but were used to sticking with strict rules and guidelines.

“I think in my experience I'm so used to working with limitations and very strict limitations and there are only so many options and the process is very clear and with this it's almost like give me some rules, give me some limitations because are we allowed? Can I think like that? Am I allowed?” Team 2

In contrast those with both design and engineering backgrounds embraced the need for exploration and iteration

“When you go out in industry, my own experience is that you'd be dealing with ambiguity all the time. So, like one thing that, like on reflection on this, like this project compared to other academic projects I would have done for the undergrad, this is probably the closest to what it would be like to do an actual project out in industry. Because sometimes you get given no brief at all in the industry.” Team 1

Through practice and close facilitation by staff and peers, the healthcare students began to appreciate the design approach.

“My background is very structured and formal, and things are a certain way, and you know this immersion has really tested that and stretched that in so many ways, especially the ideation stage. There were many times, where I was stumped on a lot of things and I just had to like to shut my brain down and restart to like to give myself the chance to explore outside of what I've always known” Team 3

However, to support all students in the process the students felt it would have been helpful for them to have clearer mapping of the process from the outset so that they could be better prepared. They stated that a small taster project in advance of the project that hit on the milestones would have prepared them better for this project.

Acquisition of new skills; Use & limits of design tools

Several tools helped with communication, the ability to capture data, understand the issues and generate and communicate solutions. Miro was a very useful tool to leverage off the diversity of the groups, to share and organize material, pool ideas and educate those new to the process.

“Miro, I really liked it. It's easier to put your thoughts, whatever you're thinking. Later, you can just come and organize them, I think Miro's the best thing for group work for just like dumping out all the work you're doing as a group and annotating every idea.” Team 2

Journey mapping was a powerful tool during the research phase to visualize the research and identify pain points along a service system flow. They were also a jumping off point for idea generation.

“We made journey maps, so we find that each and every small step matters. It's very important. It's like a branching kind of thing. We'll find multiple problems and their solutions and ideas. So, it's like a good thing to have this kind of thinking. It's like you'll think broadly.” Team 3

These were printed out in full scale and discussed in person with the partners to confirm the service flow and the ruling out of assumptions and biases. Another advantage of the journey maps was that when left in situ other stakeholders who were not available during the interviews could add to them at another

time with sticky notes to confirm the research and propose ideas. Brainstorming on sticky notes was as already outlined was a good means of leveraging the diversity of the teams, however many of the students new to the process needed staff facilitation to think divergently and generate multiple ideas. The students tended to settle for limited ideas and required the experience of tutors to support the fluency of ideas. There was a strong learning curve for the students that did not have design representation skills and in service design projects there are multiple methods to convey solutions creating a further demand.

“My design skills are really lacking and being able to interpret ideas visually is like a real barrier for me and like the affinity classes and the sketching and all those, like it's really nice to have access to those. But I think like in hindsight, I mean, it's easy to say you should have or whatever. I feel like I should have maybe put more kind of emphasis on like the practical skills for myself that would help me interpret things like to be able to visually explain things a bit easier.” Team 2

One notable difference between those with design backgrounds and those that didn't was that the non-designers relied much more on AI but managed to create some reasonable representations. The students were facilitated to learn both Affinity and Procreate to help with story boarding and line work and Figma to create UI solutions. Many of the students created line work over photos to represent their ideas which helped with communication. The non design background students were slow to prototype and build models and did so only when they were prompted by tutors to do so. These models, while low fidelity, were helpful to explain and discuss solutions with the clients and were created to explain both space and product solutions. However, the use of AI and the variation in design skills amongst the team members created challenges for staff in the grading of the projects. A further variable in the grading was to consider if students who produced reasonable representations using AI deserved higher or similar grades to someone who tried design tools but produced less polished results. Equally the students from a design background deserve higher marks because they had those skills at the beginning of the project. Students were required to disclose all tools used in the project and produce a process book of every aspect of the project including AI prompts.



Figure 1. Journey maps, AI storyboarding and Procreate sketching over a photograph

Communication & rapport with stakeholders

The ability of the teams to communicate with the stakeholders varied. The pharmacy project was the most difficult one as it involved observing and interviewing frontline staff in a busy clinical area from the pharmacy dispensary to the ward. The fact that most of the students were from healthcare backgrounds helped them to achieve a rapport with the hospital staff in trusting their understanding of the problems. One of the students had worked as a clinical pharmacist previously in a hospital so he was able to compare practices in pharmacies in Indian hospitals with the chief pharmacist. Hospital environments are multicultural, so diversity of nationality was very normal and accepted.

However, due to the pace of the work at times it was difficult to get the attention of frontline staff and observations worked best when they were too busy to respond to questioning.

“She couldn't answer all the questions, but we were just following her. And she was going on getting the medications.” Team 3

The students found that it was often those that were not frontline staff who also had a lot of knowledge and information about the entire service system.

“So, I was with the porter for the most part and there was a plethora of information that I was able to get from him that I probably wouldn't have otherwise gotten from the chief pharmacist who was busy or the nurses, but he knew so much about everything.” Team 3

4 CONCLUSIONS

This study demonstrates that embedding multidisciplinary, healthcare-based design projects within design education meaningfully enriches student learning and innovation. Diversity in disciplinary, professional, and cultural backgrounds introduced challenges—particularly in communication, managing ambiguity, and assessment—but these tensions also acted as catalysts for reflection, skill development, and collaborative growth. Healthcare contexts, characterised by complexity and diverse stakeholder groups, provided an authentic environment in which students were required to negotiate human, organisational, and technical considerations, effectively preparing them to address real-world societal challenges. The findings indicate a need for institutional-level support to address language and communication barriers, ensuring that students with English language difficulties are supported without overburdening peers. Multidisciplinary teamwork proved highly effective for sharing disciplinary knowledge and delivering coherent outcomes for external partners; however, individual assessment structures are better suited to addressing imbalances in team contribution and ensuring fairness. Students from non-design backgrounds benefited from clearer orientation to design processes and short preparatory projects that introduce both design skills and design modes of thinking. Many such disciplines are not accustomed to alternating between divergent and convergent thinking, making explicit process scaffolding essential. Service design tools such as journey mapping and collaborative platforms supported all students, while advanced design tools and prototyping presented a steep learning curve for non-designers. AI-enabled visualisation tools helped bridge this gap but introduced additional complexities for assessment. Overall, the study highlights the importance of emphasising critical thinking, problem framing, and decision-making over technical design polish. Further research is required to develop robust assessment frameworks that fairly reflect learning across diverse disciplinary backgrounds, while careful tutor facilitation remains essential to the success of externally engaged healthcare design projects.

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CHALLENGES OF TEACHING SOFT SKILLS IN DISTANCE LEARNING: A CROSS-DISCIPLINARY APPROACH

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ABSTRACT

Soft skills are essential for degree accreditation and individual professional registration with an expectation that students should develop and demonstrate these skills in their education alongside technical knowledge. Soft skills is a loosely defined term involving several different but related characterisations covering skills such as problem solving, communication and interpersonal relations. They depend upon general tacit and explicit knowledge about human interaction which can be applied in many different fields and hence may also be termed transferable skills. In engineering degrees project work in teams plays a significant role in development of soft skills allowing students to practice various roles. Soft skills therefore pose a particular challenge for distance education in engineering as comprehensive groupwork is difficult to organise. Many students in distance education are mature bringing soft skills already developed in their personal or professional lives. However, the pattern and development of these skills vary with intersecting dimensions of diversity such as gender and socio-economic status. Recognition of existing soft skills has potential to boost confidence whilst the development of soft skills supports career progression. This paper reports on a research project about the development of soft skills at a UK based university which is an established distance education provider. The research engages with the question of whether soft skills can be taught in a generic way for different subjects or through a common approach that is customisable to particular subject contexts. As part of addressing this there is reflection on how soft skills expectations and teaching differ between engineering and nursing.

Keywords: Competence, engineering, distance education, professional practice, soft skills

1 INTRODUCTION

Engineering education focuses primarily on technical knowledge. Vincenti [1] classifies engineering knowledge in his seminal book *What Engineers Know and How They Know It* into fundamental design concepts, theoretical tools, criteria and specifications, quantitative data, practical considerations and design instrumentalities. Universities largely concentrate on the first two of these categories as the others are situated in the context of products, organizations and markets. What is missing from this, and other classifications of engineering knowledge derived from it, is an explicit discussion of soft skills in engineering. Engineering is a sociotechnical activity. Products are developed by teams of people with a wide range of skills and backgrounds and operating in a multitude of environments and use contexts that combine social, technical, and managerial skills [2]. Engineers usually rely on building their relational skills upon their technical skills [3]. The reliance on relational skills and other soft skills is slowly being recognized for example in degree accreditation requirements for several UK professional institutions. However, this poses a challenge for engineering educators as most universities rely on team projects as a vehicle for teaching and reinforcing soft skills. This option is much more limited for distance education courses where students have far less opportunity to interact as they also often work asynchronously. Distance education students, especially mature students, often have rich experiences from outside of engineering to draw on. Some of these issues also apply to part-time degrees at face-to-face university, where the part-time students, take some courses remotely and are less integrated into the student communities. This paper reports on some of the challenges and opportunities of teaching soft skills in distance education. These issues are addressed from the perspective of the skills an individual does or should possess as opposed to the skills that an organization requires. Nevertheless, the two are

intertwined and directly related to the exercise of skills in professional practice. As many soft skills are transferable between different fields this also raises the question whether soft skills can be taught in the same way or jointly across different degrees. The possibility of shared teaching of soft skills for engineering and nursing students is considered.

2 WHAT ARE SOFT SKILLS?

The notion of soft skills is surprisingly recent having first appeared in a 1972 US army conference [4]. While there is general consensus on the importance of soft skills there is little consensus on a definition. Soft skills are also referred to as generic skills, transferable skills or employability skills and are often described by contrast to hard skills, technical skills or professional skills.

2.1 Theoretical base

Soft skills are linked to tacit knowledge. Individual tacit knowledge is typically developed from experience and the application of explicit knowledge. Explicit knowledge might be shared in the process of acquiring tacit knowledge but cannot be fully described by explicit knowledge [5]. Wagner and Sternberg [6] define tacit knowledge as knowledge that is not formally taught, but underpins knowledge acquired from daily experiences [7]. Joie-La Marle et al. [8] carried out a systematic review of soft skills and point to the challenge of divergent terminology between different fields. Individual soft skills are highly interlinked and therefore can be described on different levels of detail and from various perspectives. For example, Joie-LaMarle et al. [8] illustrate that planning and organising is strongly related to other skills like team working, problem solving or leadership. While this is unsurprising it poses a challenge for how individuals and educators describe soft skills. What is seen as soft skills or core professional skills also varies with the context. For example, creativity is included in many classifications of soft skills but in the context of engineering it can also be a core professional skill.

2.2 Soft skills from experiences outside engineering degrees

Soft skills can often originate from everyday activities or be developed through non graduate jobs, as illustrated in Table 1. The suggestions are based on informal conversations with undergraduate students during residential schools held by the university and are purely intended to be illustrative.

Table 1. Top 10 soft skills identified by Joie-La Marle et al. [8] and potential everyday sources of them

Soft Skill	Potential origin of experience
Teamwork	Past job, involvement in running a charity
Communication	School presentations, working with customers
Planning and organising	Domestic life, running a scout group
Responsibility	Family, jobs
Leadership	Sport club, church
Creativity	Hobby
Commitment	Doing a part-time degree
Interpersonal skills	Social life
Adaptability	Parenthood, working in different jobs
Ethics	Personal beliefs

In particular, mature students enter degrees with considerable life and work experience. For example, the authors participated in student conferences where several students had worked in call centres handling customer enquiries or complaints which developed their communication and interpersonal skills. Another example is that a significant group of our university undergraduates are current or former soldiers who have army training in planning and organising or leadership skills. Whilst these students bring soft skills to their degrees the nature and level of attainment of these skills is highly varied. Importantly students might not be aware that they possess them. For example, a student working in a customer complaints department did not realise that she would be ideally placed for customer facing engineering roles. The extent to which people possess all soft skills is a matter of degree. In engineering at the lowest end of the soft skill range everyone communicates or works in teams and at the upper end some people are especially good at individual soft skills to the extent that they and other people recognise it. The importance of soft skills raises the issue of whether students possess particular soft skills to a

sufficient degree to claim that they have these skills. In a face-to-face university students can judge themselves against each other and also receive formal or informal feedback from fellow students. For example, if a student team has to give a presentation together, they might meet to work on the slides together, do a run through and then present to their peers. They give each other feedback in the team and negotiate over a presentation style but also are likely to get verbal feedback from their peers as well as being able to read the body language of peers to see whether they were engaged or not. If they get a top grade for their presentation and engaged their peers, they probably feel confident about their presentation abilities. This is much harder in an online setting where the direct and indirect feedback is much more formal. Soft skills are deeply personal because every person has differing experiences and skills. For example, artistic creativity is different from that involving solving abstract mathematical problems which differs again from that of an engaging storyteller. As the example illustrates, it might be hard for a person to recognise that they are creative because they can tell an entertaining story because this might be entirely normal and unremarkable for them so universities need to help students in recognising their skills. Although soft skills are transferable by definition, they are manifested differently in various academic disciplines and contexts. For instance, in a philosophy context people sometimes read out a talk to be sure they get the nuances correct but this mode of presentation would be considered dull and unengaging in an engineering context.

3 SOFT SKILLS IN ENGINEERING

Whilst the perceived stereotype of an engineer is a man who is technically and mathematically capable and rational [9] and who does not take human or social elements into account in the context of his work the reality is that engineering is highly social and most engineering roles rely heavily on soft skills [10].

3.1 Soft skills in professional practice

Engineering is done by people with complementary skills. For most modern products this involves a mixture of different disciplines (such as mechanical, electrical, software, production or materials engineering) each involving their own vocabulary, presentations and ways of working in what Bucciarelli [11] termed object worlds. Engineering teams require expertise covering the life cycle of the product and the stakeholders involved in it - from product users, material suppliers to capital investment project participants as well as business and quality control roles. Whilst many engineers are hired for their technical expertise, they acquire additional non-technical roles, such as strategy, coordination, communication or relationship building and maintaining roles (see Hatmaker [12]) throughout their careers. Typically, university focuses on the technical skills required to carry out these technical roles which leaves engineers to fall back on personal skills or on the job training to acquire soft skills

3.2 Accreditation requirements

Learning outcomes for UK engineering qualifications are set out in Accreditation of Higher Education Programmes (AHEP) [13] and the Approval and Accreditation of Qualifications and Apprenticeships [14]. These reference standards are designed to be compatible with the UK Standard for Professional Engineering Competence and Commitment (UK-SPEC) [15]. The current versions of the standards do not explicitly use the term soft skills but rather embed them in core professional competencies. One of the core competencies is responsibility, management and leadership which covers team leadership, project management and professional accountability (competency C). Another core competency is communication and interpersonal skills (competency D), which requires engineers to communicate complex engineering matters to technical and non-technical audiences and to work with others. The UK-SPEC also places emphasis on the values that engineers espouse like ethical practice or sustainable and social responsibility (competency E). The competencies C and D would be considered soft skills whilst competency E illustrates the blurred zone between soft skills and other skills (such as through discussion of ethical values). Accreditation is determined by various Professional Engineering Institutions (PEI), under licence, with the emphasis and extent tailored to the field. For example, the Institution of Mechanical Engineers (IMechE) requires an understanding of “human skills needed in manufacture” [16] whilst the Institution of Engineering and Technology (IET) highlights skills for lifelong learning [17]. As universities seek to accredit their degrees, they need to interpret the AHEP learning outcomes required for professional accreditation in the context of the different PEI and the courses that are on offer. This poses a particular challenge for general engineering degrees where beginning students do not know what registration they are seeking, with the course possibly being accredited by multiple PEI.

4 SOFT SKILLS IN THE UNDERGRADUATE ENGINEERING CURRICULUM IN DISTANCE EDUCATION

Whilst many face-to-face universities frequently require students to work in teams with differing roles and ask for oral presentations, this can be more difficult in the context of distance education. In distance education what are often tacit skills picked up by students during their degrees have to be taught explicitly and opportunities for students to acquire these skills have to be specifically created. For example, the soft skill of team working has been carefully designed into our level 1 university online summer school. One instance of this is that students spend a day learning team working skills based around understanding how different materials that maintain water temperature. This is followed by a research exercise to answer a bank of about 50 questions, covering topics including heat retention, sustainability and commercial development, through self-organised division of the work involved. The knowledge gained then feeds directly into a design task where the team identifies a use context and designs an insulated mug for this context, with each team member presenting an aspect of the design. This gives the students a flavour of different communication and leadership tasks and also reminds them of the value of their personal experience for engineering practice. The students have worked together as a small group but are missing aspects of non-verbal feedback and personal relationships with other students that enable them to exchange feedback in a positive way. This puts more onus on tutors and the assessment to provide students with feedback on their soft skills. Online summer schools balance the greater soft skills learning from face to face teaching with the cost for students and the fact that not all students can attend face to face summer schools. Another instance is that at the end of their degrees a component of student MEng dissertations is reflecting on how their project learning contributes to the UK-SPEC [15] competency requirements, especially those around project management. Both examples show the challenge and opportunity of designing soft skills learning into teaching activities.

Online opportunities for presenting and showcasing student work can also be created. For example, at our university final year project students are required to produce a poster summarising their work. There is an online extracurricular event where the students can show their posters, and prospective students can see what project expectations are. However, extracurricular events are optional with not all students wishing or being able to contribute to them. Organising and marketing online extracurricular events to students both involve considerable effort. Whereas an extracurricular event at a face-to-face university can generate a positive buzz and become what might be thought of as an occasion, it is harder to attract the attention of distance education students. A significant reason for this is that distance education students can be overwhelmed by the volume of university communication, so invitations to extracurricular activities can disappear unnoticed into this. Mature students are typically much more aware of their help or support needs but are far more restricted in being able to take advantage of these opportunities. They come to university to acquire the technical skills required for the roles they aspire to; hence soft skills may not be a priority for their limited study time. These considerations really put an emphasis on the deliberate integration of soft skill training into curriculum design so that our university can ensure that the necessary soft skills are included in modules.

Accreditation requirements are a driver of integration, to ensure that all students can develop and demonstrate the required learning outcomes. Our university offers a modular general engineering degree where different pathways are accredited by different institutions. As a result, compulsory modules need to provide a framework for all the institutional accreditation requirements. The university offers an engineering practice and skills module where soft skills, such as presentation skills or decision-making skills, are wrapped up with practical skills, such as data analysis, measuring and modelling or research and information evaluation. As the work students undertake on the module is to some extent guided by their interests and abilities, the soft skills they acquire may vary. Assessment design is therefore critical to encourage and confirm the development of all required skills.

Preliminary results of a mapping of AHEP learning outcomes against Core skills proficiencies from the UK Standard Skills Classification [18] has illustrated the challenges of identifying appropriate proficiency level and demonstrate academic progress, see Figure 1, as the definition of the skills required at each level are subject to interpretation. The ambiguity in the definition of skills level poses a significant barrier to making soft skills transferable in practice. Given the effort to include some soft skills in distance education, it is necessary to teach soft skills at lower points of academic progression to a higher proficiency level.

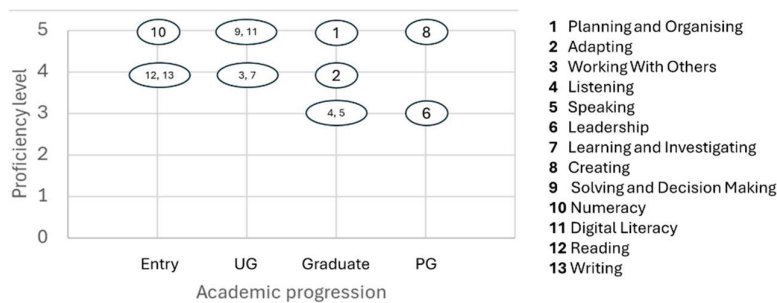


Figure 1. Core skills proficiency levels and academic progression for Engineering

5 TRANSFERABILITY OF SOFT SKILL TEACHING ACROSS DEGREE SUBJECTS

Professional expertise across a wide range of areas centrally involves the acquisition of complex perceptual, judgement, and decision-making skills such as planning, co-ordinating, considering alternatives, considering advantages and disadvantages, communicating and evaluating. These soft skills rely upon and support the exercise of professional autonomy in the workplace, which is essential for expert performance in various tasks [19]. A plausible account of professional expertise that aligns with this view of soft skills is that expert knowledge is cognitively held in discrete chunks, which are gradually built upon and integrated as expertise increases, with these chunks being located within particular professional areas of activity [20]. Soft skills are shared across a wide range of professions and disciplines along with differences between various areas. These similarities and differences enable shared, suitably tailored teaching of soft skills across a range of degree subjects.

Engineering education is strongly influenced by PEIs that require soft skills, which as a consequence are designed into modules to ensure the accreditation process is smooth. Other vocationally orientated degrees such as nursing are accredited by professional bodies with a similar kind of requirement for both technical nursing knowledge and soft skills. In distance education it is important that soft skills are considered in the design phase of modules with effort required to design activities that support the acquisition of soft skills. As the example of our university online summer school indicates, the activities could have been carried out by students in isolation and asynchronously but were designed to enable a learning journey and team building. In this case, the design had to strike a balance between allowing the student groups to organise themselves but offer guidance in sufficiently small steps such that team learning outcomes would not be excessively compromised by variations in individual student skill levels. A greater challenge across all qualifications is that of generating spaces where students can give each other feedback on their soft skills, such as presentation or leadership. Making collaboration mandatory is difficult because not all students are able to take part in joint activities due to their personal circumstances. As many students bring soft skills acquired from outside the university, there is a need to help them to recognise the skills that they have already. This could either take place through case studies and examples where these skills are highlighted in the accompanying narrative to these studies and examples, or by explicitly teaching soft skills. Within disciplinary contexts it can be difficult to distinguish between the particular exercise of soft skills and expert performance in various tasks. Hence, soft skill teaching done jointly across a range of disciplines might enable individuals to recognise how skills displayed in unfamiliar contexts could be valuable for performing tasks in areas that they are familiar with. In addition, broadening inter-disciplinary study beyond the standard grouping of allied professions, can promote inclusive practice by increasing diversity of both demographics and perspectives. As women are under-represented in engineering cohorts [21], improving gender balance may be particularly significant to ensure that all students have opportunities to work in mixed groups.

6 CONCLUSIONS

Soft skills are a valued element of engineering education, with development and assessment required for accreditation and professional registration. There is scope for transfer of soft skills from other contexts, including prior experience, extra-curricular activities and inter-disciplinary study. Recognising the soft skills that mature students already possess can free up time and attention for other learning outcomes and boost their confidence. Inter-disciplinary study, across the broad range of professions that also require both technical and interpersonal skills, has potential to enhance students' recognition of

soft-skills and promote inclusive practice. Teaching soft skills in distance learning is therefore not just a challenge but an opportunity to enhance student experience and professional development.

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THE VITRUVIAN WOMAN FROM PATRIARCHAL DESIGN TO GENDER EQUITY THROUGH ERGONOMICS EDUCATION

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ABSTRACT

The physiological differences between women and men result in higher musculoskeletal disease risk for women. Despite this, industrial design has historically tended to rely on men as the “average person”, often overlooking women’s characteristics. This male-default bias aggravates women’s health risks, limits their function and constrain equitable participation in professional domains, evident in fields like medicine. For example, surgical instruments are generally designed for large hands and grip strength, systematically disadvantaging women and small-handed surgeons by increasing physical strain and reducing usability. Moreover, such design choices function as structural gatekeepers, creating barriers to equal professional participation and dictating terms for career entry and success.

Industrial design education has a responsibility to eliminate this inherited bias. Drawing on research in ergonomics, medical device design, and design pedagogy, this paper proposes a gender-responsive ergonomic pedagogical model for industrial design education as a change agent aimed at deconstructing and counterbalancing patriarchal dominance historically embedded in industrial design paradigms. The model integrates biomechanical and anthropometric analysis, experiential product interaction, reflective case-based critique, and role modelling through female designers, to equip students with tools to identify and correct gender disparities within the design process.

By repositioning ergonomics as a generative and critical design competence rather than a technical check, the proposed framework aims to embed gender equity within core design reasoning. In doing so, it contributes to the formation of designers capable of producing products that are safer, more functional, and inclusive across genders, while reinforcing the broader societal role of design in advancing social equity.

Keywords: Design education, ergonomics, pedagogical model, gender, inclusion

1 INTRODUCTION: TRANSFORMATIVE DESIGN EDUCATION - HARNESSING ERGONOMICS FOR GENDER EQUITY

Sex-related physiological differences between women and men place women at a higher risk of developing function-related musculoskeletal disorders. These differences include variations in hand size, height, grip force, and biomechanical loading, which are directly relevant to the interaction between users and physical products [1]. Although men may present with more severe or complex individual cases, epidemiological evidence indicates that orthopaedic and musculoskeletal diseases are substantially more prevalent among women than men [2,3]. A significant proportion of these disorders arise, in part, from inadequate ergonomic product design and prolonged exposure to ergonomic risk factors associated with product use [4]. Despite this evidence, design practices have historically tended to treat men as the “average person”, often overlooking women’s unique characteristics [5].

This paper addresses the persistent dominance of patriarchal design within industrial design practices and presents the ergonomics discipline as an agent of change, through educational strategies aimed at mitigating the negative impact of such an inequitable approach. In this context, this paper proposes a gender-responsive ergonomic pedagogical model for industrial design education, offering a framework to guide the development of more gender-balanced design practices.

2 BACKGROUNDS: MALE-DEFAULT BIAS IN MEDICAL DEVICE DESIGN AS GENDER GATEKEEPER

The male-default worldview not only aggravates risk and harms women's health but also fails women by undermining their ability to function optimally and by creating barriers to equal participation in various domains, including medicine.

Surgical handheld instruments are typically designed for large hands and significant grip strength. Historically, they have been designed by men, for male users, with limited adaptation to the changing demographic composition of the surgical workforce (currently, women make up 50.5% of medical school students, and nearly 30% of surgeons are women). Additionally, the names of surgical tools are mostly derived from their inventors - predominantly male surgeons - which further reflects the male-centred legacy embedded in medical device design. Although the gender gap in innovation is shrinking, at the current rate it is estimated it will take another 118 years to reach gender parity. [6].

Surveys indicate that up to 60% of surgeons, predominantly women and small-handed users, report difficulties operating standard surgical instruments, and nearly 90% of surveyed female surgeons report musculoskeletal injuries associated with instrument use [6]. These findings highlight how the often-invisible design bias systematically disadvantages women (and surgeons with smaller hands), creating both functional barriers and health risks. Thus, instrument design itself acts as a gatekeeper, undermining equal participation in medicine and highlighting the urgent need for ergonomically inclusive solutions. Empirical studies further demonstrate that design solution challenges are not solely a matter of scaling instruments down. Surgeons with glove sizes ≤ 6.5 report significantly higher rates of discomfort and pain compared to those with larger glove sizes, with women reporting more problems than men even when hand size is equivalent [1]. This suggests that sex-related biomechanical and ergonomic factors extend beyond size differences and require more comprehensive design responses. Current instruments often compel surgeons to adapt their posture and technique to the tool, rather than the tool accommodating human variability [1].

Endoscopy represents a well-documented example of persistent mismatch between technological advancement and product design. Although imaging and diagnostic capabilities have evolved substantially, the endoscope-human interface has remained largely unchanged since the 1980s, with minimal attention to user ergonomics [7,8]. Career-long prevalence of endoscopy-related injuries exceeds 60%, with female gender identified as one of the significant risk factors, in addition to higher procedural volume and years in practice [8]. Female trainees report higher rates of neck, shoulder, and upper limb pain, partly due to smaller hand size, shorter stature, and equipment dimensions optimised for male users [9].

Beyond product design, research in design and engineering education emphasises the importance of integrating ergonomics as both a technical and reflective discipline. Educational approaches that link ergonomic theory with hands-on design practice support students' ability to recognise human variability and translate it into inclusive design solutions [10]. Inclusive teaching methodologies in design education have been shown to enhance awareness of equality, diversity, and representation, particularly when experiential and reflective learning strategies are employed [11]. Furthermore, exposure to gender-equality information has been shown to positively influence students' attitudes and motivation toward STEM fields (science, technology, engineering, and mathematics), indicating that education can actively shape professional mindsets rather than merely transmit technical knowledge [12].

Together, this body of literature demonstrates that gender bias in product design, particularly in medical devices, has measurable health and participation consequences, and that design education represents a critical intervention point for addressing these inequities. Therefore, industrial design education bears a profound responsibility to break this inherited bias and redefine what it means to design for humans.

3 METHODOLOGIES: A GENDER-RESPONSIVE ERGONOMICS PEDAGOGICAL MODEL FOR INDUSTRIAL DESIGN EDUCATION

The proposed pedagogical model integrates ergonomics education into product design curricula with an explicit gender-responsive perspective, thereby empowering the next generation of designers to create gender-equitable products.

The model guides students to identify male-default assumptions, apply ergonomic biomechanical and anthropometric principles, and design tools that ensure healthy, effective, comfortable, simple, and safe use for all genders.

Unlike conventional ergonomics instruction, which often emphasises generalised usability principles, the proposed model explicitly integrates gender-responsive analysis, reflective critique, and experiential examination of structural design bias within core product design education.

The educational framework combines four complementary components: (1) theoretical instruction of gender-informed ergonomic concepts and guidelines, based on key physiological and anatomical sex-related differences that impact functionality and design, (2) experiential learning through physical interaction with products, (3) reflective discussion on design responsibility and equity, and (4) role modelling through the introduction of pioneering female designers.

The first component equips the students with gender-analytical biomechanical and anthropometric knowledge and sex-disaggregated ergonomic design tactics that significantly affect comfort and musculoskeletal load, such as providing multiple alternative ergonomic grip options within a single product, positioning the product's center of gravity within the user's hand, encouraging force exertion through larger muscle groups rather than isolated distal effort, or employing dynamically variable handle dimensions to accommodate a wider range of users. The practical application of these gender-responsive ergonomic tactics is demonstrated through representative product examples (Figure 1). Although illustrated here through consumer products, these ergonomic principles are transferable across diverse design domains, including medical device design.



Figure 1. Examples of gender-responsive ergonomic design strategies in handheld products

(a) Alessi “Forma” Cheese Grater, integrating multiple ergonomic grip options within a single configuration to accommodate different hand sizes and task demands

(b) Dyson “Supersonic” Hair Dryer, positioning the motor within the handle to shift the centre of gravity into the user’s hand, reducing wrist torque and improving balance during use

(c) Fiskars “SmartFit Bypass Pruner,” incorporating dynamically adjustable handle dimensions to accommodate varying hand sizes and enhance grip comfort and force transmission

(d) Joseph Joseph “Rocker” Garlic Crusher, enabling force generation through larger proximal muscle groups via a rocking motion, reducing reliance on distal finger strength

Source: Images reproduced from the official websites of Alessi, Dyson, Fiskars and Joseph Joseph

The second component is active experiential learning: students interact with physical products that exemplify gender-inclusive design solutions, allowing them to experiment and directly experience how small modifications can dramatically improve usability for women without compromising male users. Live demonstrations are used to illustrate how gender-sensitive ergonomic principles can be applied in real-world product design. This hands-on engagement provides actionable insights that students can easily adopt, translating theory into replicable practice, and consistent with prior findings on ergonomics education in design contexts [10].

The third component incorporates case-based analysis, focusing on real-world products with documented ergonomic implications, for example in medical device design. Students are required not only to analyse products in terms of function, usability and health risks, but also to critically examine the gendered implications of product design, including the specific burdens that women may bear as a result of using these products. This approach is supported by research demonstrating that reflective learning strategies can enhance awareness of equality [11].

The last component highlights pioneering and influential female designers as role models, providing inspiration, addressing the lack of visible female achievement in the field, and expanding students' perceptions of leadership in design fields historically dominated by men. This component aligns with evidence showing that exposure to gender-equality information can influence students' motivation and attitudes toward design professions [12].

Overall, the model positions ergonomics not merely as a technical approach, but as a critical design competence with direct implications for health, equity, and professional participation. The methodology is replicable and adaptable, allowing integration into diverse design education contexts without requiring extensive curricular restructuring.

4 DISCUSSIONS: IMPLICATIONS FOR INDUSTRIAL DESIGN EDUCATION

The findings synthesised in this paper indicate that male-default bias in product design is not only a representational issue but a functional and health-related concern. When design is tacitly modelled on male bodies, women may experience reduced usability, increased physical strain, and professional disadvantage. Medicine serves here as a salient example, yet similar dynamics exist in other professional domains. The consequences extend beyond compromised comfort or efficiency: limited ergonomic compatibility may constrain career advancement by effectively closing professional pathways. In clinical contexts specifically, diminished performance potential may also affect patient outcomes, as suboptimal tool–user fit can influence precision, endurance, and overall procedural quality.

Within industrial design education, such bias often persists not through explicit exclusion but through unexamined assumptions about the “average user,” embedded in standards, precedents, and teaching practices.

The pedagogical model proposed in this paper addresses these issues by reframing ergonomics as a critical analytical instrument for identifying bias and generating inclusive design solutions. Rather than treating ergonomics as a compliance checklist, the model positions it at the conceptual core of the design process, where user definition and dimensional assumptions are first established.

Importantly, the model avoids framing gender-responsive design as a zero-sum correction. The objective is not to substitute one normative body for another, but to expand the design reference frame and strengthen product adaptability across user populations.

The framework is designed for practical implementation within undergraduate industrial design education, both through ergonomics or human factors courses and through integration into core studio-based design projects.

For industrial design programs, the implications are structural rather than symbolic. The model achieves maximal impact when it is not delivered as an isolated theoretical module, detached from the core curriculum, but embedded in direct linkage with foundational studio projects. When students are required to apply gender-aware ergonomic analysis within their primary design projects, inclusive thinking becomes operational rather than declarative. In turn, this integration influences studio instructors and project mentors, allowing gender-responsive ergonomics to permeate the broader academic paradigm. Under such conditions, inclusive design principles shift from supplementary content to an integral component of the institutional DNA.

By combining evidence-based theory, hands-on exercises, real-world case studies, structured analysis, and applied studio implementation, the proposed pedagogical model demonstrates how gender-conscious ergonomics education can shape not only better-designed products but also a more inclusive

and equitable design culture.

5 CONCLUSION & REFLECTIVE PRACTICE

Male-default assumptions in product design are sustained not only by industry practice but by the ways designers are trained. Addressing this structural bias therefore requires intervention at the educational level.

The proposed framework equips future designers with ergonomic methods that render gender disparities explicit and correctable within the design process. Ultimately, this educational model fosters a professional mindset in which gender equity is treated as a design standard, ensuring products are functional and empowering for all genders and reinforcing the role of design practice in advancing social equity.

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HOW ENGINEERING DEGREE APPRENTICESHIPS HAVE AN IMPACT ON EQUALITY, DIVERSITY AND INCLUSION (EDI): A LOCAL STUDY

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ABSTRACT

This paper explores the impact of Engineering Degree Apprenticeships on Equality, Diversity and Inclusion (EDI) through a focused case study within an HEI on the South Coast of the UK. It compares local enrolment and achievement data with national trends in both Degree Apprenticeships and Full-Time Engineering Degrees. Drawing on four years of data (2022–2025 starts), the study examines student demographics and outcomes across key EDI indicators, including; gender, ethnicity, socio-economic background (IMD), and learning difficulties.

Findings reveal that while the case studies engineering degree apprenticeship cohort remains predominantly male and White British, mirroring national patterns in Full-Time Engineering Degrees, there are notable differences. Female participation within the case study, though low, shows a gradual increase, aligning with national apprenticeship trends but still lagging behind Full-Time Degree benchmarks. However, apprentices with learning difficulties are proportionally better represented than in national full-time programmes, suggesting that the apprenticeship model may offer a more inclusive route for neurodiverse learners.

Socio-economic representation is mixed: while there is some engagement from students in more deprived IMD quintiles, the majority still come from mid-to-upper quintiles, echoing national concerns about the accessibility of degree apprenticeships for the most disadvantaged. However, achievement rates, within the case study, are consistently high across most demographics, indicating strong support structures once students are enrolled as apprentices.

This study contributes to the growing discourse on the role of Degree Apprenticeships in addressing systemic inequalities in engineering education and highlights the need for targeted outreach and inclusive recruitment strategies to broaden participation.

Keywords: Degree-Apprenticeships, EDI, neurodiverse-learners, widening-participation, engineering

1 INTRODUCTION

The UK's engineering skills pipeline must simultaneously meet employer demand for high-level technical skills and build a profession that better reflects society. Degree Apprenticeships (DAs) are frequently presented as a mechanism to achieve both aims. Universities UK [1] argues that DAs combine paid employment, an accredited degree, and structured progression into skilled roles, thereby reducing financial barriers and widening access for under-represented groups. Evidence from IFF Research [2] for the Department for Education shows employers use DAs primarily to upskill existing staff (61%) and support internal progression pathways (39%). Despite these advantages, persistent participation gaps remain. Bolton and Lewis [3] report that social mobility outcomes in DAs have in some cases “got worse... and were particularly acute among degree apprentices under 25,” highlighting continuing inequalities by gender, ethnicity, and socio-economic background. This paper provides an evidence-based analysis of local engineering DA enrolment and attainment by protected and widening-participation characteristics, benchmarked against national patterns in DAs and Full-Time Engineering Degrees, to assess where access and outcomes diverge and why.

2 METHODOLOGIES

This study draws on a focused case study conducted within a higher education institution (HEI) located on the South Coast of the United Kingdom, utilising four years of enrolment and achievement data from

cohorts beginning between 2022 and 2025. It investigates student demographics and outcomes across key EDI indicators, including: gender, ethnicity, socio-economic background, as measured by the Index of Multiple Deprivation (IMD), and declared learning difficulties. Descriptive statistical methods are employed to identify trends, patterns, and relationships within the institutional datasets. Chi-square tests were considered but not used due to the small sample sizes (n). These findings are then contextualised through comparison with national data sources, enabling alignment with broader sector trends across both DAs and Full-Time Engineering Degree programmes.

3 CASE STUDY

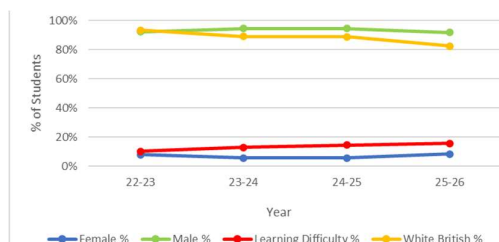


Figure 1. Enrolment: Key Characteristics

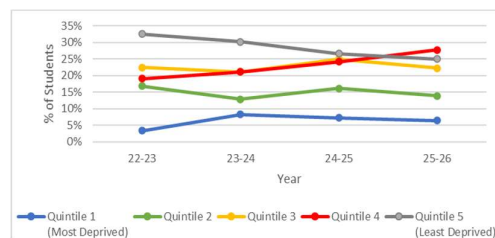


Figure 2. Enrolment: IMD Background

3.1 Participation Trends (Enrolment Data)

Gender. Female enrolments show a small but steady increase over the period (Figure 1, blue), rising from 7.9% in 2022/23 to 8.3% in 2025/26, while male participation remains consistently dominant at approximately 92–95% (Figure 1, green). Although the shift is modest, it indicates incremental progress in widening gender participation within the programme, albeit from a notably low baseline, n ranging from 6 to 9.

Ethnicity. The cohort remains predominantly White British across all observed years, comprising approximately 82–93% of enrolments, as seen in Figure 1, gold. Minor increases are observed within the “Other White” category, while representation from Asian and Black ethnic groups remains small (n=3 to 8) but stable. Importantly, the proportion of students selecting “Not provided” decreases over the period, suggesting improved confidence or willingness to disclose ethnicity data.

Declared learning difficulties. The proportion of learners reporting a learning difficulty increases markedly over time (Figure 1, red), rising from 10.1% (n=9) in 2022/23 to 15.7% (n=18) in 2025/26. This upward trend may reflect improved disclosure practices, enhanced institutional support structures, or greater accessibility for students with additional learning needs.

Socio-economic background (IMD). Learners are drawn from across the socio-economic spectrum, though with visible clustering in the mid-to-upper quintiles, as Figure 2 shows. Representation from the most deprived (Quintile 1) is low, averaging at 6.3% (n=4). In contrast, enrolments from the least deprived (Quintile 5) constitute the single largest group most years, averaging at 28.6% (n=15). The pattern indicates a mid-to-less-deprived skew, with some if limited reach into the most deprived quintile.

3.2 Analysis of Achievement

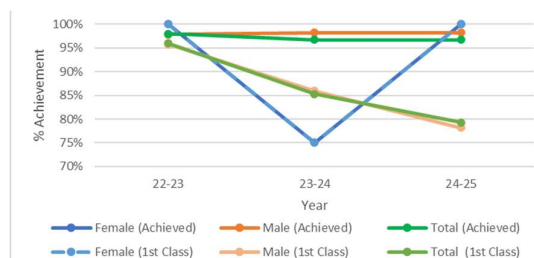


Figure 3. Achievement by Gender

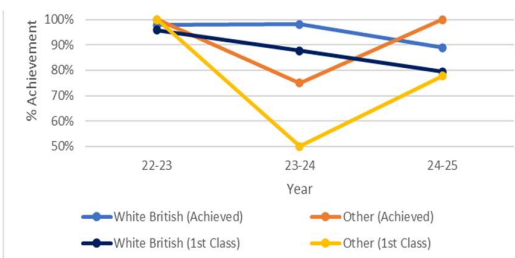


Figure 4. Achievement by Ethnicity

Overall patterns. Achievement rates, shown in green in Figure 3, remain consistently high across the period of study, with completion at approximately 98% (n=50) in 2022/23 and 96.7% (n=85) in 2023/24. First-class attainment is consistently lower than overall achievement, showing a steady decline.

Gender. Figure 3 also shows achievement by gender. Male learners, who represent the majority of leavers each year, demonstrate consistently strong achievement rates: around 98% each year, with those

achieving first-class grades dropping from 95.7% to 78.2%. Female outcomes display far greater volatility due to very small cohort sizes. In 2022/23, results for the three female leavers were uniformly positive, with 100% in both achievement and first-class attainment. In 2023/24, both achievement and first-class outcomes declined to 75% (n = 4), by 2024/25, both measures returned to 100% (n = 7). While these fluctuations preclude strong inference, the available data do not indicate systematic under-performance among female learners once enrolled.

Ethnicity. Figure 4 shows White British leavers, the majority group, consistently achieved $\geq 90\%$, with first-class attainment declining from 95.8% to 79.5%. Other ethnic groups appear in very small numbers (often n=1 to 4), and while recorded achievement is frequently 100%, the small sample sizes preclude meaningful interpretation or inference when attainment percentage falls.

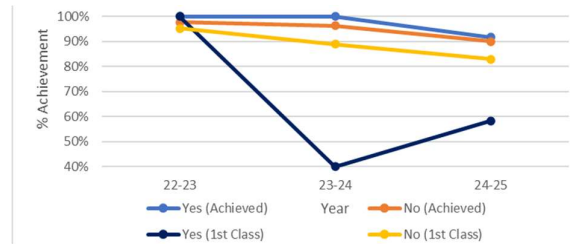


Figure 5. Achievement by Declared Learning Difficulty

Declared learning difficulties. Learners declaring a learning difficulty achieve highly overall but exhibit lower first-class degree outcomes relative to peers without such declarations, as can be seen in Figure 5. For example, in 2024/25, for 12 learners, their achievement rate stands at approximately 91.7%, with 58.3% attaining a first-class degree. This contrasts with achievement of 90% and first-class attainment of 82.9% among those 70 learners without a declared difficulty.

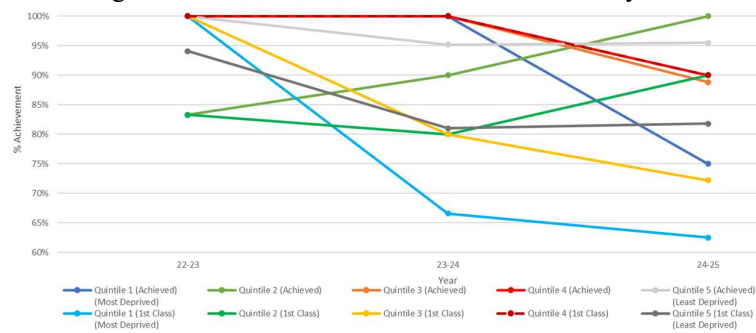


Figure 6. Achievement by IMD Background

Socio-economic background (IMD). Figure 6 shows achievement remains strong across IMD quintiles, though first-class attainment displays considerable variation. As with other subgroup analyses, many of these cells contain small numbers, limiting the reliability of comparisons. Nevertheless, there is no consistent evidence that learners from more deprived neighbourhoods experience lower achievement once on programme. However, the observed decline in first-class attainment for Quintile 1 and the corresponding rise for Quintile 2 merit closer examination, as this convergence appears to normalise the aggregate outcome profile.

4 NATIONAL CONTEXT AND COMPARISON

4.1 Degree Apprenticeships (National)

Gender. According to an EngineeringUK [4] report, “the proportion of female apprenticeship starts has been improving for engineering and technology-related subject areas, but remains below the average across all subject areas,” with female entrants accounting for only 17% of starts in 2023–2024 compared with 52% across all subjects. This disparity is largely driven by persistently low female participation in sectors such as Engineering and Manufacturing, where women constitute approximately 10% of apprenticeship starters. At the DA level, however, year-on-year growth has been more pronounced, with a 13% annual increase in female participation between 2022 and 2024. Complementing these findings,

an Aura [5] reports a 19% decline in female retention at this stage, signalling a significant challenge for achievement outcomes.

Ethnicity. The same EngineeringUK [4] report found that “14% of starts for engineering and technology-related apprenticeships in 2023/24 were by people from a UK minority ethnic background, up from 8% in 2017/18”, indicating a sustained long-term increase in participation.

Declared learning difficulties. Although not publicly available, dataset reports participation or achievement rates within engineering DAs, broader apprenticeship data, Aptem [6], show an increase in disclosure: rising from 11.9% in 2020/21 to 14.5% in 2022/23.

Socio-economic background (IMD). Evidence from the Sutton Trust [7] shows that recent apprenticeship reforms “have not delivered radical change in social mobility,” with only 29% of engineering DAs coming from the two lowest IMD quintiles, underscoring persistent socio-economic inequalities in access and progression. With a Department for Education [8] dataset highlighting that achievement rates from these two lowest IMD quintiles is around 50%; 48.2% and 51.1% respectively.

4.2 Full-Time Engineering Degrees (National)

Below are key benchmark figures for students in engineering and technology first-degree courses in the UK, primarily based on the EngineeringUK [9] 2023 report on Engineering in Higher Education, unless otherwise noted.

Gender. Across engineering, women remain significantly under-represented. EngineeringUK [9] reports that women constituted only 18.5% of first-degree undergraduate entrants, in stark contrast to the 56.5% female participation observed across all undergraduate subject areas. This pattern is reinforced by the most recent 2023/24 HESA [10] data, which indicates that men account for approximately 78% of students enrolled in engineering, confirming the field as one of the most persistently male-dominated academic domains. Longitudinal data further illustrates the slow pace of progress. According to SWE’s [11] analysis of HESA figures, the proportion of women enrolled in engineering undergraduate programmes has increased only modestly over the past decade; “from 14.5% in 2015 to 19.8% in 2024”. Parallel improvements are reflected in degree completions: the number of degrees awarded to women rose from 13.9% in 2015 to 19.3% in 2024. Although these trends signal incremental improvement, they also highlight the enduring gender disparity.

Ethnicity. According to EngineeringUK [9], courses recruit a higher proportion of minority ethnic entrants compared with the undergraduate sector overall, with Asian students particularly well represented. This diversity is reflected in the wider student population data for 2020/21, in which only 66.1% of undergraduates were white. Degree outcomes similarly display important differences across ethnic groups. Across all major ethnic categories, engineering and technology students were more likely to achieve first-class honours than qualifiers across all subjects generally, with White, Asian, and Mixed-Ethnicity students each surpassing the 40% threshold for first-class awards. However, a more varied pattern emerges for upper-second degree classifications: 33.5% of White qualifiers, compared with 43.0% of Black qualifiers, indicating meaningful variation in attainment profiles across groups. This data illustrates both the comparatively strong representation of minority ethnic groups within engineering programmes and the nuanced attainment differences that persist across ethnic categories.

Declared learning difficulties. However, the report focuses on disability rather than declared learning difficulties. Stating that only 10.5% of first-degree engineering and technology undergraduates have a known disability, compared with 15.1% across all subjects, indicating a persistent participation gap within the sector. Despite this lower level of participation, attainment patterns suggest that disabled students achieve at least as strongly as, their non-disabled peers, with 81% achieving a first-class or upper-second honours degree, compared with 80.3%.

Socio-economic background (IMD). The report also highlights that the lowest participation, only 11.2% of undergraduates come from the most deprived areas (Quintile 1) compared with 13.5% across all subjects. In contrast, 32.4% originate from the least deprived areas (Quintile 5), highlighting a substantial socio-economic skew in access. However, differences in attainment across socio-economic groups appear less pronounced within engineering and technology than in the wider undergraduate population. With the difference achieving a first-class honours between Quintile 1 and 5 being only 2.6% and notably this pattern reverses for upper-second, with the most disadvantaged students outperforming by 2.5%. These findings indicate that although socio-economic background continues to shape patterns of access to engineering and technology degrees, it has less influence on academic outcomes for those who progress into these programmes. They also suggest that once enrolled, students

from lower-participation areas demonstrate strong levels of academic achievement, underscoring the importance of widening participation initiatives aimed at improving access rather than capability.

5 DISCUSSIONS AND CONCLUSION

5.1 Limitations

The local dataset covers four entry cycles but includes small sample sizes for several demographic groups, particularly women and minority ethnic learners. As a result, apparent fluctuations in achievement or grade outcomes may reflect sampling variability rather than meaningful change. Additionally, national benchmarking draws on data from multiple external sources with diverging timeframes, definitions, and disaggregation levels (e.g., engineering and technology broadly versus engineering DAs specifically). These inconsistencies limit the precision of direct comparisons and require cautious interpretation.

5.2 Discussions

Access versus Outcome. The local evidence demonstrates that engineering DAs can offer a financially accessible and high completion pathway for those who secure a place. The removal of tuition fees and the integration of paid employment substantially reduce the financial barriers that typically restrict access to higher education. However, the data also indicate that limited entry, rather than performance once enrolled, remains the primary constraint on EDI. Patterns of under representation; particularly for women and minority ethnic groups, mirror national trends, suggesting that structural barriers to entry persist irrespective of institutional support or programme design. Consequently, while outcomes for those who enrol are generally strong, these successes do not yet translate into a representative intake.

Gender. Collectively, the local and national evidence illustrate a consistent pattern:

- Women perform strongly once enrolled, and there is no indication of gender-based performance gaps.
- Participation remains the binding constraint, with women significantly under represented in engineering DAs and engineering education more broadly.
- Retention at the DA stage requires attention, as national evidence suggests attrition among female apprentices even where recruitment is improving.
- Structural barriers, such as perceptions of engineering, school subject choices, workplace culture, and the visibility of role models, continue to shape entry patterns far more than academic capability.

In this context, the modest local increase from 7.9% to 8.3% female enrolment mirrors the incremental gains seen nationally but falls well short of addressing the underlying structural imbalance. The challenge, therefore, is not in female learners' capacity to succeed, but in ensuring that more women have the opportunity to enter engineering pathways in the first place, and that they encounter supportive environments that sustain retention and progression.

Ethnicity. Taken together, the local and national data illustrate several important themes:

- Access, not achievement, is the primary site of ethnic disparity. Minority ethnic learners are under-represented in the local programme, even though national participation in engineering-related apprenticeships is increasing.
- Once enrolled, minority ethnic apprentices perform strongly, and local achievement data provide no evidence of performance gaps.
- Variability in small cohort outcomes underscores the need for caution when analysing and interpreting local data for under-represented groups.
- National degree-level patterns highlight both progress and complexity: strong Asian representation, gradual increases in Black and Mixed-Ethnicity participation, and nuanced differences in attainment.
- The apprenticeship experience itself, particularly workplace culture, mentoring, and belonging, remains central to ensuring equitable progression and retention.

Overall, the evidence suggests that enhancing ethnic diversity in engineering DAs requires interventions focused primarily on recruitment and access, paired with ongoing cultural and academic support to maintain high levels of achievement once learners are enrolled.

Declared learning difficulties. Participation among learners with declared learning difficulties shows encouraging growth, accompanied by strong overall achievement. Nonetheless, the comparatively lower proportion achieving first-class degree outcomes points to the need for more consistently robust academic and workplace support. This includes refinement of reasonable adjustments, enhanced coaching, and more inclusive assessment design. Such measures could strengthen the alignment between

widening participation and high-level achievement, ensuring that increased access is matched by equitable academic progression.

Socio-economic background (IMD). The socio-economic profile of the intake, particularly the continued over representation of learners from the least deprived quintile, indicates that structural inequalities remain influential. While engineering DAs reduce cost barriers, they do not fully counterbalance entrenched disparities linked to geographic deprivation and prior educational opportunity. This local pattern aligns with national statistics, that DAs have not yet achieved their full potential as vehicles for social mobility. Strategic interventions; such as targeted community-based recruitment, pre-apprenticeship bridging provision, and partnerships with employers operating in high deprivation areas, could help shift the distribution towards a more socio economically diverse cohort.

Culture and Progression. EDI outcomes extend beyond recruitment. The transition from access to retention, high performance, and progression depends heavily on the cultural and developmental environment within employers and training providers. National evidence consistently emphasises the importance of inclusive workplace practices, high quality supervision, and clear progression pathways. Local observations similarly suggest that small cohorts of underrepresented learners can achieve highly when appropriately supported. Strengthening the cultural dimension of the apprenticeship experience is, therefore, central to converting diverse entry into long term success.

5.3 Conclusion

Local evidence indicates that Degree Apprenticeships in engineering deliver high completion and strong attainment once learners are on programme; the primary constraint remains entry rather than capability. Compared with national patterns, female participation is lower, ethnic diversity remains limited, and socio-economic representation is skewed away from the most deprived quintile, despite improvement for learners with a learning difficulty. In response, this study has informed changes to the interview and selection process to improve inclusivity. Outreach has also been expanded through school engagement and the use of current apprentices from more diverse backgrounds as visible role models. These actions, alongside inclusive employer recruitment and supportive workplace cultures, represent key levers for improving access. Future cohorts will be monitored to assess whether these targeted interventions lead to measurable improvements in participation and EDI outcomes.

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ECOSYSTEMS SURROUNDING NEURODIVERSITY IN DESIGN EDUCATION; A CASE STUDY

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ABSTRACT

University level design education represents a paradoxical environment in relation to neurodiversity. Current literature suggests neurominorities in the general population represent 15 - 20% with estimates in art and design education as high as 30%. Design methodology and research evolve towards care, inclusion and social innovation issues, suggesting growing awareness/sensitivity to neurodivergence. Design is also increasingly reliant on computing and new technologies, domains where neurodivergence is sometimes seen as a super-power. But many areas within design cannot yet be considered fully inclusive or supportive for the wellbeing of neurominorities in their midst. The design industry and educational institutions continue to accept a culture of competition, and of intense/irregular work patterns leading to high levels of stress and physical/psychological discomfort.

This study considers the eco-system surrounding neurodiversity in a medium sized European design school, working to improve the experience for their students. Areas for improvement are considered valuable for the whole student population. The research is based on in-depth interviews with a wide variety of stakeholders, providing different viewpoints on the experience of neurodivergent students, recognizing the need to actively involve neurodiverse actors in research related to their experience.

We consider neurodiversity (both between and within individuals) as a relevant framework and highlight specific links and paradoxes related to design education. Three eco-system related challenges are discussed reflecting the relational and environmental nature of more effective inclusion and understanding of the diversity of neurotypes in our school.

Keywords: Neurodiversity, education ecosystems, student well-being, inclusivity, learning environment

1 INTRODUCTION

Awareness of neurodiversity is growing with initiatives to promote equal opportunities and representation in the majority of institutions [1], including in higher education. In media and technology fields neurodivergent thinkers are valued [2] leading to better student support and recruitment opportunities. But this vision of a system that from the outside appears to be changing might not be matched by micro-level lived experiences of the students concerned [3]. Current figures suggest neurominorities within the population to be around 15 - 20% [4] [5] but neuro-inequalities [6] still exist. Public/educational spaces are not yet neuro-neutral [6] and disfavour neuro-minorities. In HE, less than 40% of autistic students may successfully complete their studies [4] [7] with figures difficult to establish due to non-disclosure, and/or lack of formal diagnosis at the start of studies.

University level design education is both a relevant and paradoxical environment in relation to neurodiversity and the above-mentioned need to continue to work towards a better experience for neurominorities. The context of this case study is a medium sized French design school, working to improve experiences for their neurodiverse student population, with many adjustments already established and appreciated. It should be noted that the French context [8] may generate specific issues, reportedly being behind other European countries due to historical/cultural factors and prevalent psycho-analytical theories, despite growing awareness of the neurodiversity movement [8].

This study represents the start of a wider research programme to gauge effectiveness of current initiatives, identify areas for improvement and specific research themes to be developed. Our initial aim is to better understand both the lived experience of neurodivergent students and the eco-system surrounding neurodiversity with involvement of a variety of stakeholders within the school structure.

2 NEURODIVERSITY

The debate around neurodiversity is continuously evolving, and researchers highlight there still lacks a single unifying theory for any of the conditions [5] commonly included in this definition: Autism, also known as autism spectrum disorder (ASD), Dyslexia, Attention-deficit/hyperactivity disorder (ADHD) and Developmental Coordination Disorder (DCD). In an area where misconceptions are still very common and have real impact on the experiences of neurodivergent students and staff - it is important to be aware of harmful narratives [10]. Neurodivergent people are neither “broken” nor “talent” [5]. Strength-based models may also be problematic [3]. Dwyer (2022) advises considering both strengths and weakness and being aware of (our own) biases [11]. The distinction between “neurotypical” and “neurodivergent” is not straightforward [1] due to the multidimensional nature of neurodiversity. These distinctions are also dynamic, due to evolving social norms, as the case of left-handed people illustrates, representing 10-15% of the global population and clearly today no longer considered “sinister” [1].

2.1 Definitions

The term neurodiversity was created by stakeholders in the 1990s, influenced by a social model of disability, linked to the idea of biodiversity - where diversity is considered essential for a thriving ecosystem [5]. The term is generally used to cover Dyslexia and DCD (not considered health conditions), ADHD and autism (currently considered health conditions). Individuals with mental ill health conditions such as anxiety and depression (which are potentially transient) may be included as neuro-minorities [5]. Hypersensitivity shares many common conditions and may be reasonably included in a broader definition of neurodiversity [12]. In the context of this research we use a holistic definition, with the emphasis (present in the terms neurominorities and neurodiversity) on difference rather than disability or disorder.

This framework is valuable for encouraging a view of difference “between” individuals in a context of social responsibility, but neurodiversity is also “within” the brain. Neurodivergent individuals often demonstrate a spiky profile with high variability in psycho-cognitive and executive function performance [1]. Given the high hereditary rate and the fact that the cognitive functions concerned are in phylogenetically late-developing brain areas, current research suggests a possible evolutionary explanation for this neurodiversity [1]. Neurodiversity may be linked to changing environments and higher order survival functions - which are not an issue if neurodivergent individuals are part of a group, potentially giving advantages to the group/species.

2.2 Neurodiversity and the Design Context

There are likely to be a higher number of neurodivergent individuals in art and design [13], [14] with some estimates as high as 30% of student populations. The specific skills linked to neurodivergence; “high order cognitive functioning reliant on comprehension and creativity” [5] are highly valued in the context of Design Education (see Table 1). But equally neurodivergent students may lack skills in time management, organization and concentration. Fitzwater, 2017 [14] highlights the complexity of equitable and effective instruction increased by this high proportion of neurodiverse learners.

Design teaching involves flexible and nonlinear teaching methods which is both positive for neurodivergent students (less formal lessons and writing) [14], but very different from the high school context and potentially lacking in structure. The design teaching environment is increasingly complex and also highly competitive [15], with curricula also relying on moments of extreme stress “the crunch” in Game design, or “charettes” in design/architecture for example.

Design is also increasingly focused on user experience, therefore appropriate consideration for neurodivergent profiles shouldn’t even be a subject, reflecting design’s ethical dimension (Latour,2008) [16]. As a study area that attracts a neurodiverse population, design education has a responsibility but also the capacity to show, sensitize and communicate issues surrounding neurodiversity [17].

Table 1. strengths/weaknesses of neurodivergent individuals - adapted from Doyle, 2020 highlighting skill sets valued in Design education

	Difficulty	Strength
ADHD	*Time management *Concentration, attention & self-regulation difficulties *Teamwork difficulty	*Creative thinking *Visual-spatial reasoning ability *Hyper-focus, passion and courage

Autism	*Time management *Concentration and coping with more than one task *Social and communication difficulties *Need for routine	*Memory ability, and other ‘specialist individual skills’ including reading, drawing, music and computation *Innovative thinking and detail observation
Dyslexia	*Literacy, memory, organisation, communication and self-esteem *Memory, organisational skills, time-management, stress management *Workplace participation in terms of mental functions and social interactions *Cognitive functioning and social self-esteem	*Entrepreneurialism *Creativity and cognitive control *Visual reasoning *Practical skills, visual-spatial skills and story-telling ability

3 METHOD

This research considers difficulties for neurodivergent individuals as a bi-directional issue [9] with relational and social aspects of their environment as central (7). The approach for this first phase of research was to ensure the lived experiences of a variety of neurodivergent students were included [3]. 13 students identifying as neurodivergent took part, recruited through the school handicap coordinator, and through word of mouth. These included two recent alumni, one final year masters student, 5 fourth year students, two second year students and one first year student. Our aim was also to collect a variety of views from other stakeholders within the school eco-system on these experiences. In-depth semi-structured interviews, allowed long exchanges (averaging 1 hour). Respecting individual preferences, three anonymous replies were completed via Googleform, and one reply was in correspondence form. In the wider eco-system, 15 supplementary interviews included: a representative of the student union, two pedagogical coordinators, two permanent department referents, two department heads, five regular part-time staff, the human resources director, and the director of an external association. All participants received information concerning the nature and aims of the study and of anonymization. The interviews were carried out over a period of 2 months.

4 FINDINGS

Analysis of collected materials is ongoing, reflecting that this study was carried out at the start of a wider research programme. We focus here on relational issues that implicate the whole eco-system and may exist in other design education institutions. The three issues presented below illustrate possible differences of viewpoint between neurodivergent students and other stakeholders and also differences between neurodivergent stakeholders themselves (both students and members of staff).

4.1 Invisibility

In France a successful comic strip book relating the experience of a young autistic woman [18] is named “La Différence Invisible”. Despite improvements and despite the proven high incidence of neurodiversity within art and design education, different forms of invisibility remain a challenge. A recent graduate comments “*I was never aware of it. First of all because no one spoke about it, there must have been neuro-atypical people in our year but no one came forward*”. Most student interviewees are aware of at most one or two other neurodiverse students in their class groups, but with two notable exceptions “*most of my friends are on the spectrum*”, “*nearly everyone at [school name] is neurodivergent*”. The two students quoted here are in the same class, suggesting class dynamics play an important role. The perception of prevalence of neurodiversity in the student population is very varied, with responses nevertheless suggesting a much lower percentage than what is statistically likely.

An invisible subject? “*It’s perhaps a kind of ghost subject*”... “*I’d like people to know but I just can’t talk to them about it, I don’t want to be looked at strangely*” Students interviewed considered that neurodiversity related themes were not discussed, but replies highlighted heterogeneity in experience which might be attributable to different class dynamics or as suggested by many interviewees to different sections of the school attracting different profiles of student, or a progressively tolerant environment: “*the younger students seem to be more open*”. Students and staff commented on the fact that it is a “*relatively new*” subject *not present a few years ago*, with some (staff) admitting learning about neurodiversity only in the last year, which may be a reflection of the specific French case [8].

Invisible judgement is also an issue, echoing findings [9] that neurotypical peers may judge autistic people within seconds and be reluctant to engage in social interactions with them “*People tended to choose me as a last resort*” “*they said I was different*”. Vincent (2025) [19] discusses how autistic

students may apply negative stereotypes to themselves, internalising stigma and negatively framing their neurocognitive distinction leading possibly to masking their differences and undermining their authentic identity.

Kai Syng Tan [13] suggests that neurodiversity is a hidden resource in HE. Our findings clearly reflect the invisibility of neurodivergent staff, which could have value for improving student experience [20]. Interviewed staff were not officially aware of neurodivergent colleagues, while considering their presence likely. Neurotypical staff are unlikely to fit the stereotypical depictions people may have of autistic people (or those with ADHD) [17]. However, of the eight members of teaching staff interviewed, 5 identify as neurodivergent, three of whom are diagnosed, suggesting the actual percentage of neurodivergent staff may be considerable. The student cohort had differing views on neurodivergence among the staff, with some detecting a potentially large number among part time tutors *“yes, clearly [laughing] you can feel it, autistic, attention disorder, there’s not much doubt...teachers who can’t stop talking, jump from one subject to another...”*. The hidden value was reiterated by students; *Yes their experience would be really useful, to know how they managed - could reassure people*. Echoing findings [20] on the possible added value of dyslexic teachers (with greater somatic sensitivity) staff identifying as neurodivergent commented on their ability to read the faces of students, see gazes drifting, spot more easily students in difficulty, and particularly those with sensory or attention issues. The director of a local association supporting employment for autistic people highlighted how autistic teachers can be very effective with students (but less with their hierarchy). Equally, learning, teaching and researching [13] may be strengths of this population. An inclusive staff cohort [4] may give better understanding of neurodivergent students, facilitating better adapted adjustments for their needs.

4.2 Sandbox, Ongoing learning

“What I learn at school - I learn to adapt myself”, “School is a good setting to test things out, to find stability, a good sandbox” These quotes, from two different students in their 4th year of study, highlight the obvious; school is a place for learning. But in the case of neurodivergent students school can and should be a “sandbox”, where students can safely and progressively evolve. A student diagnosed at the end of her third year describes a recurring pattern: *“I compensated enormously. I did far more sleepless nights [working] than my classmates. I had to redo the lessons. The first year I don’t know how I passed. The second year I saw that I had to do something...The more you understand, the more you can adapt and find solutions. I grew at the same time. ADHD is not at all an obstacle to learning.”*

The first and second years are highlighted by many students as difficult *“the first year was very complicated for me - my work was no longer the same and I had to organise myself alone”*. The experience of this student was compounded by the distance from her family, and the very different nature of study compared to high school, a problem signaled by a number of students.

A growing proportion of autistic people, especially women, go through the diagnosis process in adulthood, and thus make sense of their new identity during HE [19]. A student (autistic, with ADHD) diagnosed at the end of high school commented she is still *“trying to understand herself”* in her 4th year of study. The usual time between first contact and diagnosis is 1 to 3 years in France [8], with a lack of trained clinicians, leading to patients having difficulty finding psychologists without “outdated ideas” – echoed by participants in our survey. A rollercoaster of alternating emotions following diagnosis [8] is reflected in our research. The period following diagnosis generates a mental shift [5] at identity level which can lead to feelings of disempowerment, but can, more positively, lead to understanding one’s strengths/weaknesses. Our findings suggest students are often managing recent or ongoing diagnosis, and need to come to terms with personal experiences, health concerns and fear of stigmatization [4]

Syng Tan [13], diagnosed after her PhD, comments she is still learning *“how it impacts her work, how others (mis)understand it and how I can communicate it”*. Damiani [17] writes how he has *“learnt to control the flow of his [autism] and to recognize patterns that are better for me”* in adulthood. A diagnosed staff member comments *“I organise my life at work around what I can and can’t do”*

Design school is an environment for discovery of neurodiversity in our cohort: *“I didn’t know ADHD existed. I met a lot of people here - that’s how I knew about ADHD”*. And in another section of the school *“there are a lot of exchanges between people - people discover...[I learnt through] my ex-girlfriend of the time...for a long time I didn’t know what it was”*. Multiple references in the literature point to the value of neuro-affirming and positive affiliative relationships [19], [20]. But it is important to highlight that this discussion is not happening across all sections of the school. Our research so far shows that the 5 year study period, and its design specializations, represent an environment with

responsibility, accompanying an important period of sense-making, particularly for neurodiverse students. Findings suggest students tend to play down their needs, verbatim from four different students: *“I don’t know if the school can do more”, “I don’t have so many needs - it’s more up to me to adapt”, “I couldn’t ask for more...I’ve got the minimum I needed”, “I don’t know if it is the responsibility of the school”*. Equally we should keep in mind the high drop-out rate signaled in research [4], [21] and alluded to in our interviews.

Part of this accompaniment involves the transition to a career at the end of studies. A number of students mentioned tutors reacting negatively to accommodations/adjustments such as filming/recording parts of classes, but as one student stated the *“school mentality [is] to prepare for the professional world [but] my brain will be developed and I will have found the solutions”*. While there is evidence of growing acceptance and interest in employing more neurodiverse students [2], this is also an unknown and source of anxiety for many neurodiverse students representing an area where the value of neurodiverse staff could bring value.

4.3 Confidence/System

Many reactions from stakeholders in our study paint a very positive picture. A member of coordinating staff highlighted that although the numbers of neurodivergent students is very different today from when she joined the school eight years ago, the problems don’t come from these students, and she estimates that perhaps only 10% to 15% keep their diagnosis to themselves. A part time tutor familiar with the subject teaching both in our school and elsewhere noticed a positive difference in the school, with individualized accompaniment for all students. Almost all students positively mentioned the nurse/handicap coordinator and many their department referent as being part of their support system. Equally a diagnosed member of staff related feeling comfortable in the school compared to other teaching establishments due to the understanding atmosphere, and support given to students. A student commented that the school was “serious” compared to equivalent establishments. Mutual aid and positive atmosphere were mentioned by around half of the student cohort.

Nevertheless confidence is a key issue. The only people mentioning super-powers were two (neurodivergent) staff members. Lui et al [15] report issues of lower self confidence and self-efficacy. Students in our study commented having *“self-trust issues”* and the importance of confidence. An issue where this confidence still appears fragile relates to their view of the system. *“There isn’t a method at school, there isn’t a system”, “I don’t know what has been put in place”*. Equally many students don’t appear confident that tutors are aware of their specific cases *“they don’t remember”, “I don’t think the teachers know”*. A number of students also mentioned that the attention and consideration received was not equitable *“the school should treat everyone the same - they listened to me”, “I feel pretty lucky, I’m not sure if others were”, “unequal - if you get on well with the peda(gogical team)”*

Despite the evident progress and many adjustments put in place for a large number of students, continuing to work towards (and not assuming) a climate of confidence for the students concerned remains essential.

5 DISCUSSION/ CONCLUSION

Two limitations in our study concern the self-selection of student participants and an over representation of older students - which while illustrating the sense-making/evolutionary nature of student experience (mentioned above) indicates future research (and support) should also focus on experiences of students in their first and second years of study.

The three issues/relational challenges illustrate the diversity of experiences, and need for ongoing sensitizing with a need for more and better communication even in the design education context. Even in this context backlash and negative reactions may be an issue. One neurodivergent participant commented *“[they say] ‘they’re all autistic now’ - it feels defensive - if they only stopped demonizing - some feel aggressed by the diversity of the student body”*

Amongst our findings, issues surrounding external, part-time tutors in design education represent a key action area. These teaching staff bring appreciated direct input from the design industry and could be valuable for diversity representation, but also have very different levels of sensitivity to, and knowledge of neurodiversity, affecting student learning experiences and well-being.

The complexity and the diversity of experiences necessitate the involvement of the people concerned, both students and members of staff. These initial insights highlight action areas, while emphasizing the relational nature of valuing (neuro)diversity, taking the evolutionary view that strengths and specialized

skill sets (spiky profiles) contribute to the whole, when the whole is supportive and sensitive to individual differences.

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UNDERSTANDING GENAI USE IN STUDENT ENGINEERING DESIGN WORK: INSIGHTS FROM A PILOT INTERVIEW STUDY

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ABSTRACT

Generative AI (GenAI) tools are increasingly capable contributors to design work, though human judgement in design ideation and decision-making remains essential. Design learners' use of GenAI tools is shaped by characteristics of the design task, their own skills and attitudes, and the broader learning context. Student-AI interactions unfold within a complex "jagged frontier" - a boundary where AI excels in some areas but may degrade design process and outcomes in others. For design educators, helping students navigate this frontier through guided, hands-on experience is an emerging pedagogical challenge. This pilot study investigated how three undergraduate engineering students used GenAI in the early stages of design, and its perceived benefits and limitations. Using an adaptation of the echo interview method, each student was interviewed twice – following individual and group projects respectively - during a third-year engineering "pre-capstone" design course that explicitly integrated instruction on effective GenAI use. Students used GenAI primarily for research, ideation, and writing support, citing efficiency as the key benefit. They developed verification practices and prompting strategies largely through peer learning and individual experimentation rather than formal instruction; this over-reliance on peer networks may not benefit all students equally. A perceived negative impact on creative exploration also emerged, with students tending to settle for "good enough" AI outputs under time pressure. Findings offer preliminary recommendations for design educations seeking to integrate GenAI in ways that foster effective, critical, and inclusive design practice.

Keywords: Problem definition, design projects, Generative AI, qualitative, student experience

1 INTRODUCTION AND MOTIVATION

Organisations are rapidly integrating AI across operations including product design, making AI proficiency a baseline expectation for employees and new hires. Generative AI (GenAI) tools now match or surpass human performance in many design tasks, though human oversight in design ideation and decision-making remains essential [1]. Integrating AI into design work introduces a complex "jagged frontier" [2] - a boundary where AI excels in some areas but may degrade decision making in others. Understanding these limits is critical given limited formal AI education in design curricula [3] and evolving AI capabilities [4, p. 142]. Becoming "expert designers in the loop" - thoughtfully integrating AI tools while maintaining critical oversight - requires practice and reflection.

Design practice is shaped by the socio-technical context in which design unfolds [5]. As such, student adoption of GenAI in design is shaped by characteristics of the task, the student, and their broader context [6]. Navigation of the jagged frontier is thus unlikely to be uniform; variation in prior AI exposure, confidence, and access may introduce new forms of inequity into design learning.

This research investigates how undergraduate engineering students use GenAI in early stages of design, and how this use affects their design thinking, behaviours, and self-efficacy. Specifically, we ask:

- 1) In what ways do students integrate GenAI into early-phase design tasks?
- 2) What benefits and limitations do students perceive?
- 3) How do socio-technical contextual factors shape the nature and extent of GenAI use?

Findings of a pilot study highlight student-identified use cases and inform recommendations for design educators seeking to integrate GenAI in ways that foster effective and responsible practice.

2 METHOD

The study setting was a 13-week third-year management engineering design course at the University of Waterloo, Canada, in fall 2025. The course acts as “pre-capstone” and serves two primary roles in the curriculum: 1) offer training in engineering design methods, especially those most relevant to the early phases of the design process, and 2) provide multiple structured opportunities for students to develop skills in problem finding, analysis, and conceptual design. Students are encouraged to take an analysed problem from this course into their capstone design courses in fourth year. Capstone projects in this discipline are typically software-based decision support tools that leverage AI, analytics, and optimisation approaches. The instructor explicitly integrated instruction on effective use of GenAI tools throughout the course, providing examples of how AI can support key tasks (e.g., publication research, developing interview questions). Figure 1 shows the complete course timeline.

This study (REB #47748) was designed as a pilot to establish and test the interview protocol with a small participant pool. Three students – all male – were recruited to participate. While each had some prior experience with GenAI tools, the nature and extent of that experience varied considerably – from personal use (e.g., to study) to intensive professional use on industry internships, providing a range of perspectives within a small sample. Each student was interviewed twice in the term, at the conclusion of two cycles of open-ended problem finding and analysis (highlighted in pink in Fig. 1) – the individual project in weeks 1 to 6, and the group project in weeks 7 to 13. This design enabled the capture of changes in design reasoning and GenAI tool engagement over time.

Week	1	2	3	4	5	6		
In class instruction	Course intro	Problem finding	Analyzing needs	Research with secondary sources	Research with primary sources	Problem framing & conceptual design	Design Comms	Design thinking
Project	-----Individual project-----							
			M1	M2			M3	
		7	8	9	10	11-13		
		Requirements analysis		Design impact				
		-----Group Project-----						
		Group formation, topic selection	M1	M2 - peer critiques		M3-design reviews		
		First set of interviews				Second set of interviews		

Figure 1. Course overview and alignment with two sets of study interviews

The six interviews (each 60 min to 90 min in length) were conducted by 2-3 members of the research team and were structured in three parts. In *part 1* participants assessed their prior experience and confidence in both design and GenAI use, relative to their peers. In the first interview this was framed around starting a new design project; in the second, participants reflected on how their skills and perceptions had developed over the course and looked ahead to future academic and co-op (industry internship) experiences. In *part 2*, participants described their current design problem, key tasks performed, challenges encountered, and any resulting plan changes. As they spoke, interviewers noted elements in the students’ context (influences), including people (e.g., instructor, TA, peers) and social and technical factors (e.g., course materials, technologies, project instructions). In *part 3*, an adaptation of the echo interview method (as described in [5]) was used to investigate how elements in the students’ socio-technical context influenced the nature and extent of GenAI use in their design tasks. Participants identified actions or decisions that made the task more challenging, then ranked the socio-technical factors described in part 2 according to impact on their task. For each influence, they provided examples of the ways these influences had been helpful or unhelpful.

The six transcripts were coded by the first author using a mix of deductive and inductive analyses. Deductive coding was guided by the questions in the interview protocol (e.g., self-assessed confidence in GenAI use, contextual influences), while inductive codes captured other topics or patterns that emerged in the interviews. This process resulted in 283 unique codes applied across 622 excerpts, which were iteratively grouped into eight themes. Coding and thematic grouping were then verified by a second member of the research team. One of the themes (46 codes over 148 excerpts) comprised all excerpts that related to GenAI use, and is the focus of this paper, as detailed in the next section.

3 RESULTS

Two sub-themes illustrate how students incorporated GenAI into their workflows and how they responded to the tools' limitations, as detailed below. Student quotes have been minimally edited for clarity and brevity.

3.1 GenAI uses cases and benefits

Students described GenAI as a practical support tool integrated into their design workflow rather than an all-purpose solution. In line with the scope of the course (viz. early stages of design) students used GenAI primarily in three areas: 1) in problem research (to identify related problems, generate initial research directions, develop search queries, identify sources, and summarise lengthy reports or technical documents, 2) in ideation and prototyping (to generate low-fidelity concepts as inspiration, or preliminary user interfaces from text prompts, and 3) as writing support and quality assurance (to review drafts against deliverable criteria, generate outlines, refine tone and clarity, and reduce word count). Students selected tools based on task needs: Copilot for coding tasks, ChatGPT for writing and general reasoning, Gemini for image generation or tasks requiring numerical precision, and Perplexity for consolidating research information. Some described preferring to rely on AI tools they personally found more effective rather than built-in platform assistants – *“we all have our own AIs that we prefer using ... what we're comfortable with and what we think will give us a better output.”*

Students described several ways GenAI supported their course and project work. The most common benefit was increased efficiency. They noted that time pressure influenced when they turned to GenAI: *“I think GenAI wasn't something initially that we had in mind... the time crunch we had for our second milestone [is] why the GenAI was incorporated”*. Participants noted different ways that LLMs helped them expedite their research workflow, including screening large sets of materials, extracting potential quotes, and compiling sources, which allowed them to spend more time on verification and synthesis:

“I do think it does make a lot of these processes more efficient because it does that initial like processing step for, not necessarily for you because you still have to verify that the information is correct, but for you in the way that you don't have to look through a million sources that Google search presents to you ... Now LLMs check if they're relevant and then give you a list so that you can check if they're correct or not.”

One participant noted that Gemini supported their design tasks by speeding up early concept development and reducing repetitive work they had to do with Figma (a user interface prototyping tool): *“...having that initial idea from the conceptual design created using Figma in a [smaller] amount of time was very efficient for us”*. Another participant described how GenAI helped them broaden their research, identify new research directions when they felt stuck, and notice important details they might otherwise overlook:

“I think before I used AI... I felt a little bit overwhelmed because I was kind of stuck on where I should go next or what should I use for my potential solutions... that's when I started moving to Chat [GPT] and then with [it] I was able to kinda get myself back on track.”

Students developed their GenAI practices through a combination of peer learning and individual experimentation. Participants described sharing workflows, recommending tools to teammates, and adopting new models after seeing how classmates used them: *“I'm continuously learning by like having conversations with ... classmates as well as like friends from other [engineering programmes] ...learning how they're using it in their fields”*. Students described improving their prompting through *“trial and error”*, learning not only to adjust prompts but also to guide the model toward desired outputs – *“I have to kind of structure it sometimes in a certain way to kind of push it into the right answer that I want”*. Two participants reported relying primarily on prompting styles that felt natural to them, one noting that their informal approaches often worked as well as the structured prompting guidance provided in class: *“[instructor's way of prompting] was only different with the structure, so hers were a lot more like professional... but when I talked to Chat[GPT], it's very like scrappy... I don't think in quality... there is much of a difference”*. While instructor guidance may have served as useful background knowledge, students' own habits and preferences ultimately shaped their prompting strategies.

3.2 Recognising and responding to GenAI limitations

Students frequently encountered problems such as hallucinated citations, broken links, inconsistent answers, and numerical errors. There were also noted limitations stemming from model training data,

with noted difficulties in finding recent or rapidly evolving information: “some of [the new articles] won’t be there because the data have been trained up on them and they are fairly new. So [Chat]GPT tends to give out the ones that are not yet updated”. The rapid pace of model updates introduced another layer of uncertainty: “as the model’s improving, it’s trying different outputs as well. So, you could ask the same thing in like two different Chat histories and then it might output different results.”

To address these concerns, students relied on multiple ways of verification. One participant described cross-checking outputs across different models to assess consistency and reliability:

“I have used like Gemini to compare to [Chat]GPT and then in terms of code I know Claude is like one of the top performing models for coding, so I’d use that to compare to like traditional GPT models, etc. To see which one’s more efficient, which one’s easier to use, and which outputs are more consistent.”

This cross-checking extended to validating AI-generated findings against original sources:

“...then once Chat [GPT]... give us a list of things or a list of quotes that we can use and then we’d go back, make sure that all the quotes are there and then just do a quick skim to make sure everything’s fine and then ... use that as a source for a lot of our research.”

Verification thus became a routine part of their workflow, adding additional time to refine prompts and confirm the accuracy of GenAI-generated information - “it just wasn’t understanding what I wanted and it outputted something like completely random...[which required] more time kind of fixing my prompt to get it back to where I want it to be”. For source credibility specifically, one student noted that asking ChatGPT for credible sources could double the time needed to find one.

Despite these challenges, students did not believe GenAI use affected the overall quality of their work, given that they still verified sources: “As long as you have that like initial structure in mind, I don’t think the quality will dip because you’re still vetting the information and you’re still like synthesising your conclusions from it individually...”

Students also faced uncertainty about acceptable use of GenAI, especially when expectations varied across courses. Even as GenAI has become more normalised, students were still navigating unclear boundaries around what was academically appropriate: “I couldn’t tell if maybe I was using too much AI or too little AI, so I feel like that fine line is still really fine on what is morally right to use for this and what’s not”. They were thus attentive to aligning their use of GenAI with course expectations, noting that these rules had loosened over time:

“I remember earlier on they were very strict on no AI and then the more that it’s developing, the more they’re like OK, maybe we can kind of shift how we structure it. So, you can use it more... another example is my last STAT [course] ... [the professor] said do all the math by hand...the write up you can make AI do it. I don’t care.”

Students also grappled with how they perceived AI use affected their design thinking and behaviours. For example, one described feeling that relying heavily on AI-generated visual concepts reduced their creative exploration, noting a tendency to settle for outputs that looked “good enough” rather than generating alternative concepts, particularly when teams were working quickly:

“Oh, I think it sort of takes our creativity as, away from us at some point, because we might not come up with things on our own..., it sort of restricts our creativity at like a certain level, I guess that would be a drawback that I would say...I think it sort of creates a mindset of it’s enough like this sort of looks OK, so we don’t try to go above and beyond...”

One way in which students described retaining some of their agency in the design process was by evaluating GenAI outputs selectively rather than adopting them wholesale. For example, in front-end design work, they explained keeping AI-generated elements that aligned with their design goals and discarding parts that did not fit. GenAI’s usefulness thus varied depending on the complexity of the task:

“...in the broad aspect of things, for example where our navbar should be ... or like where our search button should be ... it was pretty similar, but for example how our graph should look like or how our accountability page or like the peer pressure aspect ... was completely different. So, it completely depends on the complexity of things.”

Here, GenAI served as a mid-process aid for exploring layouts rather than a substitute for careful design refinement. It was helpful for generating initial directions, but the student remained selective in what they adopted. While broader layout suggestions were often usable, more complex or context-specific elements required human intervention.

4 DISCUSSIONS

4.1 Key findings and implications

This pilot study set out to understand how undergraduate engineering students integrate GenAI into early-phase design tasks, what benefits and limitations they perceive, and how socio-technical contextual factors shape the nature and extent of their GenAI use. The results broadly align with other research exploring undergraduate engineering students' use of GenAI in design. Findings about the use of GenAI in the early stages of design [7], [8], [9] and writing [10] are consistent, as are those reporting on perceived improvements in efficiency [11], [12] and quality of work [10], [13], and the challenge of verifying GenAI output [10]. Acknowledgement of whether the use of GenAI is acceptable is noted - while a previous study indicates that students do consider the ethical considerations and design authenticity, they are "secondary to perceived functional advantages" [7]. Notably, students in this study developed prompting strategies and verification practices largely through peer learning and individual experimentation rather than relying on the available formal classroom instruction on effective AI use in the design process - suggesting that AI literacy in design education may be emerging unevenly, shaped by students' social networks and prior exposure as much as by curriculum.

There are two key areas where the current study strays from previous research. First, students in this study perceived a negative impact on their creativity – settling for “good enough” AI outputs rather than exploring alternatives. This is counter to students in other studies who are motivated to use GenAI to improve their creativity [10] or who experience a positive impact on their creativity [11]. In this study, the risk appears most acute in visual ideation tasks under time pressure, where AI-generated outputs can appear convincing enough to discourage further exploration. Educators may be able to mitigate this by requiring students to generate and document their own concepts independently before engaging GenAI, preserving the divergent thinking that early ideation is meant to develop. A second point of divergence from the literature was noted in the reported verification of GenAI results during the design process, which appears counter to studies that report students frequently accept GenAI responses without rigorous verification [7] and develop an over-reliance on unverified GenAI output [8]. This may reflect the explicit attention given to verification in this course - pointing to the value of directly teaching critical evaluation of GenAI outputs as a core design skill, alongside prompting and tool selection.

The shared findings and new insights reflect the everchanging landscape of GenAI use in the engineering design process and its highly contextual nature [5], [6], and reinforce the need for design educators to move towards actively shaping how students engage with GenAI across diverse learning contexts.

4.2 Limitations and future work

This research was a pilot study, and as such there are important limitations to consider. First among them is the small participant pool (three students, each interviewed twice). Compounding this issue, two of the students were in the same project group for the second half of the course, potentially limiting the breadth of experiences/perspectives captured in the study. This limitation was evident as each interview continued to unearth new insights with limited repetition between participants. Clearly, the study would have benefited from including a larger sample population. Finally, the course the students were recruited from was focussed on the early stages of the design process, and so the uses of GenAI were limited to those stages as well. So, while there was mention of using GenAI to quickly develop prototypes of user interface designs, GenAI uses in code generation (for example) were outside the scope of the study.

This study was conducted in an engineering programme which typically generates software-based solutions to problems. This limited the applications of GenAI tools to use cases that aligned with this context. Future research could utilise a similar research approach to look for novel applications to other engineering domains (e.g., mechanical or electrical design). More generally, future studies could also intentionally recruit across diverse student populations – varying in prior AI exposure, demographics, and institutional context - to explore how these factors influence the nature and extent of GenAI use in design, and how students evaluate different trade-offs that may emerge [5].

Future studies could also explore student uses of GenAI tools with more depth. For example, study designs with verbal protocol analysis could investigate student uses during a live design task instead of relying on self-reports. Additionally, analyses of generated artifacts/assignments/AI chat logs may provide a broader perspective on the uses of GenAI tools across an entire student cohort.

5 CONCLUSIONS

This pilot study aimed to capture engineering students' use of GenAI during the early stages of design, and how it affected their design thinking and behaviours. Students integrated GenAI pragmatically, primarily for research, ideation, and writing support. They developed prompting strategies and verification practices largely through individual experimentation and peer learning, rather than formal instruction. Notably, students showed critical awareness of GenAI's limitations, including outdated training data and the risk of loss of creativity under time pressure. Findings suggest that educating "expert designers in the loop" may require not only introducing GenAI tools into the curriculum but also attention to how students develop AI literacy, including the ability to evaluate AI output, and ensuring these opportunities are accessible across diverse student populations and socio-technical contexts.

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REFLECT, REPRODUCE, OR CHALLENGE? DECOLONISATION AND THE FUTURE OF IRISH PRODUCT DESIGN EDUCATION

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ABSTRACT

This paper examines how Irish Product Design education continues to *reflect*, *reproduce*, or *challenge* the colonial and industrial epistemologies that underpin Western design pedagogy. Drawing on a polyphonic positionality methodology, the authors analyse their three Irish university programmes to understand how design knowledge is shaped, taught, and questioned. Across all programmes, familiar Western design models and teaching traditions continue to guide how students learn and how “good design” is defined. These structures remain in place even as educators increasingly acknowledge their limits and the narrow worldview they often promote. At the same time, each programme shows efforts to push back against these inherited frameworks. Lecturers introduce new perspectives, challenge universal assumptions, and create opportunities for students to see design as culturally situated rather than neutral. In some cases, institutional constraints unexpectedly create space for experimentation, alternative voices, and more diverse approaches to emerge. However, these changes tend to rely on individual educators rather than systemic shifts. Ireland’s own complex position as both formerly colonised and firmly embedded within Western knowledge systems creates a unique and sometimes tense environment for this work, revealing opportunities for alternative ways of knowing while highlighting the persistence of structural constraints. This paper aims to open up opportunities for further conversation, that may at times prove challenging and uncomfortable, about how Irish Product Design education can grow toward more inclusive, reflective, and culturally grounded futures.

Keywords: Decolonisation, Eurocentrism, product design education, programme design, inclusive pedagogy

1 INTRODUCTION

Continuing reflections within product design education in Europe have increasingly engaged with questions around representation, particularly regarding gender balance, ethnicity, and socio-economic status. Such efforts are necessary, but they often address diversity at the level of participation and visibility. Less frequently examined are the foundations of the knowledge of the discipline itself; the histories, values and frameworks that we develop our educational practice around. Academics working within decolonial design discourse posit that inclusion cannot be limited to demographic diversity but must interrogate the structures that shape what we define as legitimate design practice [1, 2].

The paradigm for European design education developed within the context of Western industrialisation and is closely linked with narratives of technological progress and universal problem-solving [3]. These frameworks are historically entangled with colonial expansion and the advocacy of European knowledge systems as preeminent. Escobar [4] argues modern design practice often operates a “one-world” reality, presuming a universal interpretation rather than acknowledging plural epistemologies. Mignolo [5] defines this as the coloniality of knowledge, in which colonial logic endures within learning environments even after the end of colonial rule. This raises an important question for design education: *to what extent do our curricula continue to position a single worldview as universal*, even within contexts that have themselves experienced colonial subjugation?

Ireland has an almost unique context through which these dynamics can be examined; a European nation shaped by British colonial rule but fully embedded within Western academic and professional systems. Irish higher education institutions have historically served as sites of cultural assertion while engaging with broader Eurocentric knowledge systems. Within this context, design education in Ireland remains structurally embedded within Global North knowledge structures and continues to reproduce dominant Western frameworks while attempting to negotiate alternative pathways.

It is important, then, to approach decolonisation as going beyond Western-oriented frameworks of equity and inclusion and providing the impetus to question our institutions and the pedagogical approaches that we practice within them. By examining academic positionality across three distinct Irish universities, this paper seeks to establish a baseline understanding of how Irish education reflects, reproduces, or challenges colonial narratives in design. This paper opens a conversation but does not look to draw conclusions.

2 METHODOLOGIES (POLYPHONIC POSITIONALITY)

Through engaging a method of polyphonic positionality, this work examines how the institutional contexts from Technological University Dublin (TUD), Maynooth University (MU) and University of Limerick (UL) shape the knowledge structures of design education. The approach begins with the premise that education is not neutral but inseparable from the power dynamics which determine what types of knowledge are valued [6]. Within the wider context of design education, these hierarchies are reproduced not only through formal learning but also through our assessment practices, taught histories, and even our studio culture.

Building on Noel's argument [7, 8] that design educators should critically examine how our social and cultural positions shape hierarchies of knowledge. This paper treats positionality as a methodological tool, not a biographical one. As educators, we participate in defining disciplinary norms through the ways we design our curriculum, briefs, and assessment criteria. Noel and Paiva [9] further demonstrate the subtlety with which exclusion can operate within design work, reinforcing the need for critical reflection on how we shape belonging in the studio.

Sara Ahmed's [10] critique of institutional diversity work informs this approach, especially her argument that inclusion can become performative when structural systems remain intact. For this reason, the approach extends beyond concerns of representation to interrogate the narratives of institutions, the default to Western modernity, thinking around industrial progress and Ireland's position within European Knowledge Systems.

In avoiding privileging a singular institutional voice, we adopt polyphony as a method. Each author developed an individual positionality statement that reflected on their institutional history and programme culture as well as their individual understanding of their own cultural and socio-economic background. These statements were shared and subjected to structured mutual interrogation. This dialogic approach draws on hooks' [6] idea that what we know is shaped by our relationships.

2.1 Positionality/Positionality Statements/Statements on Positionality

Our collective positionality as design educators is shaped by our varied identities, histories, and disciplinary formations. Our experiences across race, gender, class, sexuality, ability, nationality, and career paths inform how we understand, teach, and practice Product Design. Despite our different backgrounds and perspectives, we share an understanding that design knowledge is never neutral. We remain committed to ongoing self-examination and accountability, recognising that our subjectivities shape our teaching, assessment, and interpretations of design practice, and that our contributions are always situated rather than universal.

Oratile: I position myself as a Black Southern African female design educator whose formation was shaped by a Euro Western design curricula that obscured their own colonial foundations. My experiences teaching in Botswana, South Africa, and now Ireland continually foreground how race, gender, and inherited structures shape my authority and responsibility. I am committed to ongoing unlearning, reflexivity, and accountability in the knowledge I teach and reproduce.

Alastair: I am a white, Anglo, nonbinary, queer design educator whose early practice was shaped by Christian cultural norms, colonial assumptions, and a saviour-oriented design mentality. Through decolonial critique, I have reoriented my practice toward dismantling oppressive systems and supporting self-determination. I now position the designer as a storyteller who enables situated knowledge to circulate and be rescripted.

Muireann: My middle-class upbringing as a white Irish female and my long academic career shape how I teach and understand Product Design. My educational values are grounded in the social purpose of teaching, yet I remain aware that my worldview frames, and potentially limits, how I engage with, assess and support students. I continue to question how subjective experiences intersect with the possibility of fair, meaningful, and varied learning experiences.

Ceri: I am a white, British, male, Product Design educator shaped by early training in market driven, Western design traditions, now working within institutional structures that both shape and constrain my teaching. My interests in low-tech, care oriented, and sustainability focused design inform how I read and question design curricula. I offer my perspective as one situated voice, contributing to collective reflection rather than definitive judgment.

3 FINDINGS (CROSS-INSTITUTIONAL THEMES)

Comparative interrogation of the authors' positionality statements and their respective programme structures enables discussion of the current state of product design education within an Irish context. The three lenses: reflect, reproduce, challenge, allow examination of how colonial-industrial heritage persists, adapts, or is contested within these distinct programmes. These lenses are not mutually exclusive stages but concurrent conditions which operate within and across the education landscape.

3.1 Reflect

Across all three universities, product design education reflects a Western industrial understanding of knowledge, which has been developed alongside narratives that emphasise technological progress with concepts on the universalisation of problem-solving. While each programme occupies a distinct location within its university's organisational structure, all are shaped by inherited models of design rooted in European modernity. This includes framing the design process around the British Design Council's Double Diamond model [11] and IDEO's Three Lenses of Innovation [12]. These inherited models are visible in theory and history classes, studio formats and their related pedagogies and the progress models that structure students' understanding of what counts as legitimate design thinking.

By founding pedagogy on these models, the institutions continue to centre patriarchal value systems and colonial-settler cultures, which are 'out of place' with the liberatory struggles against colonialism within Ireland and the contradictory lived realities of colonisation produced by the Irish diaspora; as descendant from, or ancestor to, or currently living populations under colonial occupation whilst, simultaneously, actively resisting the occupations of Indigenous lands across the globe [13]. Ireland's design pedagogy and industry is inherently reflective of the nation's wider dual position as simultaneously resisting and relying upon colonial laws, politics, and economics.

The authors apply a critical approach to their institutional pedagogy, attempting to bypass rigid structures by reframing module content and teaching 'speaking between the lines' of dominant models. However, critical design approaches that are presented as tools for resistance can often reproduce the very structures they seek to critique. Without true systemic structural reorganisation, design educators can continue to reproduce the colonial structures that the Irish diaspora are complicit within and perpetuates reductive narratives of Irish interactions with colonialism; focused on post-colonial perspectives that seemingly ignore Ireland's transition from one white polity to another, cultivating a history of exercising whiteness and nationalism as independence from colonialism without any formal actions towards decolonisation and new kinds of governance founded in Irish Indigeneity [14].

Given the situation each programme finds itself in, reflection does not imply endorsement; rather, it signals structural continuity. Increasingly, the programmes demonstrate awareness (even if not explicitly stated) of the boundaries of Eurocentric definitions of design, yet the foundations upon which curricula, assessment strategies, and the professional industries to which the programmes align continue to operate within a pattern formed by these industrial and colonial histories. Even where contextual awareness has expanded, Western assumptions remain architectural to Irish Product Design Education, which continues to reflect these narratives, not through explicit ideological framing but rather through non-reflective inheritance. To critique continued colonial influences on Irish design pedagogy and practice we must, firstly, invite new critical perspectives and other ways of knowing and doing into the space between coloniality and decoloniality, which currently reproduces and maintains colonial design ontologies.

3.2 Reproduce

If reflecting on our programmes describes inheritance, then considering how we reproduce knowledge could provide insight into how we have continued to stabilise it and how we can, potentially, dismantle it. Developing programme coherence, building studio culture, replicating assessment strategies, and seeking professional accreditation collectively reproduce dominant knowledge paradigms, at least procedurally, if not intentionally.

In two of the three programmes, studio-based pedagogy is central to identity formation and forms a core spine of the programmes in UL and TUD. Through critique, interrogation, iteration and dialogue, students learn to articulate and defend practice. In contrast, MU has cultivated a pseudo-studio culture where fieldwork and practical labs are the primary influence on design practice. This is not a purposeful pedagogical choice but is due to real-world limitations on studio space that dictate student-lecturer and student-student relationships. In the place of studio activities, fieldwork encourages students to apply ethnographic research methods through design-specific discourses whilst labs encourage practical experimentation within varying design methodologies, through which students also learn to articulate and defend their personal practice.

In either case, studio culture or fieldwork/lab culture is not neutral. Confidence, flexibility and cultural formality can act as tacit markers of legitimacy. Assessment approaches may reinforce these norms, often privileging coherence, feasibility and viability as indicators of “good” design. Even where educators seek to encourage risk-taking, experimentation and norm-breaking, institutional commitments to authentic assessment and structured grading systems create pressures towards professional legibility. While authentic assessment is frequently positioned as progressive pedagogy, its alignment with existing professional standards may unintentionally privilege culturally dominant forms of legibility and practice.

A programme's “home” within a university will also shape reproduction. Those programmes embedded within engineering or business faculties often align metrics of success with measures of employability and industry relevance. Although this alignment is not inherently conservative, indeed, it provides learners with clearly defined and signposted pathways toward professional practice, it does also reinforce a singular vision of what design does and who it is for.

3.3 Challenge

All three programmes are making strides to challenge, but this rarely manifests in radical change to the structure or institutions. Instead, decolonial and ethical shifts arise primarily through insertion alongside traditional structures, recalibration of existing content, and strategic subversion within inherited frameworks. Indeed, efforts to include pre-colonial knowledges within design discourses is a task mostly taken up by Indigenous scholars as protective acts [15] that ‘speak between the lines’ of a dominant discourse, aimed at tackling censorship using various discursive devices such as allegory, parody, and reduction to create a hidden layer of meaning within design discourse that can only be understood by certain people [16].

Noel [1] exemplifies a more direct decolonial approach that does not try to avoid the censorship of pre-colonial knowledges but, instead, confronts and subverts the power dynamics central to censorship by explicitly reframing colonial models as vehicles for decolonisation. MU adopts a similar approach by directly questioning and reinterpreting the ARRIVE framework [18], overlaying seven decolonial strategies that better reflect design's changing role in a transitional Ireland. However, there is no institutional support for such actions, as they challenge the colonial values on which the institution is built. As a result, “working between the lines” of existing structures remains the primary route for critical pedagogical practice.

In the TUD programme, low-tech approaches and framing of materiality of practice act as ethical provocations within the structured studio are used to question narratives of growth and sufficiency without undoing the programme's industrial orientation. In the UL programme, practice is developing through increasing contextual awareness and the reframing of design as culturally situated rather than universally neutral. At MU, the absence of a studio spine to the programme and staff transition has produced what might be described as productive disorder, enabling justice-oriented content and pluriversal perspectives to enter the curriculum through diverse staff specialisation.

Conventional module titles are retained while content is reframed and dominant design models are taught as breakable rather than prescriptive. University hierarchies are subverted to protect studio culture through altered and negotiated timetabling and the reversing of granularization through the sharing of

project-based learning across multiple modules. These strategies reveal that challenging is often individual-led and dependent on lecturer relationships and positionality. While such practices create spaces of resistance, they remain embedded within the same assessment systems and institutional architectures that stabilise inherited epistemologies. Decolonisation, therefore, appears less as a conscious replacement and more as a layered intervention.

4 DISCUSSIONS (BEYOND EDI)

Ireland emerges as a particularly complicated and interesting site through which to interrogate the intersections of design, knowledge systems and inherited power structures. Its history of colonisation positions it simultaneously inside and outside dominant Euro-centric epistemologies, creating a context in which identity, sovereignty, and cultural production remain in constant negotiation. This instability positions Ireland not as a fixed or settled terrain but as an evolving epistemic space, where confusion, discomfort, and productive discordance may operate not as weaknesses but as generative conditions. Such states of uncertainty can create openings for alternative voices, situated knowledges, and less-established design practices to emerge, particularly when educators consciously frame unlearning as an ongoing, shared pedagogical experience. Embracing these ruptures challenges the presumption that design education must be orderly, linear, or tied to inherited logics of industrial progress; instead, it invites a pluriversal understanding of design practice that acknowledges multiplicity rather than seeking consensus.

Laying bare the 'productive disorder' of MU's design programme provides potential to deconstruct disciplinary norms and re-examine the definition of design knowledge itself [19]. Diverse academic backgrounds and marginalised perspectives contribute alternative viewpoints, while strong peer-to-peer learning fosters pluriversal ways of knowing grounded in students' own lived experiences.

The legacy of coloniser culture inherent within Irish institutional structures may inadvertently provide the disorder required to catalyse decolonial actions that resist reproducing colonial logics, and hold space for contradiction, negotiation, and dissent. Within this shifting landscape, questioning what forms of knowledge ought to be legitimised within Irish institutions, whose perspectives shape our curricula, and how pedagogical structures can evolve to accommodate pluriversal ways of knowing, making and being, take on a renewed urgency. Questioning the very notion of what constitutes the design discipline also marks a transition towards new epistemic modes that reimagine design education in Ireland as relational, situated, and culturally grounded- respectful of history, responsive to the present, and open to emergent futures.

5 CONCLUSIONS

This paper does not attempt to conclude the question of decolonisation within Irish design education but seeks to surface the tensions and contradictions that shape it. Decolonisation is not a singular act of curricular replacement but an ongoing negotiation within institutional structures and hierarchies that remain structurally embedded in epistemologies of the Global North. Ireland's history of colonisation does not exempt it from participating in colonial knowledge systems; rather, it complicates how responsibility should be understood.

Ireland's unsettled position within colonial history creates not clarity but a form of productive instability, and within this dissonance, there is room for a plurality of voices to emerge. Such plurality requires moving beyond academic positionality to engage directly with student experiences and the lived realities of those navigating these programmes. The present work, therefore, serves as a reflexive beginning, establishing a baseline for further investigation into how students articulate belonging, exclusion and possibility within Irish Product Design education.

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THE VALUE OF BEING LOST: WHY UNCERTAINTY MATTERS IN DESIGN EDUCATION

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ABSTRACT

Design education is often framed as exploratory, yet contemporary pedagogical practice frequently removes the uncertainty that makes exploration meaningful. This paper argues that ambiguity and constraint can function as deliberate pedagogical materials, supporting learning by creating productive friction rather than smoothing the design process. The discussion is situated within a second-year product design studio structured around two contrasting projects: an individual, ambiguity-driven exploration and a group-based Low-Tech project shaped by clearly defined constraints. Drawing on reflective teaching practice and routine studio artefacts, including sketchbooks, process books, critiques, and guided reflections, the paper examines how students engaged with uncertainty, limitation, and collaboration. Within this context, ambiguity enabled diverse interpretations, narratives, and forms of expression to emerge. At the same time, constraint-supported inclusive collaboration through shared evaluative frameworks and collective decision-making. Rather than treating difficulty as a barrier to inclusion, the paper reframes it as a condition that enables students to develop judgment, autonomy, and confidence. By presenting ambiguity and constraint as complementary strategies within a single module, the paper proposes designed friction as a means of valuing diversity of thinking and practice in design education, positioning being “lost” not as failure, but as a formative condition of studio learning.

Keywords: Design education, studio culture, ambiguity, diversity of thinking, learning through friction

1 INTRODUCTION

Design education should offer a space where learners are free to explore, yet the learning environments we create often seek to remove the uncertainty and ambiguity that make exploration meaningful. Contemporary pedagogical approaches tend toward prescriptive scaffolding, which undoubtedly supports some learners but can also act as a barrier which limits the development of autonomy, resilience and the capacity to be truly reflective. Björk and Björk’s[1] concept of desirable difficulties suggests that deep learning requires effort. In design, we can create this environment by embracing ambiguity rather than avoiding it.

This paper proposes that a degree of uncertainty, specifically managed to create the necessary conditions for learning, can be purposefully introduced. Dewey[2] describes that the feeling of difficulty is the starting point for reflective inquiry, while Schön[3] positions design practice in indeterminate situations, which require constant reframing of problems as designers work. These ideas provide the opportunity to reconsider confusion and uncertainty, not as pedagogical failings but as fertile spaces for learning – forcing students to make judgements and develop non-linear thinking. With this paper, the intentional incorporation of such conditions is referred to as designed friction.

The class which this paper reflects on is a second-year module in a BSc Product Design programme. The class is structured around two problem-based projects, each introducing distinct forms of friction, which ran for 6 weeks (half of the semester) for each. The first created friction through providing a large amount of creative freedom. Students worked individually with an open-ended provocation centred on *time*, using abstract interpretive lenses to develop a speculative design response. Many students initially felt lost and unsure how to begin but gradually learned to navigate this uncertainty through exploratory sketching, experimentation, and iterative reflection. They learned to navigate uncertainty and become more comfortable with ambiguity in the design process, developing greater confidence in self-directed decision-making.

In the second project, friction was introduced through constraints, where students worked in project teams on a human-centred “job to be done” that framed the problem space in terms of low-tech

constraints. This aligns with Illich's [4] notion of convivial tools in which limits encourage ingenuity. Within this project, friction was designed to be social and technical. Students were forced to negotiate diverse perspectives, long-held beliefs about the notion of technical process and efficiency and engage with alternative values of "good design".

By applying ambiguity and constraint as complementary pedagogical tools, this paper proposes the conceptual model of design friction. It argues that carefully structured uncertainty can act as a catalyst for learning, prompting students to reflect and adapt, and develop a more diverse and robust relationship with creativity. In this way, discomfort becomes part of the studio provocation, creating conditions in which diverse forms of thinking, participation, and design judgement can emerge, rather than converge toward prescriptive norms.

Conceptual Model: Designed Friction in Design Education

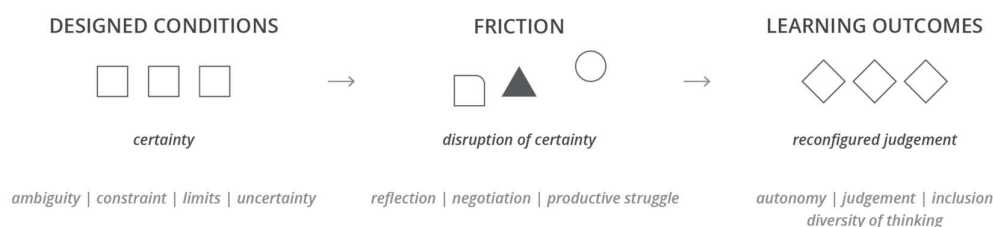


Figure 1. Conceptual model of designed friction illustrating how structured learning conditions are intentionally disrupted, leading to reconfigured judgement and diverse learning outcomes

2 APPROACHES

The reflections that inform this paper arise from routine classroom practice, including tutorial conversations, reviews, critique and structured reflective activities. The module cohort consisted of approximately 48 second-year students, working individually in Project 1 and in groups of 4-5 in Project 2. Class artefacts and reflections were produced to support learning and assessment, and are interpreted here as indicators of how students engaged with ambiguity, constraint, and collaboration across the two projects[5]. The patterns observed resonate with Kapur's[6] notion of productive failure in which early struggle can lead to later insight and increased confidence.

Interpretation was thematic and practice-led rather than formally coded. Teaching observations and reflective notes were reviewed alongside student work to identify recurring patterns in behaviour and decision-making, particularly moments where uncertainty, limitation, or disagreement prompted reframing, negotiation, or increased engagement[6]. Attention was paid to how students navigated difficulty individually and collectively, and how these conditions influenced autonomy, confidence, and participation.

This approach reflects the realities of studio education, where learning is revealed through process, dialogue, and making. This work seeks to offer practice-based insight into how ambiguity and constraint can be intentionally used as learning tools.

3 FINDINGS

3.1 Friction Through Freedom: Ambiguity in Individual Practice

Project 1 deliberately introduced ambiguity as a designed studio condition (rather than an absence of structure). Students were asked to engage with an open brief centred on time, using interpretive lenses, to develop a non-prescriptive outcome. From the outset, this produced a sustained sense of being lost for the learners. Early exploration frequently sought safety in familiar interpretations such as *timekeeping*, which were explicitly ruled out within the brief, creating confusion and resistance. The subsequent introduction of the lenses was initially met with scepticism, with some students perceiving them as an added layer of complication rather than support.

This disorientation was not treated as a problem to be resolved quickly. Instead, it was allowed to persist, requiring students to pay closer attention to their own assumptions, habits, and ways of working. Throughout the project, many students expressed uncertainty about whether they were “doing it right”, particularly in the early weeks of the project, where learners measured progress through sketchbook activity rather than visible outcomes. This sustained ambiguity demanded patience and trust, both in the process and in one’s own capacity to navigate it.

Sketchbooks became a central site where this struggle played out. Initially unfamiliar as primary design tools, they were sometimes used defensively, with students investing effort in aesthetic presentation as a form of positive procrastination[5]. The early use of sketchbooks as polished artefacts functioned as a defensive response to uncertainty, substituting aesthetic control for conceptual commitment. Over time, however, this performative impulse diminished. As deadlines approached and pressure increased, many students abandoned the idea of the sketchbook as a beautiful artefact and began to use it pragmatically as a working space. Pages became denser, more provisional, and more synthesised, with handwritten notes, diagrams, and sketches arranged alongside one another without the hierarchy that had been common early in the project. In post-project reflections, students frequently noted the value of having all thinking in a single physical space and the ability to “turn a new page” as a way to move forward when ideas stalled. Compared to digitally mediated work, reflections appeared tighter and more resolved, suggesting that the material constraint of the sketchbook supported synthesis rather than fragmentation[7].

Project 1: Making Sense of Ambiguity

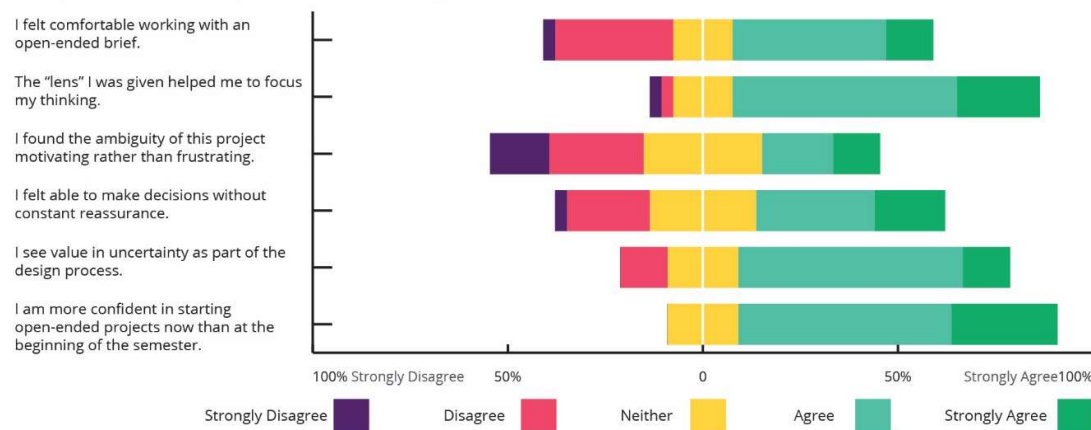


Figure 2. Student perceptions of ambiguity and decision-making during Project 1

As the project progressed, ambiguity shifted from initial confusion to productive struggle[6]. Students began to articulate their own values and metrics, asking not only what they were designing, but why it mattered, who it was for, and what it questioned. Ethical positioning, narrative framing, and experiential intent frequently preceded any formal or material decisions. Learners increasingly shifted from a linear thought process to an iterative approach, revisiting and revising earlier assumptions and ideas. Autonomy emerged not through freedom alone, but through the necessity of acting without external validation. Lecturers deliberately resisted early clarification of process, offering reassurance without validation and acting as critical interlocutors rather than guides toward specific outcomes, a role that has been discussed as supporting autonomy and reflective judgement in design education[8].

This autonomy was unevenly distributed, and intentionally so. Some learners stabilised late, while others never fully reframed their practice, often interpreting the brief as an invitation to produce artwork rather than speculative design. These differences were closely tied to engagement and attendance within the studio, underscoring the importance of studio culture in supporting difficult work[9], [10]. Rather than being treated as a failure of the approach, this unevenness revealed differing tolerance thresholds for uncertainty and varying readiness to work without prescriptive direction. Learners with lower tolerance for ambiguity were supported through sustained studio presence, which provided greater lecturer feedback and peer visibility, ensuring that difficulty remained shared rather than isolating. Assessment data, compared to previous cohorts in this module, show increased differentiation within the class but

no decline in overall attainment, suggesting that ambiguity redistributed performance toward more diverse creative outcomes rather than undermining learning.

The first project demonstrates the value of being lost as a formative condition of the studio. Ambiguity required students to slow down, carefully consider their own thinking, and persist through uncertainty. The struggle was not always comfortable, nor was it uniformly resolved, but it demanded engagement and fostered resilience. In this sense, ambiguity functioned as a return to a core studio experience, in which learning is shaped by difficulty, reflection, and the gradual development of judgment.

3.2 Friction Through Constraint: Low-Tech Collaboration

The second project introduced a different form of designed friction by replacing ambiguity with constraint. Students worked in groups to design a Low-Tech, domestic tool, to complete a clearly defined job to be done. There were explicit limits on technological intensity, materials, and energy use. Where Project 1 expanded the problem space, Project 2 deliberately narrowed it. Constraint was framed not as a limitation to be overcome, but as a means of focusing attention and fostering collective responsibility. In this context, constraint operated as both a technical and a social condition[4]. Technically, students were required to prioritise sufficiency, mechanical clarity, and appropriateness over optimisation or automation. Socially, these limits structured collaboration by defining a shared evaluative framework to allow design teams to define what they considered “good design” for this brief. Early ideation often began broadly, but process books show rapid and systematic reduction. Tasks, rooms, and mechanisms were ranked, eliminated, or deprioritised, resulting in a tightly framed problem definition. Constraint acted as a stabilising force, enabling groups to converge without relying on instructor validation.

Project 2: Making Sense of Constraint

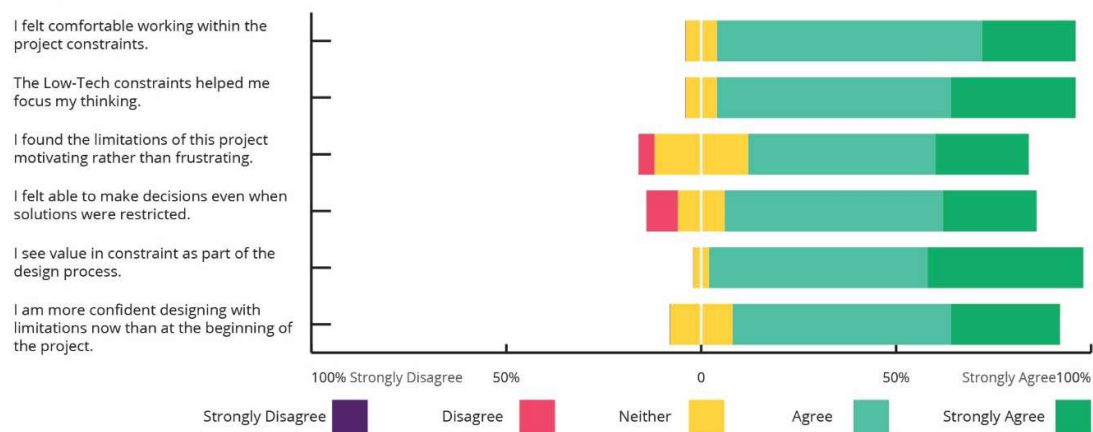


Figure 3. Student perceptions of constraint and decision-making during Project 2

Working within these limits surfaced moments of disagreement that became central to learning. Unlike the individual sketchbooks of the first project, process books made negotiation visible through comparative evaluations and annotated decision points. Ideas were debated not on the basis of novelty or ambition, but on the basis of user effort, clarity, and suitability. Disagreement did not stall progress but functioned as productive friction, forcing students to articulate values, accept compromise, and let go of more complex or expressive ideas in favour of what was sufficient.

Low-Tech artefacts played a critical role in mediating this process. Prototypes were deliberately rough and built to test specific actions within the design. These artefacts were not expressive or speculative; they were pragmatic tools for testing design limits. Failures were immediate and embodied, revealing awkwardness, inefficiency, or unnecessary complexity through use rather than dialogic critique. In many cases, physical testing led to either the development or abandonment of ideas that were initially appealing but impractical. Thus, this functioned as a reframing device, aligning the group's understanding around what was necessary rather than what was possible.

Authorship in Project 2 was explicitly collective. Reflections consistently refer to shared decisions and collective learning, suggesting that understanding emerged through dialogue and artefact-mediated negotiation rather than individual intuition[10]. Constraint reduced the dominance of personal

preference and supported more inclusive participation, particularly in groups with diverse working styles.

Together, these observations show how constraint can be used to generate a quieter, more structured form of studio friction. Where ambiguity in Project 1 demanded individual perseverance through uncertainty, constraint in Project 2 demanded collective discipline, compromise, and attention to sufficiency. Both forms of friction required students to engage deeply with difficulty, reinforcing the studio as a space where learning is shaped through struggle, negotiation, and sustained attention rather than ease or clarity.

4 EDUCATIONAL IMPLICATIONS

Using intentionally designed friction within the studio environment, space was created that allowed for diverse thinking, working and participating. The ambiguity evident in the first project allowed students to interpret the brief through their own experiences and values, resulting in varied design narratives rather than a convergence toward a single normative approach. This openness supported diversity of expression without requiring differentiated pathways, suggesting that uncertainty can enable inclusion by legitimising multiple forms of sense-making and design judgement.

The educator's role in sustaining such conditions is critical. Rather than resolving uncertainty, teaching centred on holding it, offering reassurance without validation, and encouraging students to trust their own emerging decision-making criteria. This positioned difficulty as a shared condition rather than an individual deficit, supporting students with different levels of confidence and prior experience. In this way, inclusion was framed not as the removal of challenge, but as the careful calibration of it, ensuring that friction remained productive rather than exclusionary and something visibly experienced by all working on the brief. One accessible starting point for introducing friction through freedom is to replace outcome-led briefs with an open provocation supported by interpretive lenses rather than deliverables. Constraint in the second project provided a complementary route to inclusive learning. Clearly defined limits required groups to establish a shared evaluative framework and collective responsibility. By prioritising sufficiency, appropriateness, and Low-Tech principles over optimisation or novelty, constraint reduced the dominance of individual preference and encouraged negotiation, compromise, and mutual understanding. Together, ambiguity and constraint operate as complementary pedagogical tools, supporting both individual expression and collective engagement, and positioning diversity not as a problem to be managed but as a resource that enriches learning.

Within contemporary discussions of inclusion, there is often an implicit assumption that accessibility requires increased scaffolding and the reduction of uncertainty. However, the findings in this studio class suggest a more nuanced position. Diversity of thinking does not necessarily flourish within tightly prescribed processes, where outcomes converge, and risk is minimised. Nor does inclusion require the removal of difficulty. Instead, structured friction can surface and legitimise different modes of participation, allowing students with varied thresholds for ambiguity, levels of confidence, and prior educational experiences to develop judgement in distinct ways. When difficulty is shared and carefully calibrated, it can become a collective condition rather than an individual deficit, enabling heterogeneity to emerge rather than be suppressed.

This recalibration of difficulty is reflected in student perceptions across both projects. In the first project, despite the inherent difficulty of an open-ended brief, over 50% of students found the ambiguity motivating rather than frustrating. Furthermore, a significant majority (over 60%) reported feeling more confident in starting open-ended projects by the end of the semester, supporting the argument that being “lost” functioned as a productive condition for developing autonomy.

In the second project, the shift toward a shared value set saw even higher levels of student alignment. Nearly 90% of respondents agreed that the “Low-Tech” constraints, which could be replaced by any number of conditions to produce friction, helped focus their thinking, and a vast majority felt comfortable working within these project limitations. These reflections by learners on the two projects suggest that while ambiguity fostered individual expression, the designed friction of constraint provided a stabilising structure that the cohort highly valued.

5 CONCLUSIONS

This paper has argued for the value of uncertainty and constraint as deliberate pedagogical materials within design education. Through two contrasting projects, Studio 201 demonstrates how designed friction can support learning by requiring students to engage with difficulty, make judgments in

indeterminate conditions, and negotiate meaning individually and collectively. Rather than smoothing the learning experience, ambiguity and constraint created space for diverse forms of thinking, expression, and participation to emerge. In this context, being lost was not a failure to be corrected, but a necessary condition through which students developed confidence, autonomy, and reflective capacity. Importantly, friction is not only an educational strategy but an increasingly articulated design stance within contemporary practice. Designers and studios who explicitly embrace friction position it as a catalyst for engagement, criticality, and meaningful interaction. By foregrounding friction within the studio, design education can cultivate not just tolerance for uncertainty but competence in working productively with it. As design responds to complex social and technological contexts, embracing friction offers a way to move beyond prescriptive processes and homogenised outcomes, positioning diversity not as a challenge to be managed but as a resource through which richer, more resilient design practice can be cultivated.

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MAPPING KNOWLEDGE INTEGRATION CHALLENGES IN PARTICIPATORY AND CO-DESIGN PROCESSES: TOWARDS A DESIGN KNOWLEDGE INTEGRATION SPECTRUM

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ABSTRACT

Participatory and co-design approaches have been widely recognized for enabling collaboration between designers and non-designers. However, despite their emphasis on shared creativity and co-creation, existing frameworks often offer limited explanations of how diverse forms of knowledge are identified, exchanged, and integrated throughout the design process. This paper presents a critical review of recent participatory and co-design studies to examine how knowledge integration is conceptualized and operated within contemporary design research. Building upon Sutcliffe and Sawyer's (2013) classification of knowledge into known knowns, known unknowns, and unknown unknowns, this study analyses how these categories are implicitly addressed within the design frameworks. The findings suggest that current design approaches primarily focus on the first two types of knowledge, while largely neglecting strategies that enable the emergence of the knowledge that cannot be acknowledged from existing experience. To address this gap, the paper proposes the Design Knowledge Integration Spectrum, to map these epistemic boundaries and guide knowledge activation in design practices.

Keywords: Design process, knowledge integration, knowledge activation, codesign, participatory design

1 INTRODUCTION

Co-design has evolved from a workplace democratic initiative into a core system for addressing complex challenges in engineering and product development [1]. The shift from "designing for users" to "designing with users" requires integrating collective knowledge from various disciplines and stakeholders [2]. However, A significant portion of co-design research remains focused on addressing "known knowns"(knowledge derived from the observer's existing experience) and "known unknowns"(knowledge that the observer can recognize as potentially existing, but which belongs to others). In these cases, designers often work within established frameworks to find surface-level needs or use brainstorming to fill predictable gaps [1], which limits the potential for product innovation. Thus "Unknown Unknown Knowledge" is essential, which is defined as knowledge that the observer, based on their existing experience, is entirely unable to foresee or realize [3].

Design is not just about solving existing problems; it is a process of exploration that deals with high levels of uncertainty [4]. Traditional user-centred design (UCD) often treat users only as sources of information, which only captures explicit "known" data. Because of differences in background and power between stakeholders, "Unknown Unknown Knowledge"—which is often hidden in deep cultural contexts or outside of daily routines—cannot be activated [5]. These gaps in knowledge can lead to inefficient solutions and make co-design a procedural formality rather than a generative collaboration [6].

Addressing this challenge, design education should go beyond teaching form-giving or user research tools; it should focus on managing collaboration and understanding user perspectives [7]. The essential goal is the construction of user knowledge on the designer-side. To bridge these existing design cognitive gaps, this research introduces the "Design Knowledge Integration Spectrum." This model is a cognitive tool for identifying and activating different types of knowledge during the early stages of product development. It helps teams move systematically from "Known Knowns" to "Unknown Unknowns." By proposing this tool, this paper aims to provide a new way for design education to use collective creativity to address complex social and technical challenges.

2 METHODOLOGIES

2.1 Research approach

This study employs a bibliometric analysis approach using CiteSpace (version 6.4.R1) to examine the evolution and knowledge structure of co-design and participatory design. This quantitative method was chosen to provide an objective, macro-level perspective that complements traditional qualitative reviews by visualizing large-scale citation data and identifying key shifts within the field.

2.2 Data collection and refinement

The data were retrieved from the Web of Science (WoS) Core Collection. To ensure relevance, the search was limited to five major journals: *Design Studies*, *Design Issues*, *Design Journal*, *International Journal of Design*, and *CoDesign*.

The search string is: "participatory design OR co-design OR codesign OR co-creation OR cocreation". The search was limited to "Topic" and restricted to "Article OR Review" types. After filtering, 722 valid documents were obtained, spanning from June 2004 to December 2025.

2.3 Bibliometric mapping and analysis

The analysis followed a dual mapping process to identify both research hotspots and theoretical foundations.

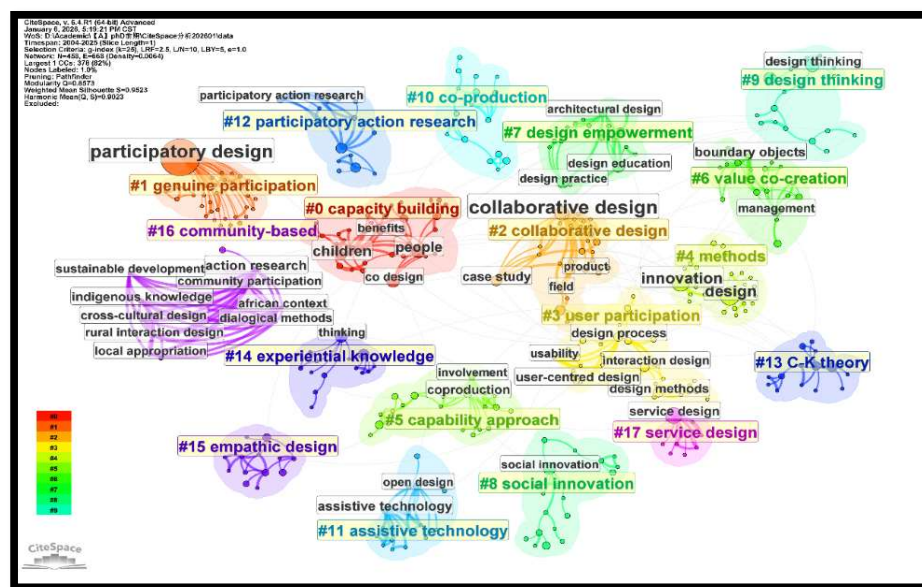


Figure 1. Keyword co-occurrence cluster map

Figure 1 represents the thematic segmentation of the field, identifying core research nodes such as social innovation, capability building, and experiential knowledge. These clusters demonstrate a transition in research focus from instrumental #4 *methods* and #17 *service design* toward more complex social and cognitive dimensions, such as #8 *social innovation*, #13 *C-K theory*, and #14 *experiential knowledge*. The dense interconnectedness of these nodes illustrates how co-design has expanded from a technical process into a multidisciplinary paradigm concerned with #7 *design empowerment* and #10 *co-production*.

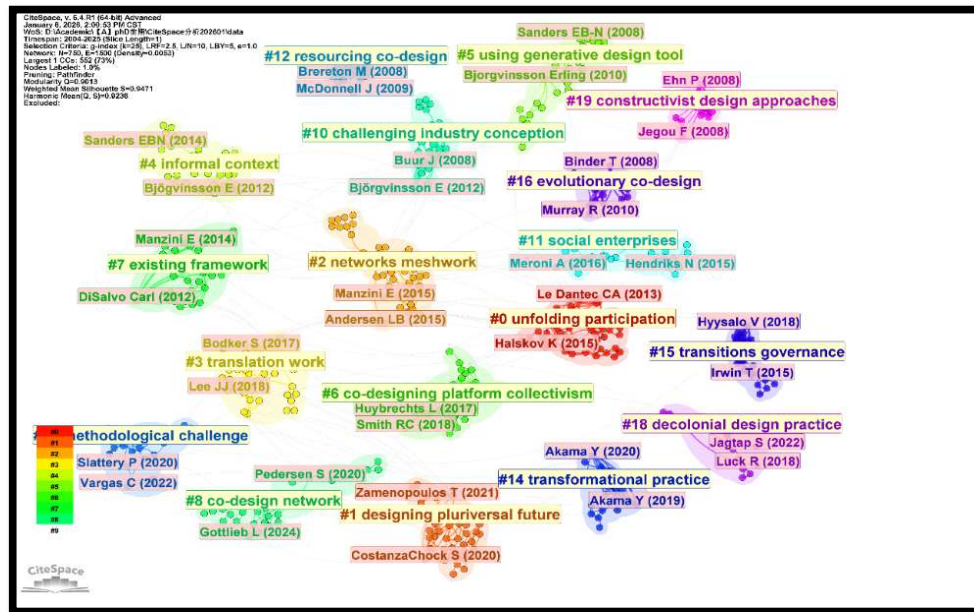
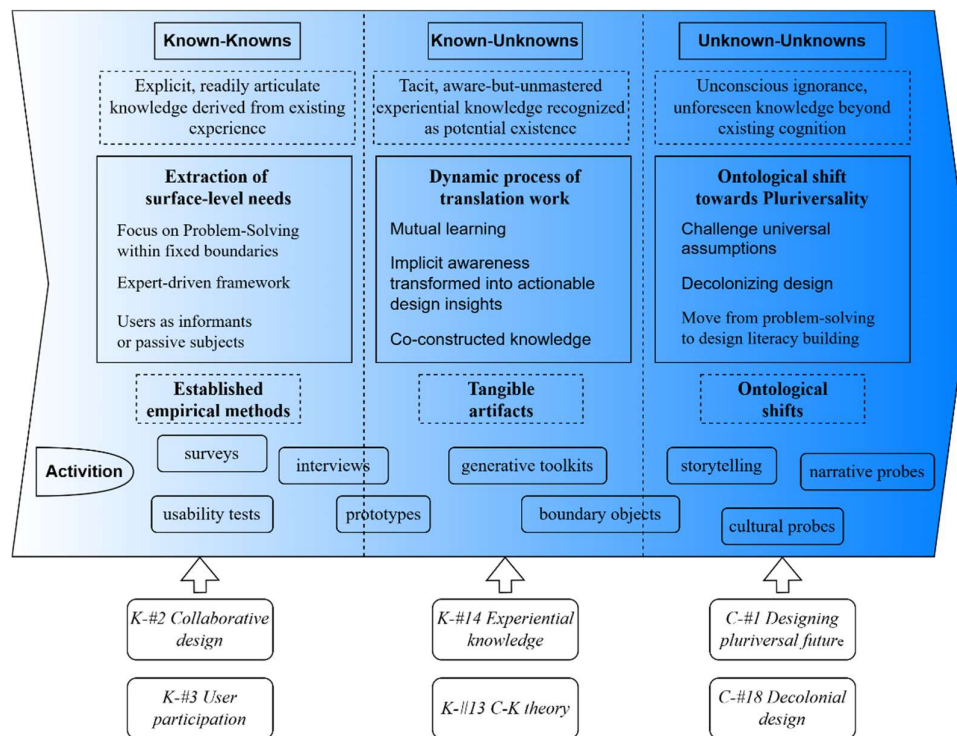


Figure 2. Document co-citation cluster map

Figure 2 illustrates the distribution of key theoretical frameworks, highlighting the prominence of constructivist approaches and recent shifts toward pluriversal and decolonial design practices. Key clusters such as #0 *unfolding participation*, #3 *translation work*, and #5 *using generative design tools* represent the field's established constructivist basis. More significantly, the map reveals a recent peripheral expansion toward radical frontiers, represented by #1 *designing pluriversal future* and #18 *decolonial design practice*.

3 THE DESIGN KNOWLEDGE INTEGRATION SPECTRUM



Clusters derived from the bibliometric analysis

Figure 3. The Design Knowledge Integration Spectrum

Bibliometric analysis reveals a lack of a guiding framework to assist design researchers and educators in identifying diverse knowledge types within collaborative design processes and providing corresponding activation actions. Building upon Sutcliffe and Sawyer's classification of knowledge [3], this study proposes the Design Knowledge Integration Spectrum (Figure 3). As illustrated, this spectrum is developed from the clustering results of the bibliometric analysis. The deployment of a "spectrum" as the representational modality for this framework is predicated on two reasons. First, the design knowledge integration process is a continuous progression rather than a linear workflow composed of discrete, encapsulated steps. Second, design knowledge types and the activation mechanisms involved in the integration process do not share the same solid boundaries. This fluidity is demonstrated by the various activation mechanisms traversing the dashed lines in the diagram.

3.1 Known-Knowns: Extraction of surface-level needs

At the initial segment of the spectrum, co-design focuses on Known-Knowns. As shown in Figure 3, this stage is characterized by a focus on problem-solving within fixed boundaries, utilizing an expert-driven framework where users serve as informants or passive subjects [2]. According to the bibliometric results, this domain is represented by Keyword Cluster #2 *Collaborative design* and Keyword Cluster #3 *User participation*.

At this level, designers use established methods. While this approach is efficient for capturing known variables and meeting basic requirements, it stays within the limits of expected user needs. It often fails to overcome cognitive boundary to explore knowledge beyond what they already know, which limits the potential for significant innovation [9].

3.2 Known-Unknowns: Dynamic process of "translation work"

As collaboration deepens, the domain of Known-Unknowns. This stage is identified as a dynamic process of "translation work", where implicit awareness is transformed into actionable design insights through mutual learning and co-construction. This phase corresponds to Keyword Cluster #14 *Experiential knowledge* and Keyword Cluster #13 *C-K theory*.

To activate this knowledge, designers use "boundary objects" such as prototypes [10]. These objects act as supports that allow non-designers to show their hidden needs and experiences in a shared space. Theory like Concept-Knowledge (C-K) theory provides a logical way to explain this process by showing the interaction between established knowledge and the exploration of new concepts [11]. In this part of the spectrum, knowledge is not just transferred from the user to the designer; it is co-constructed through shared work [12].

3.3 Unknown-Unknowns: Ontological shift towards Pluriversality

At the end of the spectrum, co-design deals with "Unknown Unknowns", which is represented by Co-citation Cluster #1 *Designing pluriversal future* and Co-citation Cluster #18 *Decolonial design*.

Research in these clusters challenges the standard ways of thinking that often dominate design. Scholars argue that traditional design methods can ignore the different ways of knowing held by marginalized or local communities, making this knowledge invisible. To find this hidden information, researchers suggest a shift toward "pluriversal design," [19] which means designing for a world where many different viewpoints can exist together.

Accessing these Unknown Unknowns requires to create "safe spaces", in which power is shared more equally, allowing different or marginalized stories to be heard without pressure to follow standard design logic [13]. By using methods like storytelling and cultural probes, participants are encouraged to question their basic assumptions [14]. This openness helps teams move past their usual habits and find unexpected knowledge, allowing communities to redefine their problems and create new, transformative futures.

4 DISCUSSIONS: IMPLICATIONS FOR DESIGN EDUCATION

4.1 Enhancing design literacy through knowledge activation

The Spectrum provides an assessment tool for design education. Traditionally, design education evaluates students on their ability to collect and organize explicit user requirements—the "Known Knowns" [2]. To improve design literacy, educators should focus on how students identify and activate tacit, unarticulated experiences, which represent "Known Unknowns" [15].

This change in teaching requires assessing students on their ability to create and use physical tools, such as prototypes and boundary objects [16]. In a collaborative setting, prototypes are more than early versions of a final product; they act as physical supports that allow non-designers to show their hidden needs in a shared space. Therefore, educators should evaluate students on how well they use these objects to support shared learning and uncover hidden knowledge among different stakeholders, rather than just judging the technical details of the final product [17]. Subsequent to this stage, students should be directed towards the exploration of "Unknown Unknowns" via approaches like cultural probes, facilitating a further enhance of design literacy.

4.2 Navigating uncertainty

As co-design moves into the "Unknown Unknowns" phase, design education must actively prepare students to manage high levels of uncertainty and conflicting viewpoints [18]. To manage this uncertainty, students must learn to move away from using only standardized or one-size-fits-all solutions. They need to recognize and integrate different worldviews [19]. This requires being ready for unexpected changes. By learning to tolerate uncertainty and working through the disorganized early stages of a design project, students can move past their current cognitive limits [20]. Developing this tolerance for the unknown is essential for creating physical products that address deep social complexities rather than just fixing superficial issues. More fundamentally, design education needs to purposely foster an appreciation for diversity among students; this requirement exists because pluriversal and decolonial lenses tend to elicit deeper uncertainties.

4.3 Building facilitation and collaboration skills

To achieve these levels of knowledge integration, design education must help students change their professional identity from an "expert" who gives orders to a "facilitator" who supports collaboration. Traditional training can sometimes lead to an expert-centred approach where the professional acts as the only creative lead. Instead, students must develop sensitivity to the social and emotional aspects of working in a diverse team [21].

Students need to learn how to build "safe spaces" [13] so that participants without a design background feel secure and valued. By practicing active listening and sharing decision-making power, students can empower others to become active co-creators. This change in teaching ensures that future designers move beyond surface-level participation and achieve genuine shared knowledge creation, leading to more responsible design results. Guided by the Design Knowledge Integration Spectrum, the directional focus of design education is clearly shown. Within the collaborative and participatory design context, the primary goal of design pedagogy is to foster students' ability to construct their own design knowledge for their own design practice, rather than the passive replication of established knowledge transferred from educators and users.

5 CONCLUSION AND REFLECTIVE PRACTICE

This paper has traced the development of knowledge integration in co-design by analysing five major journals published between 2004 and 2025. The findings show that co-design has moved from being a simple set of tools to becoming a complex social and cognitive system. To help practitioners and educators manage this complexity, this study introduced the "Design Knowledge Integration Spectrum", for navigating the cognitive boundaries between explicit, tacit, and unforeseen knowledge. The bibliometric analysis confirms that while the field has mastered the extraction of surface-level needs through collaborative design and user participation, it must now embrace the radical frontiers of pluriversal and decolonial design to activate the most hidden dimensions of knowledge.

The results of this study have important implications for design education and product development. This research provides a view shift that encourages design educators to move from a focus on the final product to a focus on knowledge integration. By using the "Design Knowledge Integration Spectrum," educators can prioritize developing students' skills in collaboration and managing uncertainty. Ultimately, this approach improves the design literacy of both future designers and even other non-designers involved into the whole design process, helping them co-create knowledge and solve the complex design problems of the modern world.

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ROLL THE DICE, RANDOM QUESTIONS IN THE MIDDLE

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ABSTRACT

Reflection is widely recognised as a powerful mechanism for deep learning in engineering and design education. "[It] stimulates people to 'own' their learning, which again stimulates the intrinsic motivation to apply lessons learned.". However, in practice, reflection is often treated as an afterthought and, increasingly, outsourced to generative AI tools, reducing its authenticity and impact.

This paper explores an inclusive and engaging approach to reflection within different bachelor and master courses at Industrial Design Engineering. In these courses, student teams collaborate on complex design challenges. While technical skills are essential, team performance and collaboration are more critical to success. To support this, we have developed and implemented a set of coaching tools aimed at improving team dynamics and fostering equitable participation.

One tool that has proven particularly effective is the 'Reflection Dice', a simple and playful method for stimulating dialogue and self-awareness within teams. By rolling a dice, students are prompted to share insights on topics such as collaboration, progress, and personal contributions. The dice has been used in various contexts, and the activity should create a safe space for reflection, encourage diverse perspectives, and strengthen team cohesion, but this has not been tested yet.

In this paper we have researched the effects of the dice on these aspects. We executed a mixed-method study, where data is collected through surveys from students and faculty members. The results will be presented in this paper.

Keywords: Collaboration, team dynamics, dialogue, reflection

1 INTRODUCTION

In the IPD master's course Products Now Design Studio (PNds), students cooperate in design teams on a client-based design project for one semester consisting of 10 European Credits. PNds is a core design course within the Integrated Product Design master's programme at the faculty of Industrial Design Engineering (IDE) at the Delft University of Technology (TUD). Students collaborate in teams which differ in nationality, prior education, and socio-emotional development on a client-based and highly complex project [1]. The diversity between team members can lead to complications within the team due to miscommunication, frustration, and sometimes interpersonal conflicts. These complications often lead to lower performance due to the inability of the team and the coach to dealing with these complications constructively.

To improve learning and working in dynamic teams, reflection is widely recognised as a powerful mechanism for deep learning in engineering and design education [2]. "[It] stimulates people to 'own' their learning, which again stimulates the intrinsic motivation to apply lessons learned." [3]. However, in practice, reflection is often treated as an afterthought and, increasingly, outsourced to generative AI tools, reducing its authenticity and impact [4]. Within the Products Now design course we introduce students to "reflect as a designer" consisting of a lecture given by one of the authors and methods to do this correctly. The lecture introduces them to the importance of reflecting, different ways of reflecting using the Kolb's Experiential Learning Cycle [5], the Reflection Cards [6] based on Bateson's framework on logical levels of learning, Reflection with Proverbs [7], and other methods neatly summarised and described in the "Reflection Methods" book written by Femke Gordijn et al. [3].

To help the process of becoming a team, executing the work, and reflect on team and individual performances, we have researched team-performance in previous years [1,8-10] and published our learnings in our book "Connect: The Secret Formula of Coaching Design Teams" [11]. Next to our learnings the book also includes 12 educational activities and tools which can help in all three stages of

the project from start, run, to finishing an engineering project. One of the activities is reflection using the in-house developed Reflection Dice (RD). A simple, safe, and fun tool designed for team reflection, but it works just as well for individuals at the start, during, and finals of a project. Simply 3D-print it, roll it, and take a moment to reflect on your project, your collaboration, or even the meal you just shared (Figure 1). Rolling the dice is all it takes to spark meaningful thoughts and conversations [12].



Figure 1. On the left the 3D printed dice, in the middle the dice in action with two volunteers, and on the right the book chapter with instructions on the use of the dice [12]

We believe the dice is very helpful in getting meaningful conversations, but this is mainly based on observations and our first hunches. To confirm our hypothesis of the effectiveness of the dice as a tool to do meaningful reflections, we have researched the effects of the dice on these aspects by answering the following main research question:

- MRQ: How do users of the RD experience the dice as a tool within team reflection?

With the following sub-questions:

- RQ1: What are the current experiences of the participants when using the RD?
- RQ2: How effective is the RD for team reflection?

We executed an explorative mixed-method study, where data is collected through surveys from students and faculty members. Section 2 will present the Reflection Dice and discusses the activity of reflecting using the different sides of the dice. In section 3 we will present the design of the survey and the approach to answer the main research question. In section 4 the results are presented, and section 5 will discuss the results which leads to the conclusions of this research.

2 DESIGN OF THE REFLECTION DICE

Reflective learning involves stepping back from an event or experience to analyse it from different perspectives. In doing so you relate it to earlier experiences and discover meaning. It requires taking time to think, feel and digest, and it concerns identifying lessons learned. These are discussed and prioritised to be integrated into a strategy for action to improve future performance. In 2022 we started using the Reflection Cards [6] taken from the “Reflection Methods” book by Gordijn [3]. We noticed that students executed the exercise, often individually, without going deeper into the questions asked, they answered questions without thought.

To increase engagement and depth of reflection, the reflection cards were gamified in 2024. We developed the 8-sided reflection dice, first as a folding plate [11], later as an open-source 3D printable [13]. A key strength of the dice-based reflection tool is that it structures the process as a guided conversation. It prompts emotional, cognitive, and physical reflection, and it concludes with concrete “next steps,” like the action-planning stage in Gibbs’ reflective cycle [14]. Engaging in a dialogue with others enables the person who is reflecting to retrieve experiences more effectively, because the interviewer can probe, clarify, and encourage deeper exploration. This level of recall and depth is far more difficult to achieve when reflecting alone. The gamified format also reduces the sense of “having to reflect,” which many participants resist and therefore tend to approach superficially. This dice is designed for team reflection, but it works just as well for any reflection. Simply print it, roll it, and take a moment to reflect on your project, your collaboration, or even the meal you just shared. One roll is all it takes to spark meaningful thoughts and conversations.

At least two persons sit or stand around a table and decides to discuss how the team performed so far. One participant rolls the dice and the symbol that faces upwards symbolises the one to share with the group. The team member shall answer the question on the spot in a few minutes. It helps to make one participant the ‘facilitator’ to ask the question or support finding an answer. All team members roll the dice in turn. If needed, you can do a second or third round.

The dice consists of 8 sides, with eight different symbols: brain, thumbs up, key, heart, puzzle, hand, foot, and camera. Figure 2 shows these symbols including the concerning question(s) which are asked by the interviewer, when the side is rolled. The interviewee answers the question, while the interviewer is expected to deepen out the answer by using Who, What, Where, When, Why and How (5W1H) questions. 5W1H is a method used to obtain a thorough understanding of the situation which is described by the interviewee in their answer.



Figure 2. The 8 different icons on the reflection dice together with the questions to be asked

3 RESEARCH DESIGN

We have used the reflection dice on several occasions. In the first place during the PNds course, but also in several other bachelor and master design courses, social-safety workshops for TU Delft employees, during graduation projects, or just for fun in social events.

To address the research question, an online survey was developed and administered to students from several bachelor and master courses who have used the dice to reflect on their work individually and as a team. In addition, it was distributed to potential users inside and outside the programme through email and various social media channels.

The survey consists of 9 questions, of which the first two are related to the status of the participant (question 1) and in which context the dice was used (question 2). Question 3 comprised quantitative items measured on a five-point Likert scale ranging from 'strongly disagree' to 'strongly agree.' These items address (a) the perceived usefulness of the dice, (b) comfort in sharing, (c) engagement, (d) enjoyment, (e) anticipated future use, and (f) preference for alternative reflection methods or tools. In Question 4, participants were asked to indicate their preferred side of the eight-sided dice. The survey was finalised with five open-field questions where participants can describe their experiences while using the tool (question 5) and the insights they acquired during this process (question 6). Question 7 and 8 relate to the recommendation and prohibitions of using the dice in the future. The final question is an open-comment box.

The questions having Likert-scale scoring options will be summarised into general trends using frequencies and distribution patterns for all participants in the survey.

The open qualitative questions were analysed using Thematic Analysis [15]. For this we selected only those responses which were entered by bachelor or master students when used within a team context. All responses were imported per question into Claude.ai (Haiku 4.5) to identify the key themes related to participants' experiences (questions 4 and 5) and the effects of the dice (questions 7 and 8). Subsequently, all responses were individually reviewed and assessed by the authors to ensure accuracy, authenticity, and alignment with the identified themes. Responses to question 4 and 9 were limited and therefore excluded from this research.

4 RESULTS

In total, 68 responses were collected: 29 from bachelor students, 34 from master students, and 5 from employees or master's alumni. The dice-based reflection tool was used on multiple occasions, with some participants engaging with it more than once. It was applied 58 times during team evaluations within a course, 19 times for individual reflection, and 9 times for general team evaluations. Additional uses included social-safety meetings (3 instances) and informal or social settings (3 instances). To answer the main research question of the effectiveness of the dice in a student team environment, we will focus

mainly on group reflections within our bachelor and master student teams. This relates to 44 responses out of the total 68.

4.1 Quantitative data analysis

Question 3 consisted of six statements where the participants are asked to indicate their level of agreement with them (Figure 3). The findings indicate an overall positive perception of the dice as a means of supporting reflective practice for all participants in the survey.

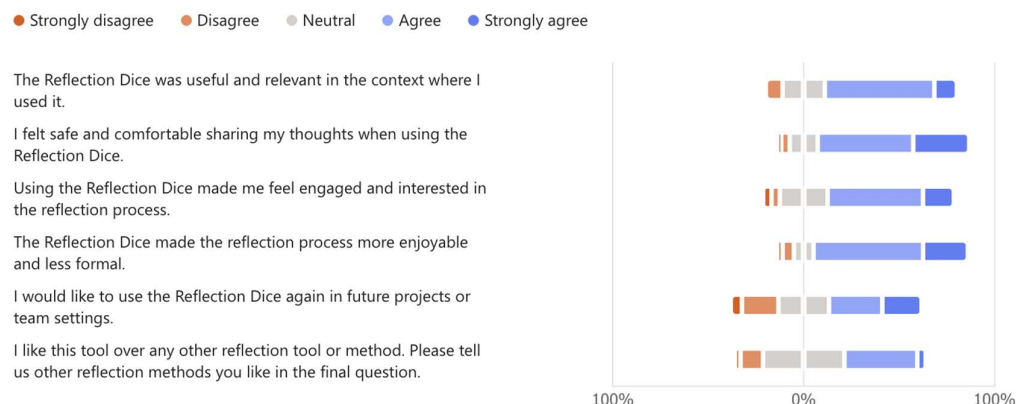


Figure 3. Responses to the six quantitative questions using a 5-point Likert scale for all 68 responses

4.2 Experiences

For the thematic analysis of the experiences the responses of only question 4 and 5 are used:

4. Please describe your experience, what happened during the process of using the Reflection Dice in your context?
5. What insight did the dice give you or what did this reflection process bring you?

The analysis was conducted on 44 responses from bachelor's and master's students reflecting within a team context. Overall, 70% of the responses were classified as positive, 20% as neutral, and 10% as negative. In total, 11 themes were identified. Table 1 presents the five main themes, each occurring in more than 20% of the responses and all classified as positive, along with the most prominent neutral theme which occurred in 18% of the responses.

Table 1. Overview of the key themes from the experience analysis

Theme	Explanation	Quotes
Enhanced communication within the team	The Reflection Dice successfully facilitated conversations that might not occur naturally.	"The dice allowed for random choice of subject, which made it easier to answer spontaneously, without over-preparing our answers" (ID 14)
Deepened relationships and mutual understanding	Participants gained deeper insights into teammates and felt greater connection.	"We learned a lot about each other, not just related to the team project but also otherwise" (ID 36)
Structured and guided reflection	The Reflection Dice provided an appreciated structure and direction for reflection processes.	"Using the dice structured the reflection in a good way where it was not just mindless reflection but more focused" (ID 48)
Fun and engagement	The playful nature of dice-rolling made reflection feel less formal and more engaging.	"The Dice helped to make the reflection less formal and fun" (ID 13)
Spontaneity and honest responses	Random selection reduced preparation and encouraged more authentic responses.	"When I threw the dice, I got an option that I wouldn't have picked as a conscious choice." (ID 53)
Context-related effectiveness (neutral)	Effectiveness significantly depended on pre-existing team dynamics and context.	"It didn't bring any new insights. Our team has a nice work environment

		and we like to spend time with each other" (ID 35)
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4.3 Recommending the dice

The same thematic analysis was conducted as in the previous chapter but now focussing on the recommendations for future use. The experiences the responses of only question 7 and 8 are used:

7. Why would you recommend this tool to someone else?
8. Why would you not recommend this tool to someone else?

The analysis again used the 44 responses of only bachelor/master students reflecting within a team context. Of these, 31 participants responded to question 7 and 26 to question 8. The three main themes for recommendations both in favour and against are presented in table 2.

Table 2. Overview of the top three themes in recommendations for the dice

Recommend for	Explanation	Quotes
Informal and gamified approach	The informal and playful nature of the tool is identified as a distinctive and valuable strength.	"Because it makes talking to each other easier. Most engineers don't talk about their experience easily; hence this gives them a little stepping stone and inspiration" (ID 49)
Structured guidance and framework	The tool provides crucial structure that guides reflection and eliminates cognitive burden.	"It helps a lot to steer the conversation. You don't need to come up with topics for discussion yourself." (ID 2)
Ice breaking and accessibility	The tool is particularly effective for teams struggling with natural communication.	"It can help break barrier with teams which feel awkward and resistant to communicating without a structure" (ID 32)
Recommend against	Explanation	Quotes
Prompt clarity issues	Several prompts lack clarity, are overly broad, or generate confusion about what response is expected, leading to awkward or blank answers.	"The questions themselves are still very broad, which can still lead to blank answers, awkwardness, and sometimes even desire to switch questions." (ID 14)
Restrictive design	The rigid structure of sticking to one topic at a time prevents participants from discussing what is actually on their mind.	"There is a chance that you roll for instance: Camera but really wanted to say something about Puzzle." (ID 13)
Problems with forced reflection	Some participants object fundamentally to structured or mandatory reflection.	"Forcing then to stick to one method of reflection made it seem like a chore. The true points of reflection came in between the actual points of the tool." (ID 8)

5 CONCLUSIONS AND DISCUSSION

The quantitative results show that participants generally perceive the dice-based method as a positive and engaging way to support reflective practice. The dice enhanced communication and discussion in a structured and guided way. Next to that it was also seen as an engaging way of reflecting, making it less formal and more fun. Participants valued sharing experiences within their teams, noting that the tool stimulates reflection through dialogue rather than through individual, checklist-like tasks. Not all respondents consider it the preferred option for future use, either of dislike for reflection but also when it is used in contexts where the team is already functioning correctly, there it might feel not adding value. RD is seen as a playful way that sparks dialogue, especially within silenced teams or in conflict resolution. It facilitates discussion and even brings forward problems, but it does not resolve the underlying conflict. The authors acknowledge this, dysfunctional teams might appear from the RD session, but need different follow-up steps like, for instance a structured dialogue session [10,11]. The icons and prompts sometimes are seen as restrictive and lack clarity. This sometimes leads to awkward

feeling and time-inefficiency, and highlights the importance of having clearer instructions, introducing the participants to interviewing techniques using structured probing (5W1H), or even introducing an external facilitator to further enhance its effectiveness, especially when used first time. Overall, the findings suggest that most students benefit from this playful format to spark conversation and for teams that struggle with team dynamics. The dice method appears to foster interpersonal dialogue, empathy, and stronger group relationships, qualities that many traditional reflection tools do not inherently promote.

6 RESEARCH ETHICS STATEMENT

The survey was conducted in accordance with the TU Delft Regulations on Human Trials [16]. Participation was voluntary and all participants were asked explicitly for their consent to use their feedback “in the analysis and [...] quoted anonymously in the paper”. Data is acquired anonymously using a survey made in Microsoft Forms without login. No personal data is retrieved or stored in the database. Open-ended questions were not obligatory and all text referring to any personal identifiable information is taken out before analysis. This paper was made using artificial intelligence tools for text and grammar support (Copilot, GPT-5.1) and for qualitative data analysis we used Claude.ai (Haiku 4.5) to assist in theme suggestions for the thematic analysis.

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APPLYING GENERATIVE AI IN DESIGN EDUCATION: AN OVERVIEW OF CURRENT WORK AND FUTURE RESEARCH DIRECTIONS

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ABSTRACT

Generative artificial intelligence (GenAI) is gradually being introduced into academic design courses. Naturally, its introduction poses many challenges for learners and instructors in any design domain. Alongside these, GenAI hold a promise for design learners, by allowing learners to quickly generate relevant visual materials for inspiration, translating simple design representations into detailed ones (e.g. sketches to renderings) and more. To further integrate GenAI effectively into design curricula, it is important to learn about the possibilities for its implementation in pedagogical scenarios, their benefits and limitations. To this end, we are reviewing the proceedings of a past international conference which highlighted the usage of GenAI in educational contexts (E&PDE 2024; Design Education in the Generative AI Era). Key findings include: (1) GenAI skills which demand instruction need to be identified and mapped, e.g. prompt engineering, selection of tools and integration of multiple tools into pipelines; (2) researchers are encouraged to report the educational framework employed in teaching GenAI; (3) suggested areas for future research include the impact of GenAI on engagement in the classroom, and on facilitating effective communication and collaboration in design pedagogy.

Keywords: Generative artificial intelligence, design education, higher learning, systematic review

1 INTRODUCTION

Developing and applying digital tools for supporting design pedagogy is among the main goals of research in design computing [1], [2]. Technological developments continue to offer new possibilities for design instructors and learners, such as virtual teleportation [3], real-time support by avatars [4], sharing of attention information [5], and more. Among these, GenAI technology emerges as a powerful force, enabling us to process large amounts of data and automate various parts of design processes. GenAI accelerates various aspects of designing, e.g. prototyping [6], and can support conceptual design [7], analysis of the artifact's environment [8], and more. The recognition that generative techniques are an important facet of design education is not new [9]. As these technologies open new possibilities for instructors and learners, it is crucial to map these and direct the course of applying GenAI in design education. A systematic literature review presented in E&PDE 2024 concerning AI in design pedagogy has found GenAI tools to be the most used type of AI tools in design education [10]. Considering this, we are investigating the impact of GenAI on pedagogy, by organizing insights from past studies. Our primary objectives were to identify opportunities for (1) curricula development and implementation, and (2) inquiry into GenAI in design pedagogy that can inform (1). Our overarching research question is - *how have GenAI tools been applied in design education?* The three sub-questions addressed in this study are: (RQ1) *in what academic scenarios have GenAI tools been applied?* (RQ2) *how have GenAI tools been applied in design pedagogy?* (RQ3) *what is the benefits/challenge of integrating GenAI into design pedagogy?* Unlike broader evidence-mapping reviews [11], this study interprets its findings through an existing theoretical framework, which highlights three critical components for studying AI in design education: learner competency, curricular content, and assessment [12].

2 METHOD

To answer our research question, we executed a PRISMA-style survey of E&PDE 2024 proceedings (N=118). The conference was selected due to its focus on design education, as well as to the topic of the specific year which was surveyed - “Rise of the Machines – Design Education in the Generative AI Era”, which directly aligns with the focus of our work. A PRISMA-style review was executed, to organize insights concerning the application of GenAI in design education. PRISMA is a widely used protocol for conducting systematic reviews that increases coherency and replicability [13]. The details of paper selection (2.1) and classification and synthesis (2.2) are now provided.

2.1 Paper Selection

In PRISMA, paper selection is conducted in two stages of screening, and determination of eligibility. An overview of the outcome of this process is provided in Figure 1. We first screened the papers based on their titles and keywords using the following criterion - was there any mention of AI? In this, we regarded any of the following as a mention of AI: (1) explicit mention, e.g. “AI”/“Artificial Intelligence”; (2) phrases related with AI, including both tools and techniques, e.g. “ChatGPT”, “generative fill” etc.); (3) keywords implying on consideration of AI, such as “next-gen technology”, etc. During screening, 65 records were removed from consideration. To determine the eligibility of the remaining records, we read their abstracts and examined whether they reported on empirical findings from a pedagogical activity (any design-related educational activity in higher learning) in which GenAI tools were used. GenAI tools refer to tools drawing on AI for generating content to users [14], including specialized tools (e.g. image generators) and general-purpose tools (e.g. ChatGPT [15]), etc. When a record was deemed as potentially ineligible, we examined its full text prior to making our final decision.

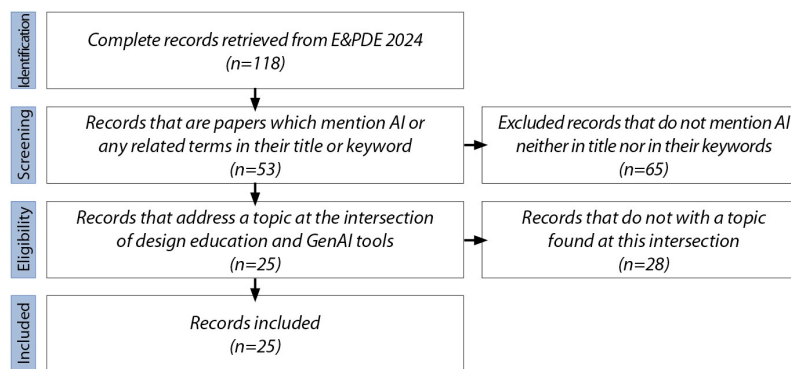


Figure 1. Information flow in paper selection

2.2 Paper Classification and Synthesis

The process of classification proceeded as follows. Two independent reviewers, who are both researchers at the intersection of design and computing, have classified all selected records independently. Then, the results concerning the classification of each paper across multiple categories were merged. This process has enabled to produce a robust classification result, as it helps to reduce bias and increase the reliability of classification [16]. In cases where differences among classifiers emerged, these were resolved via discussion and by consulting the full text of the original work. Our classification system (Table 1) was devised to answer our questions by focusing on three main aspects of each work: the pedagogical scenarios in which GenAI was used, the purpose for using it in each and the lessons learned (including positive outcomes and challenges in implementation). Finally, key findings were interpreted through the three-tiered framework proposed by Gao et al. [12] (refer to 1).

Table 1. Classification system employed in this study

Question	Aspect	Explanation
RQ1	1.1. Educational level	Undergraduate/Post-graduate/Other
	1.2 Design discipline	The discipline which the educational program focuses on
	1.3 Tool used	The GenAI software tool utilized in the educational activity
RQ2	2.1 Purpose	The pedagogical purpose of using the GenAI for
	2.2 Framework	The pedagogical framework employed (where applicable)

RQ3	3.1 Contribution	The contribution of GenAI to designing or design pedagogy
	3.2 Challenges	The challenges in using GenAI in design pedagogy

3 RESULTS

3.1 Educational Scenario, Discipline and Tools Used (RQ1)

In terms of the educational **scenario**, most studies focused on undergraduate level classes and workshops (N=14), only a few focused on postgraduate design studies (N=3), and a single study involved both undergraduate and postgraduate students. In some cases, the educational level was unspecified, or involved design professionals, or even university administrators (thus classified as “other”, N=4). As for the educational **discipline**, half of the records focused on product design (N=11) (aligning with the surveyed conference’s theme). These were followed by investigations into pedagogy in engineering design (N=5), by studies integrating multiple disciplines (N=3), and by two cases of exploring GenAI in service design and textile design (N=1 each). In a single case, the design domain was unspecified. Concerning the **usage** of GenAI tools, 12 papers employed a single tool, while 10 papers employed more than one (up to ten). ChatGPT was the most widely used tool (N=12). Several other generative tools have stood out, primarily Midjourney (N=5) and Vizcom & Bing Image Generator (N=4 each).

3.2 Manner of Employing GenAI in Design Pedagogy (RQ2)

Researchers have studied GenAI in design education with five different purposes. We introduce these from the most to the least explored. **First**, most studies focus on exploring the potential of GenAI to contribute to students’ ability to design (N=12). Examples include the attempt to enhance ideation abilities [17], [18], the understandability of student works [19]. In some cases, this potential was examined by comparing the outcome of employing GenAI with that of a traditional method [20]. Interestingly, GenAI was not only compared with traditional methods, but also used to improve upon them, by reconsidering a method (QFD) in light of current technology [21]. **Second**, several studies have explored how students use GenAI (N=3), to learn about issues which may emerge in the process and mitigate them. For example, one study has examined the ability of students to detect bias in AI-generated output [22]. **Third**, researchers have studied the potential of GenAI technology to be accepted by learners (N=4), e.g. by collecting students’ feedback [23]. **Fourth**, researchers have also explored the impact of AI on students’ design process, with the aim of describing the nature of emerging design processes in these settings. For example, Romanillos et al. [24] have examined the extent to which a learning process driven by GenAI corresponds with Bloom’s taxonomy [25]. **Finally**, one study focused on supporting instructors by helping to generate teaching materials [26]. Overall, less than half of the studies have indicated a specific framework that was employed in the educational activity (N=9).

3.3 Benefits and Challenges of using GenAI in Design Pedagogy (RQ3)

A wide range of **benefits** of GenAI tools in design pedagogy were reported by researchers. These include supporting information retrieval [27], saving time in prototyping [28], lowering the requirement for acquiring skills for creating prototypes [29], facilitating ideation and expansion of the design space [30], increasing the quality of student output [24], which may be associated with a positive experience from students’ perspective [31], and more. The positive experience among students may also be associated with the alignment between students’ expectations and the tool’s output [32]. Interestingly, GenAI was also found to increase engagement among students [33], and to enhance collaboration [34]. Alongside these, GenAI was found useful for instructors as well, as it enabled to automatically generate design briefs which were roughly equivalent to ones that the instructor would write manually [26].

Contrary to the above, a diverse range of **challenges** associated with the introduction of GenAI into design pedagogy were highlighted. First, prompts occasionally require extensive refinement by learners to produce the desired result [26], which may be difficult without deep knowledge of prompt engineering [30]. Relatedly, since image/verbal prompts are not equally well-interpreted by generative systems [32], [35], questions arise regarding the best path for aiding students in achieving satisfactory results. These imply the need for a shift from informal learning of GenAI tools to formal learning, which will demand considerable effort among instructors and educational systems for integrating such tools into the curriculum [20]. Second, despite the intuitive interaction with GenAI tools, one study has found them to be less effective among novice learners [17]. Third, additional barriers concerning the output of GenAI included the lack of cultural contextualization [26], as well as challenges with producing a desired output due to unwanted visual elements which cannot be easily removed when producing

visualizations (in interior yacht design) [23]. Fourth, in one study, GenAI was found to reduce the sense of originality/uniqueness which relates with the sense of ownership, as well as the amount of mental effort required – “...you didn’t really have to do any thinking for yourself” [18] (p5). Fifth, GenAI poses issues for instructors with evaluation [36]. Finally, one study has raised critical questions regarding the development of basic design skills (e.g., understanding space in spatial/visual design), which may be hindered by overreliance on computational pipelines [37].

3.4 Opportunities for GenAI in Design Pedagogy and Research

To identify opportunities for GenAI in design pedagogy, we interpret the results using Gao et al.’s. [12] three categories: **(A)** building learner’s competency, **(B)** content, and **(C)** assessment. Concerning **(A)**, it seems important to extend our investigation beyond undergraduate level courses. Also, to support learners, formal introduction of GenAI into curricula is necessary (overlaps with **B**). For example, instructors can consider the topic of prompt engineering as a fundamental skill pertaining to GenAI usage and invest sufficient time for ensuring all learners can reach satisfactory results via LLM-based tools. Future research can map the GenAI topics to be taught, to inform curricula development. This is important since formal integration of GenAI into curricula can reduce inequities related to access to professional skills. Additionally, critical questions such as the impact of GenAI on the development of students’ cognitive capabilities (e.g., understanding of space, composition etc.), as well as the need for these in an AI-driven design era, require further investigation. Regarding **(B)**, future curricula can consider the integration of several GenAI tools into a single pipeline, when designing courses that formally introduce GenAI to students. Researchers can contribute to these efforts by studying the process of selecting GenAI tools in accordance with the task. With respect to **(C)**, we recommend that future works which employ GenAI in a pedagogical setting explicitly indicate the theoretical framework employed, as a basis for evaluating the impact of these tools beyond local effects on process/acceptance, to establish their contribution to learning itself (i.e. what new knowledge/skill have students gained as a consequence of introducing these tools into the classroom). As our survey has highlighted, the work of instructors may be under supported by current research. Therefore, it is important to inquire into the development of robust assessment methods. Beyond these three categories, researchers can consider exploring the potential of GenAI to increase engagement in the classroom, which is extremely important from a pedagogical perspective, or deepening our understanding of its contribution to design pedagogy from the instructor’s side. Finally, while GenAI tools were found to generally enhance collaboration in a pedagogical setting, no study has focused its investigation on the impact of GenAI on communication (verbal/visual) which is fundamental to collaboration, suggesting the need for further studies.

4 CONCLUSION

A systematic literature review of the proceedings of an international conference (E&PDE 2024) has highlighted promising direction for integrating GenAI into curricula.

Concerning the application of GenAI in design pedagogy:

- To integrate GenAI into design pedagogy, is important to identify the topics which demand formal instruction (e.g., prompt engineering, best practices of integrating multiple tools into pipelines)
- Curricula content can also include pipelines for integrating multiple GenAI tools

Concerning inquiry into GenAI in design pedagogy, future studies can consider the following questions:

- How can we support design instructors in scenarios where learning is facilitated by GenAI?
- How can we use GenAI to increase engagement in the classroom?
- How can we facilitate better communication and collaboration in the classroom via GenAI?

As the field of GenAI progresses rapidly, it is essential to examine the relevance of the above insights to the current landscape. Finally, when searching for ways to effectively apply GenAI in design pedagogy, future works can also consider how this can be done ethically and responsibly.

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DETERMINING THE COMPETENCIES IN DESIGN LITERACY AND PEDAGOGICAL LITERACY FOR NON-DESIGN-TRAINED HIGH SCHOOL TEACHERS TO EFFECTIVELY FACILITATE DESIGN-BASED COMPLEX PROBLEM-SOLVING IN GENERAL EDUCATION

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ABSTRACT

The purpose of this research is to determine the competencies required by non-design-trained high school teachers to effectively facilitate design-based complex problem-solving projects in an inquiry-based subject offered in high school education. Using a Japanese high school as a case study, it was believed that a clear understanding of the objectives and the expected learning outcomes for each stage of the design-based process is necessary to develop the design literacy necessary to evaluate and critique students' progress in the design-based project. In addition, the development of design literacy may enhance teachers' content knowledge in the design process. These competencies will in turn develop the teachers' abilities associated with pedagogical literacy to read, understand, evaluate and modify existing instructional materials to better facilitate the design-based project.

Keywords: Pluriversal design, complex problem-solving, design literacy, pedagogical literacy

1 INTRODUCTION

In Japanese high school education, students are taught to solve real-world problems through the *Period for Inquiry-Based Cross-Disciplinary Study* subject, commonly known as *Soutan* (総探) in Japanese. *Soutan* is a cross-disciplinary and inquiry-based subject, where high schools have autonomy to design the programme with reference to the national curriculum guidelines [1]. When implementing *Soutan*, all high school teachers can be assigned to facilitate and teach the content. The objectives of *Soutan* are to allow students to go through the iterative process of *problem definition, information collection, data organisation and analysis and consolidate and express their findings*. High schools implement a variety of projects to fulfil the objectives, and some schools implemented complex problem-solving (CPS) projects in the *Soutan*. While in-service training may provide teachers with a good understanding of the objectives and the learning outcomes of the subject. But teachers faced significant anxieties and challenges implementing this subject in class, as there was a lack of training in preparing them to teach and facilitate the inquiry-based learning in *Soutan* [2]. This is because teachers have to teach and facilitate students to identify problems to solve, and there can be multiple solutions to engaging in the problems, which is something they have not experienced in their previous educational experience.

Since 2021, the authors and their colleagues, referred to as the research team in this paper, have collaborated with F High School to implement a yearly school-wide design-based CPS project in *Soutan*. F High School adopted design thinking in the CPS project, as the design process would allow students to go through the iterative process required in the curriculum guidelines. The research team served as consultants and are involved in working with the school in planning and designing the project. One of the main challenges faced by F High School is to prepare different subject teachers who are not trained in design to facilitate the design-based CPS project. Training workshops for teachers were not conducted due to the school's time constraints. To mitigate such challenges, all teachers received a set of instructional materials, which they could use to prepare each lesson. The instructional materials were created by the school's project coordinating team in consultation with the research team. The instructional material contains lesson plans, simple explanatory notes, and student worksheets for each

student activity. To further support teachers, a resource webpage was created by the school to contain materials such as videos explaining the design process, problem identification, brainstorming methods, and idea generation. The research team contributed to some of the content in the resource webpage. During lessons, the programme coordinator and the research team would conduct lesson observations to clarify teachers' challenges. After each lesson, the programme coordinator would clarify teachers' concerns by posting advice on the resource webpage. Despite these interventions, the research team discovered the following needs that require to be addressed [3].

1. Developing teachers' understanding of the design process and the pedagogical competencies to teach and facilitate the design process.
2. Developing educational resources to support teachers in facilitating the project. Such resources should (a) provide knowledge and methodology of the design process, including problem identification and ideation, (b) offer student-centred pedagogical strategies, and (c) include clear explanations of each design-based task and exemplars of student outcomes.

In 2024, the research team proposed and worked with the school to revamp the instructional materials to address the needs mentioned above. The detail related to the development of the new instructional materials is to be published in a separate research output. The new instructional materials updated the explanatory notes for the design process for CPS, suggested relevant design approaches (lesson plans included) for different parts of the CPS process, and provided exemplars to provide clearer student learning outcomes. While the new instructional materials may address the needs of providing the teachers with resources to teach and facilitate the CPS projects, it was observed that teachers still face challenges in facilitating processes, particularly the problem exploration, problem definition, and ideation. As teachers are facilitating students to engage CPS through design thinking, teachers will require the competencies to comprehend the process of designing. At the same time, teachers need to be able to understand the considerations and thoughts behind students' proposed solutions. Such competencies are associated with design literacy [4]. By equipping teachers with the necessary design literacy, teachers would then be able to employ relevant pedagogies to teach students to use the design process to engage in CPS. The purpose of this research is to determine the competencies required by non-design-trained high school teachers to effectively facilitate design-based CPS projects using the Japanese context as an example. From the competencies identified, this study will then determine how these competencies may be associated with design literacy and pedagogical literacy.

2 LITERATURE REVIEWS

2.1 Design literacy and its relevance to general public

Design literacy is seen as a competency that is not only required by design professionals but also by the general public. Different scholars have articulated the concept of design literacy, but there is no general definition of design literacy for the general public [5]. The purpose of developing design literacy in the general public is to obtain a sustainable society by being aware and able to evaluate the impacts of design solutions on people and the natural environment in a sustainable way [6]. In addition, stemming from the sustainability point of view, the general public require design literacy to move away from being passively accepting of the designed world created by design professionals to being a change agent to critique and shape the design of our current world [7][8]. To be able to critique design, perhaps, a person would need to possess competencies to examine, question and hypothesise the considerations and rationale behind the designed solutions and, at the same time, consider the consequences and impact that the solution may make towards the societal, environmental, political and economic aspects [9]. To shape design, a person would need to possess the competencies to create solutions through the process of design. Design literacy are competencies that are relevant for the general public to understand the process of design and the consequences and impact of design. Thus, design literacy will promote the pluriversal views of those outside the profession of design.

2.2 Pedagogical Literacy for teachers

Pedagogical literacy is an important competency for teachers in teaching and learning in a classroom. Teaching and learning are different from each other [10]. Learning involves the acquisition of and improvement of knowledge and competencies in a subject matter. While teaching involves the use of strategies to ensure learning of the content of a subject matter takes place. Thus, the competencies of teachers to turn what they know about the subject matter into the content for instructions and determine what kind of instructions are suitable to deliver the content are critical. Such competencies are closely

related to pedagogical content knowledge. Pedagogical content knowledge is to possess the instructional expertise to synthesise subject matter knowledge and pedagogical knowledge. In other words, successful teachers are able to transform their knowledge of the subject into forms that learners can understand [11][12]. Development of pedagogical literacy is crucial in the development of pedagogical content knowledge. To possess the competencies of pedagogical literacy, teachers should possess the competencies to read, understand and critique documents associated with pedagogical content knowledge and use this ability to reason for the success or failure of the pedagogical practices [13]. Thus, through the analysis and reflection on the successes and failures in pedagogical practices, teachers may develop and update their own pedagogical content knowledge in the subject area.

3 RESEARCH METHODOLOGY

To achieve the purpose of research, the key research questions (RQ) are constructed as below.

- *RQ 1. What are the challenges teachers faced in facilitating the design-based CPS project?*
- *RQ 2. Based on RQ1, what kind of competencies related to design literacy and pedagogical literacy do teachers need to allow them to facilitate design-based CPS project effectively?*

This paper used F High School as a case study to address the RQs. Focusing on the CPS project implemented in the academic year of 2024, a focus group discussion was conducted after the completion of the project to solicit qualitative feedback from the project coordinating team from the school. The focus group discussion mainly involved the authors and four teachers; namely the lead project coordinator, and three teachers who have also taught and facilitated the CPS project.

Table 1. CPS weekly lesson outline and number of teachers involved

Week	Period 1 Lesson Content (Lesson duration: 50 mins)	Period 2 Lesson Content (Lesson duration: 50 mins)	Number of subject teachers involved in facilitating the project
1	Understanding SDGs - Research on case studies related to SDGs	Exploring Problems - Using a mind map to explore problems	1. Japanese language : 5 2. Mathematics : 3
2	Selecting a Problem - Using the Axis Frame method to shortlist problems based on two most important criteria	Selecting a Problem - Using Decision Matrix to select a problem	3. English : 4 4. Social : 2 5. Science : 2
3	Understanding the Problem - Planning research approach and division of work	Understanding the Problem - Creating questionnaires/interview questions	6. Health and Physical Education : 4 7. Art : 1
4	Understanding the Problem - Conduct survey/interviews	Understanding the Problem - Consolidate and organising data	8. Business and Information : 2
5	Understanding the Problem - Conduct survey/interviews	Understanding the Problem - Consolidate and organising data	Total number of teachers involved : 23
6	Understanding of Problem - Data analysis	Define Problem Statement	
7	Generating Ideas - Using How-Might-We method	Generating Ideas - visualisation of ideas	
8	Generating Ideas - Using How-Might-We method	Generating Ideas - visualisation of ideas	
9	Creating Prototype and Presentation Poster	Creating Prototype and Presentation Poster	
10	Creating Prototype and Presentation Poster	Creating Prototype and Presentation Poster	
11	Preparation for Presentation	Preparation for Presentation	
12	Mid-Term Presentation - external commentators were invited to view the presentation and provide feedback	Mid-Term Presentation - external commentators were invited to view the presentation and provide feedback	

F High School is a co-ed school that is considered a typical public high school. The scale of the CPS project involved about 300 high school students in the second grade (17 years old). Lessons are conducted once (100 minutes) a week. The project is organised as a 12-week programme. When implementing the CPS project, 23 high school teachers will be assigned to facilitate the project. Two or three teachers, who are teaching different subjects, will be assigned to facilitate a class of around 20-30 students. Students from different classes are grouped together based on their interest in a specific area of the Sustainable Development Goals (SDGs). After being grouped by interest, the students are then divided into about eleven classes. In each class, the students form teams of 3-5 students to engage in solving issues related to their surrounding communities. Table 1 provides a brief outline of the content of each lesson and the number of subject teachers involved in the project.

During the focus group discussions, RQ1 was broken down into sub-questions to guide teachers in sharing about their challenges faced when facilitating the project, particularly in the problem phase and ideation phase. The feedback was recorded, transcribed and translated from Japanese to English. The transcript was analysed to elucidate meanings through coding [14][15]. In Vivo and Descriptive methods were used in the first cycle coding. Pattern coding was used in the second cycle coding to group codes

with similar categories. Then after, the categories were assigned to high-level codes before conducting thematic analysis to clarify the research questions.

4 FINDINGS AND DISCUSSIONS

Based on the teachers' feedback, the emerging themes related to challenges and concerns during the project can be drawn from two large categories, design process and pedagogy. Refer to Table 2 and 3.

Table 2. Categories and related codes with respect to design process

High-Level Category	Second cycle codes	First cycle codes
design process	iterative process	encouraging failures
	research and data analysis	conducting research and analysis; unsure about what to do after collecting data; not all teachers have the expertise; specialized knowledge in data science; able to collect data; how do we analyze the data; data analysis methods; we ourselves aren't that knowledgeable either; introducing tools like AI text mining
	prototyping and testing	beyond conceptual ideas; digital fabrication; prototyping
	ideation	ideation only at conceptual level; insufficient existing knowledge
	problem exploration and definition	superficial understanding of problem; lack of competency to understand complex problem; issues with problem definition process; ability to link daily problems with SDGs; unable to unpack SDGs; able to follow the design process; ability to conduct research to understand problems; inability to scope the problem; ability to understand complexity of problems and solutions; inability to explore wide range of problems; ability to scope the problem; difficulty in using design approach; deepen their understanding of the issues; bundled into a big topic; able to identify issues in their immediate surroundings; connect them to specific SDGs goals; concept of SDGs too strongly fixed in their minds; tried to tackle overly large-scale issues; followed a proper process; identifying a local issue they genuinely wanted to address; tackle enormous issues like infectious disease

Table 3. Categories and related codes with respect to pedagogy

High-Level Category	Second cycle codes	First cycle codes
pedagogy	process focus	differentiated instructions; multiple approaches to achieve learning outcomes; process rather than outcomes
	external feedback	external validations
	cooperative learning	organisation of group work; group dynamics; group member aren't very familiar with each other; collaborative learning across levels; setting expectations
	student profile	students in the humanities course; stop taking math from the second year onwards
	project implementation	operational challenges
	educational resources	common understanding among teachers; consistency in teaching and learning; teaching and learning strategies
	project consultation	teachers' role in consultation; teacher-student communication

All teachers reported facing significant challenges in guiding students to explore real-world problems and define them more specifically. Most students were able to use divergent thinking tools such as mind maps to brainstorm and explore possible real-world problems around them. But they were unable to consider the problems with more details during the brainstorming session. For example, some students identified daily real-world problems such as food loss or infectious disease in their community. However, teachers were not successful in helping students deepen their understanding of the specific issues related to food loss or infectious disease within their community. Furthermore, teachers felt that getting students to consider SDGs during problem exploration further increased the level of complexity for students. This is because students tend to view problems related to SDGs as large-scale problems rather than linking SDGs to specific real-world problems around them. While teachers felt that they were able to guide students to conduct research to understand the problems, most of them were unfamiliar with various research methods. The most commonly used research method was questionnaire surveys. Although students were able to collect sufficient data through questionnaire surveys, teachers lacked knowledge in teaching data analysis. In addition, teachers felt that students in the school are mainly humanities majors, and picking up knowledge of data science will be challenging.

Teachers recognised that ideas needed to be developed beyond the conceptual level. Teachers were able to facilitate students in generating ideas, but to test the solutions, models or prototypes are necessary. Most ideas were developed up to the conceptual level, but few got to become models or prototypes. The

school has currently set up a digital fabrication lab that includes equipment such as 3-D printers, laser cutters, and a large-scale plotter. But teachers are required to be trained in using such prototyping tools. On a positive note, teachers understand that the design process is iterative. Even though students may encounter failures during the problem-solving process, teachers feel that it is important to encourage students to navigate problem-solving through making mistakes rather than expecting students to complete the project smoothly. However, some teachers may prioritise achieving the outcomes of the project rather than the process. As such, some teachers would follow strictly the suggested design-based approaches during the problem-solving process, rather than exploring different teaching and learning strategies to guide students. Teachers reflected that as different groups of students are engaging in different problems, the guidance provided during the consultations should be more differentiated to cater to the different needs of the students. This led teachers to reflect on their roles during project consultations. The teachers were questioning how much advice they should give when facilitating the project. They were concerned that providing too much advice might indirectly lead students to take cues from teachers as an indication of getting into the “correct” direction.

The teachers agreed that educational resources are necessary to guide teachers in facilitating the project. The educational resources provided allow teachers to achieve consistent standards in project guidance and management across all the different classes. But some teachers who were unclear about the design process merely followed strictly the approaches and strategies suggested in the educational resources. Finally, pedagogical considerations that were not related to the design process, such as cooperative learning strategies to improve group dynamics and learning and seeking external commentators to provide feedback for students and other operational issues of the project, were also surfaced.

Based on the feedback, not all concerns shared by the teachers are related to design literacy. Strengthening knowledge of research methods, effective group learning, and creating encouraging learning environments are not confined within design. These are related to general pedagogical approaches to enhance students’ research abilities, group learning and motivations in learning during CPS. But three distinctive areas can be viewed as related to design literacy and may impact teachers’ ability to determine the use of relevant pedagogical approaches to guide students to navigate specific parts of the design-based process.

Firstly, teachers need to understand that how a design problem is perceived can be relative based on different individuals. Thus, all teachers need to understand that it is not sufficient for students to just merely describe the current state of the problem. But the causal reasons for the problems are required to be described. In other words, teachers need to understand to what extent the problem should be broken down so as to facilitate students unpacking the problem. Without developing competencies to dissect the design problem, teachers would be handicapped in understanding the required learning outcomes of the design approaches suggested in the instructional resources. In addition, they would also be merely trying to follow the facilitation process suggested in the instructional materials without being able to modify the strategies to cater to the students to guide them to analyse and define the problems. Secondly, the technical knowledge for prototyping will be important content knowledge for teachers to suggest appropriate prototyping techniques and evaluate students’ prototypes. Thirdly, being able to provide effective feedback in a design-based CPS project is more than just formative assessment. Effective feedback guides students to navigate the design process. Thus, teachers need to be equipped with a clear understanding of the objectives and the expected learning outcomes for each stage of the design-based process. Teachers may build on such understanding to develop competencies to evaluate and critique students’ progress in each part of the design-based process. In addition, as part of the pedagogical literacy for implementing design-based projects, teachers would also develop competencies to evaluate the effectiveness of the design approaches suggested in the instructional materials and modify them appropriately based on the needs of the students.

The current paper suggests that to develop non-design-trained teachers’ ability to teach and facilitate design-based CPS projects, it is more than just providing teachers with pedagogical approaches through instructional materials. In order to be able to facilitate the design-related processes in the CPS project, teachers need to acquire the necessary content knowledge related to design. This content knowledge can be acquired through the development of relevant design literacy. Only with the necessary content knowledge related to the design process can teachers acquire the competencies to read, understand and critique the instructional materials and hypothesise the success of the suggested design-based strategies with respect to the needs of the students. As part of the competencies for pedagogical literacy, this may

strengthen teachers' pedagogical content knowledge to modify instructions accordingly to suit the progress of their students in any part of the design process for the CPS.

6 CONCLUSIONS

Using a public Japanese high school as a case study, the purpose of this research is to determine the competencies required by non-design-trained high school teachers to effectively facilitate design-based CPS projects. Through a focus group discussion, the findings suggested that teachers require to develop competencies that enable them to evaluate and critique students' progress in each part of the design-based process by building on a clear understanding of the objectives and the expected learning outcomes for each stage of the design-based process. In addition, teachers also need to develop competencies to analyse and dissect the design problems and prototyping. The competencies mentioned are believed to be part of design literacy necessary to develop content knowledge related to the design process. Only with the necessary content knowledge related to the design process can teachers acquire the necessary pedagogical literacy to read, understand and critique the instructional materials and hypothesise the effectiveness of design-based strategies used in the classroom with respect to the needs of the students.

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DIVERSIFY EXPERIENCES: MOTIVATE SUSTAINABILITY IN DESIGN PROJECTS

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ABSTRACT

The research seeks to explore the pedagogical choices that can encourage or limit design students' choices to address a variety of sustainable initiatives as part of their design projects. The research method is based on a focus group during which participants were asked to share a significant design project experience related to sustainability. As participants were design students, the discussions highlighted which factors can motivate or prevent students from considering sustainable aspects of their design as part of their projects. Data analysis highlights challenges and good practices from the learner's perspective. The discussion exposes three main considerations: the paradox of designers, the timing and complexity of projects, and the social scope of sustainability.

Keywords: Design education, sustainability, teamwork

1 INTRODUCTION

Historically, design education is based on a strong Bauhaus-inspired "signature pedagogy" [1], which values project-based learning to encourage active learning, exploration, and creativity. Although this pedagogic frame is well adapted to design practices, many researchers and educators are questioning how design education can adapt to focus on sustainability-related skills, knowledge, and experiences. We identified many initiatives that were organised in the last decade to question design education, its values, and foundations regarding our new reality. For example, Norman and Vredenburg's *Future of Design Education* [2] seeks to discuss how designers can be better prepared to face the complex challenges ahead. They state that "designers today are asked to address new situations and consequences at scales very different from those of the past." The Design Council [3] seeks to use their influence as an organisation to "upskill 1 million designers by 2030" to "fuel the green transition." They encourage research initiatives that focus on the "many significant evidence gaps around design education" (p. 24). In 2023, Davis edited a *She Ji* special issue on *Rethinking Design Education for the 21st century*. Davis and Dubberly [4] stated that we are ongoing a paradigm shift that encourages the renewal of design practices and the adaptation of designers' skills. Moreover, Noël [5] also edited two *She Ji* special issues on design education. At a more global level, the United Nations published a report stating that education is the only possible way to reach sustainable development goals [6]. Although no clear framework has emerged yet from these discussions, a few findings are starting to be confirmed as possible future guidelines for design educators. Among these, we note particular emphasis on systemic thinking, situated learning, and participatory approaches.

Systemic thinking is a mindset that encourages the consideration of all active and passive aspects of a complex situation. Systems expose the network of interacting relations between humans and non-humans [7,8]. According to systemic thinking, local actions are considered holistically: "Even when responsible for only a small part of the system, designers need to understand the interdependent relationships within situations that produce particular patterns of behaviour and effects" [4, p. 108]. Moreover, design projects should encourage students to contextualise their ideas by considering social, historical, and cultural aspects to ensure that solutions are adapted and durable [9, 10]. In a previous paper, we mentioned, "The act of designing is situated both socially, as well as contextually, with the variables that are specific to the designer, project context, and projected uses" [11]. Inclusivity in the design process is a result of the previous two aspects. It seeks to "respect the voices of all affected by their actions" [4, p. 110]. To do so, individuals, stakeholders, potential users, and experts are included in the design process to ensure their needs are considered. Participatory approaches ensure designers are

well equipped to understand the system and situation they are studying, but also that they are accompanied and supported by communities in the transformative process [12]. The study seeks to present a preliminary investigation on the subject based on learning experiences and to share and assess our research methodology before conducting the research at larger scale.

2 THEORETICAL BACKGROUNDS

This study's theoretical background is based on Tessier (2021) and was shared in recent publications [11, 13]: the zone of proximal development for learning teamwork skills model (ZPD teamwork model). The ZPD teamwork model offers a framework for the integration of teamwork over the course of design formation programs (Figure 1). Based on Vygotsky's previous work [14], the model is based on the zone of proximal development. This concept distinguishes three levels of autonomy: what the learner can do on their own, what they can do with guidance, and what they cannot do even with guidance. Learning is interpreted as cyclic (continuously evolving) and socially influenced (supported by others).



Figure 1. Zone of proximal development for learning teamwork skills model (Tessier, 2021)

The ZPD teamwork model identifies three levels of learning. The first level, closer to the centre, refers to basic skills learned when integrating a design program. The second level refers to design-specific skills acquired over the first and second formation years. The third level, nearer to the exterior boundaries, refers to a more complex set of skills requiring authentic, professional, and personal experiences. The model is the result of the analysis of 22 bachelor students working on team projects. The analysis resulted in 33 characteristics organised in 5 zones. Each zone groups thematic characteristics that are distributed across different levels of complexity (Table 1). Learners can evolve across the different zones as they experience various design situations.

Table 1. Descriptions of the ZPD teamwork skills zones

Zone	Description
Personal zone	This zone exposes individual characteristics such as adaptability, motivations, self-esteem, stress control, concentration, and assertiveness.
Project zone	The project zone is centred on the design process and project phases, such as expressing ideas, taking initiatives, creating shared understanding or receiving feedback, attention to detail, complexity, and feasibility.
Organisational	This zone includes characteristics such as time management, deadlines, work

zone	distribution, priorities, and disciplinary expertise. Structure over the length of the project and between team members is the focus.
Learning zone	The learning zone refers to the program's specific competencies. It includes characteristics related to industrial design specific technical and technological tools, thematic and disciplinary knowledge, complementary skills in group composition, expert advice, and project authenticity.
Social zone	The social zone offers a focus on person-to-person relations through communication, teamwork, efficient sharing of tasks and roles in the team, agreeing on project-related decisions and scheduling team meetings.

3 RESEARCH METHOD

Since this research is intended as a pilot study in preparation for a larger research endeavour, we chose the focus group method to access participants shared experiences, while also promoting discussions between them. We sought to access past experiences linked with sustainability and design projects to enhance our comprehension of the brakes and levers of these projects. Before the focus group session, participants were informed that they would be sharing a significant experience in detail of designing with sustainable aims (either positive or negative). Three questions were shared before the meeting to ensure that participants were prepared to talk about their experiences: first, describe an educational or professional project experience related to sustainability; second, detail any aspects that make you proud or frustrated; third, share how teamwork or social actors contributed to the project.

The focus group was guided by the lead researcher and a research assistant. One at the time, participants were invited to share their experience, while additional questions were asked to ensure full comprehension. Other participants were invited to comment or react. Four participants were recruited to participate in the focus group (90 min). Three of these were industrial design bachelor students (fourth year) and one was a design master's student. We valued a diversity of backgrounds to access a diversity of perspectives. The focus group was transcribed into verbatim to facilitate its analysis.

Participant 1 shared experience was about the design of a shared space for an NPO with upcycled wood from sick ash trees, while Participant 2 talked about the design of refillable and reusable makeup packaging. Participant 3 shared a project focused on finding alternative uses for waste products in the textile industry (synthetic insulation) and Participant 4 discussed the exploration of the potential of a specific ceramic technique to fight against heat islands. These experiences were analysed according to the ZPD teamwork skills model. Emergent coding allowed to make sense of repeated topics, emphasising challenges, doubts, or recommended practices. To ensure coding consistency, two research assistants and the lead researcher coded the data before combining their findings.

4 DATA ANALYSIS

The analysis was conducted to differentiate between a diversity of good practices and challenges that were mentioned during the discussions with the help of the ZPD teamwork skills model. The transcription was coded according to (a) good practices, (b) challenges, and (c) challenges that are also considered good practices. Good practices are considered as integrated skills or practices, challenges are considered as not or hardly integrated, and challenges that are good practices are situated in between.

4.1 Personal zone

The discussions related to the personal zone were centred on the roles, values, and frames that influence their practices. The designer was identified as being accountable for certain responsibilities. The participants discussed how they felt when reflecting on this influence and their values:

Often, I question what is my value as a designer? But after that, I think about it... I can do things better so that the next products are more durable. (Participant 3)

I quite agree, because it is a question that followed me over my studies. What do I ultimately bring as a designer? Am I not just going to produce another plastic toy? (Participant 4)

Reflectivity was identified as the only good practice in this zone. The resulting reflections led to an overarching paradox. Consumerism is especially paradoxical when trying to develop new sustainable products. Moreover, in relation to this discussion, a challenge that is also a good practice was identified in maintaining your professional values, which can be challenging for novices lacking assertiveness

(level 3, personal zone). A possible solution discussed is inspired by other creative disciplines, such as architecture, which are bound to disciplinary rules to structure their decisions. Especially challenging aspects were identified by adopting a global vision when working alone, assuming a role and standing for its decisions as a novice and developing an interest in sustainability in design students. Although this last challenge was surprising to the researchers, the participants confirmed that some students are not interested in designing more sustainably, and others make it their own prerogative to always explore positive sustainable outcomes.

4.2 Project zone

The aspects noted in the project zone relate to the influences encouraging or limiting a project's sustainable scope. The following good practices were discussed: seek to understand user needs, work with already available materials, choose durable materials, design reusable objects, always consider sustainability in the design criteria, and openly receive feedback. The participants discussed a challenge that is also a good practice regarding the complexity of design projects that are proposed to students. They felt that sometimes projects do not favour innovation and creativity. They critiqued projects that focus on redesigning existing products (e.g., a chair) and advocated for more freedom in project briefs.

What is interesting in our projects now is that you can identify your own problem and find something that has not been done before. [...] When you have more freedom, you can find stuff to design that is more useful. (Participant 1)

They also mentioned the difficulty of answering all sustainable aspects of a project, underlining the importance of making choices. Then, the challenges identified related to some characteristics (like recyclability, flat packaging, modularity), the adoption of a global vision, and considering sustainability at each phase of the process.

4.3 Organisational zone

Characteristics identified in the organisational zone relate to schedule constraints often imposed on educational projects. Participants seemed to think that if more time was allowed, more attention could be given to sustainable aspects. The choice seems easy to make, since sustainability is sometimes not on the assessment criteria list.

But once we really get into the design phase, especially in an educational context, since projects are in such short time frames. Unfortunately, we have to take shortcuts and often there are notions of sustainable design which are put aside. (Participant 4)

4.4 Learning zone

The participants discussed various topics related to learning, but mostly pedagogical alignment. Among the challenges identified, we note to encourage the integration of sustainability-related notions from the start of the formation, integrate more opportunities to experiment with practical applications of sustainability, ensure assessment criteria on sustainability, encourage workshop tutors to demonstrate and share their views on sustainability, and offer specific training related to teamwork and collaboration.

We are encouraged to collaborate in general with classmates. But, sometimes, they tell us like, "You should talk to this person for this information" but in the end, we are pretty much alone. We don't learn about collaboration and even less regarding sustainability. (Participant 4)

Two challenges that are also good practices are identified: consider the life cycle assessment of products and value traditional know-how to value more sustainable practices.

4.5 Social zone

The last zone relates to decisions, norms, and existing rules for the designers and the other project's stakeholders. The participants understood the importance of valuing exchanges with clients, managers, and experts to enrich their ideas, but wished to learn more about teamwork in complex contexts (such as interdisciplinarity or with potential users). They were puzzled when the researcher asked what the social scope of sustainability is. Surprisingly, the challenges identified are very similar to the good practices just mentioned: collaboration with other experts and non-designers, facilitating communication between stakeholders, and integration of interdisciplinarity in their projects. A challenge that is also a good practice resides in the difficulty of strategically adapting their designer's discourse according to

the economic context and clients' aims. Some mentioned they wished to choose clients with similar values, and others said they could adapt their discourse according to the client's views to detail more or less explicitly the sustainable features.

For me, it's important to create a good concept that is ecological. I say to myself, "Ah, it's good because it's sustainable." Or it's cheaper this way; it's also more sustainable. (Participant 2)

5 DISCUSSIONS

The analysis brings us to synthesise three tensions which emerge from the diversity of influencing factors identified in the previous section. First, we note a tension between the subject (designer) and the object of design. This tension questions the paradox of the designer that works to produce new artifacts in an era where we seek to reduce and reuse. This tension tends to confirm Papanek's 1970 reflection on industrial design: "There are professions more harmful than industrial design, but only a few of them." Accordingly, the participants seemed to question their values and their roles as designers as well as their power of influence and limits as positive agents of change.

I think it is important that we question ourselves about our place in the consumption market. To create and be conscious: why am I doing this? Is there really a need for this? (Participant 4)

These questions raise ethical challenges that can be disturbing to design students. Such questions reveal a sense of responsibility, but also some important gaps which should be addressed in design curricula.

5.1 Timing and complexity

We identified a second tension between the aims for innovation and the limited time offered to educational design projects. This tension seeks new and unprecedented solutions within very limited time frames. This is challenging for learners who are not yet experts. As a result, they tend to make strategic choices and consider only the aspects that will contribute directly to their project evaluation, limiting the development of certain aspects of their design solution. As mentioned earlier, the complexity of design projects should be high enough to motivate investigations and innovations for more sustainable outcomes. More complex projects could motivate students to reach out more, work collaboratively, seek expert knowledge, and test and assess with community actors. Still, complexity should always be integrated in relation to the overall students' level. Otherwise, projects that are too complex are known to limit creative abilities [13]. Therefore, time limitations and complexity, when too drastic according to the formation level, limit innovative endeavours. This can also result in incomplete systemic vision and a lack of contextual data to frame the project.

5.2 Social scope of sustainability

Thirdly, the social components of design projects seemed hardly considered and understood by the interviewed students. Although we know sustainability should consider as equally important environmental, economic, and social dimensions, a clear lack of knowledge was sensed in the focus group regarding the social scope of their design projects. On the one hand, we note a clear tendency of individuality over teamwork or participative practices. Sometimes, this can be explained as a desire to 'get things done,' but also because this part of the process is often not made explicit. Ways to encourage more exchanges with external parties, such as experts and communities, need to be encouraged through various means (theoretical presentations, workshop exercises). This also relates to teamwork and collaboration skills and interdisciplinary experiences that should be valued within curricula. On the other hand, social inputs and outputs of sustainable design initiatives must be made explicit. Seeking a co-design practice that is sustainable thus requires not only individual commitments to participation and inclusion of other values, but also structural changes to our projects and our ways of working [15]. Participative practices are increasingly being used in practice but are difficult to put into action in a pedagogical context. Efforts should be orchestrated in that direction to offer more emphasis on participative practices and the importance of context for sustainability.

6 CONCLUSIONS

This paper raises important questions about current and future forms of design education. We underlined the importance of addressing sustainability in design education, but also other factors that can influence the learning experience of design students. The study identified a diversity of factors that can be

combined and developed in various combinations to diversify students' learning experiences according to their formation level and abilities. Further studies would be needed to refine their organisation or create a coherent hierarchy. Among the elements discussed: using reflectivity to question the students about their ethical stance and values, allow more time to address sustainable aspects of projects, motivate the search for innovative solutions, and favour teamwork and participative methods. Overall, a balance can be promoted between the innovative aims of design projects, the challenging aspects of finding new solutions, and the complexity of projects. Also, we should use the reflections shared in this paper to frame the projects we propose to design students to develop their interests and motivate their considerations of sustainability. Of course, this study is limited, as the data is sourced from one focus group, but the results are promising for the upcoming research program, which will enable the confirmation and refinement of the preliminary factors identified in this pilot study. Considering the focus group and analysis experience, we wish to integrate additional interview questions on the topics of social sustainability, teamwork and participative approaches. The analysis method based on the ZPD teamwork skills model was comprehensive and useful in organising experiential data but could be enriched based on the present study. In conclusion, sustainability should be addressed and can be motivated from a diversity of angles and perspectives. This plurality is what strengthens pedagogical experiences and raises awareness about the direct and future impact of design choices. This research was funded by Fonds de recherche du Québec Société et Culture, Grant 2025-NP-343724.

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MORE-THAN-HUMAN DESIGN PEDAGOGIES IN INDUSTRIAL DESIGN: A SYSTEMATIC REVIEW

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ABSTRACT

Calls for a shift from anthropocentric approaches toward a more-than-human (MtH) perspective in design have emerged in response to environmental crises and rapid technological developments. Despite the expanding theoretical foundation of more-than-human design (MtHD), its practical application in industrial design remains limited, with a gap between theory and practice evident in its education. To foster the discipline-specific discussion on current pedagogical applications of MtHD, we conducted a systematic review of 29 papers from four databases that present examples and proposals for integrating MtHD into industrial design education. Two main findings emerge. First, although scholars share methods, tools, and theoretical frameworks, implementations rarely extend beyond early design phases such as immersion, and they provide limited evidence of long-term impact or applicability. Second, most papers rely on reflective accounts rather than systematic assessment of educational interventions, raising questions about transferability and measurable outcomes. We therefore argue for comparative process and product outcomes along with more rigorous evaluation of pedagogical practices to better articulate and communicate the value of MtH approaches in industrial design education.

Keywords: More-than-human design, industrial design, pedagogy, teaching, entanglement

1 INTRODUCTION

Social, ecological, and technological challenges resulting from the Anthropocene are compelling designers to act on multiple fronts. As an emerging paradigm developed in response to these issues, the more-than-human (MtH) perspective [7, 24] proposes moving beyond anthropocentric approaches by de-centering humans within the design process. This shift responds to address environmental crises, the growing influence of systems-oriented design thinking, and rapid technological changes that blur the distinctions between human and machine agency [11].

Building on posthumanism [12, 13] and various perspectives stemming from science and technology studies such as Actor Network Theory [15], the theoretical foundations of more-than-human design (MtHD) have expanded over the last decade, with a marked increase in scholarly contributions in the past five years.

Despite this growing theoretical base, the practical application in industrial design remains limited with methods and processes still underdeveloped [6]. This situation poses challenges for the profession grounded in practice.

A gap between theory and practical application is also evident in industrial design education. While there are ongoing curricula reformations [4] and a number of programs trying to incorporate MtHD in their pedagogical content [21, 23, 26], educators also share concerns about the long-term application and limited impact on design practice [1].

Within this scholarly context, the main contribution of our paper is to start a discipline-specific discussion on the current pedagogical applications of MtHD in industrial design education. To this end, we conducted a systematic review of 29 papers addressing the application of MtH perspectives in design education relevant to industrial design to answer two research questions: how MtH is applied in industrial design education and how it is made actionable.

2 METHOD

We conducted a systematic review following PRISMA workflow outlined by Moher et al. [19] to examine existing pedagogical work and discussions on MtH as they relate to the industrial design.

Searches were conducted across four databases. These were Web of Science, Scopus, ACM Digital Library, and Design Research Society (DRS) Digital Library. The search query included three keyword groups: 1) terms related to MtH, 2) design as the term to indicate the field of study, and 3) terms associated with education. MtH related terms were iteratively refined to maximise relevance. We also kept the field of study term broad to avoid overlooking relevant work. All keywords were searched in the article abstracts which are shared in Table 1.

Table 1. Keywords used in the search query, with AND between rows

MtH related	"more-than-human" OR posthuman* OR "post-human" OR nonhuman OR "object-oriented ontology" OR multispecies OR "multi-species"
Field of study	design*
Education related	educat* OR teach* OR instruct* OR pedagog* OR curriculum OR studio OR student*

The search was conducted on 24 November 2025 and yielded 780 articles. Figure 1 presents the details of the paper inclusion and exclusion process. We excluded papers in languages other than English, workshop extended abstracts, entire proceedings volumes (i.e. compiled books without article-level indexing), and whole books (while including relevant chapters where applicable). However, individual peer-reviewed conference papers were included when they could be identified and accessed at the article level. We also eliminated papers from architecture, landscape architecture, interior design, and art, as their professional applications differ significantly from industrial design practice and their content was not relevant to industrial design education. Instead, we included papers addressing industrial design, product design, human-computer interaction, graphic design, communication design, interaction design, service design, and product-service systems and design more broadly without a disciplinary focus. Because our focus was on the educational implementation of MtHD, we included papers reporting studies carried out with students for education purposes, pedagogical experiences shared by scholars, and discussions on design education.

We reviewed 44 full papers that we initially considered eligible. Twenty were excluded during this stage. On the other hand, by examining the references of remaining papers, we identified five additional studies to include in our corpus.

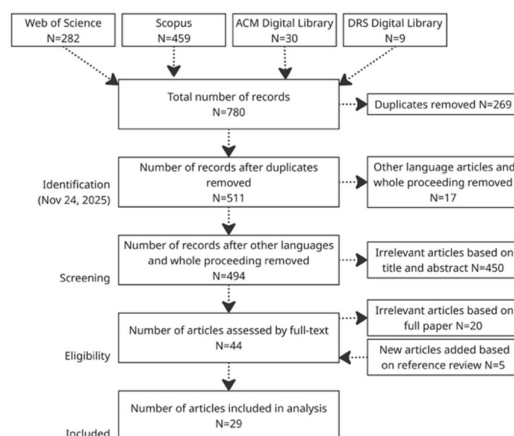


Figure 1. Article selection process flowchart

We conducted a qualitative analysis of the selected papers, complemented by a basic quantitative analysis mostly limited to their bibliographic information (e.g., publication year, number of citations). Coding categories were defined through team discussions based on trends observed in the literature. The resulting codebook consisted of four sections with a total of 24 coding categories: 1) bibliographic data (8 categories), 2) aspects of the MtHD pedagogical approach (9 categories), 3) paper methodology (5 categories), and 4) notes (2 categories). We distributed the papers equally among the authors and open coding was conducted for each category. The lead author then reviewed all coded content, grouped the codes in discussion with the rest of the team. Due to space limitation, we present a portion of the results

below. A complete list of 29 papers (instead of citing all individually, only representative examples are included to illustrate patterns) and the final codebook are available upon request.

3 RESULTS AND DISCUSSION

3.1 Corpus overview

Our corpus includes 29 papers, with conference papers the most common publication type (15 papers, including one poster). The corpus also includes nine journal articles and five book chapters.

The largest number of papers appeared in 2024 (N=10). The earliest paper in our database is by Morrison and Chisin [20] from 2017. This is also the most cited paper in the corpus (41 citations in Google Scholar as of the end of February 2026).

Only five of the articles explicitly define their field as industrial design or report studies involving industrial design students (sometimes with students from other disciplines). The remaining papers either do not specify a particular discipline, or they situate their work within fields such as human–computer interaction, technology studies, speculative design, creative sustainability, sustainable design, interaction design, UX and interface design, and product–service systems.

Five studies report work at the undergraduate level and seven at the graduate level, while four involve a mix of undergraduate and graduate students. The remaining papers either do not specify the educational level or discuss design education more generally.

3.2 Emphasising immersion as a gateway to MthD

Across the corpus, studies primarily address the early phases of design, including *empathise*, *define*, and *ideate*. While some studies extend to the prototyping phase, the nature of this prototyping often differs from prototyping practices typically associated with conventional industrial design.

Across the reviewed papers, immersion-based activities emerge as the dominant entry point to MthD. Many studies operationalise MthD perspectives through exercises targeting the *empathise* phase of design, repositioning students in relation to other species, nonhuman entities, ecosystems, or material systems. In terms of strategy, these approaches rely primarily on perspective-shifting activities such as increased interaction with nature [e.g., 18], multispecies ethnographies [e.g., 27], speculative scenarios [e.g., 16], and material explorations [e.g., 3]. This emphasis is not surprising, as many of the papers in our corpus focus on pedagogical work involving living beings (e.g., animals and plants) and natural phenomena (e.g., the natural world and environmental resources) and require empathy with nonhumans. Most pedagogical implementations introduce MthD through experiential reframing encouraging students to de-centre human perspectives before ideation or prototyping. This immersion is frequently facilitated through activities that prompt students to reconsider relationships among humans, objects, environments, and other living systems. These activities often draw on methods borrowed from other fields or adapt existing design tools for MthD purposes. Examples include Tsing et al.’s [25] “arts of noticing” used to develop a better understanding of “marginalised things” [8]; speculative toolkits such as “Who Lives in the Future” [14], which encourage students to imagine alternative futures involving nonhuman stakeholders; and role playing with specially designed and prototyped probes to experience the world as if from a certain animal [18]. Such activities are typically framed as ways to challenge anthropocentric assumptions and cultivate sensitivity to interdependence and entanglement within design contexts.

At the same time, immersion activities tend to remain concentrated in the exploratory stages of the design process. In many cases, the pedagogical emphasis lies on reframing the problem space rather than advancing toward technically or commercially viable outcomes.

This tendency is also reflected in the types of prototypes reported. 12 of the 29 papers in the corpus report some form of prototyping. However, most of these outputs take the form of speculative narratives, conceptual artifacts, or scenario-based propositions rather than fully developed design solutions. Across cases, prototyping consistently takes the form of discursive outputs, for example, Beach and Fox’s [2] students developed speculative value scenarios and design fiction artifacts (e.g. a digital zine and future-oriented design proposals) exploring human–nonhuman relations under climate change. These outputs function as discursive prototypes rather than technically resolved or industrially feasible solutions. This pattern is further reflected in Bergström et al. [3], wherein they share an exploration in which prototyping centres on hands-on experimentation with renewable gluten plastic, where students generated diverse material samples and exploratory artifacts by allowing the material to guide the creative process. Here, prototyping operates as an empathy-building, arts-based inquiry, foregrounding material agency and

sensory engagement, rather than as the development of functionally specified, production-ready industrial design outcomes.

This pattern also appears in Camozzi et al.'s study [5], where prototypes include storyboards, species cards used for embodied role-play, low-fidelity video prototypes, and artifacts taken outdoors for experimentation. For instance, students created species cards that prompted them to act as kelp, starfish, or other beings to understand ecosystem interdependence, and they developed simple physical prototypes that were tested at the water's edge or in local natural environments. These function primarily as pedagogical and relational tools to cultivate ecological awareness, rather than as technically developed products.

Consequently, the outcomes are often not viable products in the traditional industrial design sense, but conceptual explorations illustrating alternative relationships between humans and nonhuman actors. This pattern is further reflected in the limited coverage of later design stages. Within our corpus, only three studies address the testing phase of design. For instance, in Genç et al.'s study [10], testing involved implementing the card toolkit in a design course with 23 students to assess its ability to stimulate creative engagement with more-than-human perspectives, rather than evaluating the feasibility, durability, or performance of developed prototypes. Similarly, in another work [22], students engaged in iterative prototyping and testing of AI-enabled concepts within a studio course. However, the reported testing concerns how experiential exercises influenced students' design thinking and understanding of AI, as assessed through written reflections and interviews, rather than structured validation of prototype functionality, user experience, durability, or industrial viability. In this sense, testing operates as pedagogical iteration and reflective inquiry rather than as technical, comparative, or performance-based evaluation of design outcomes.

This raises questions about the potential implementation and industrial feasibility of the outcomes presented. Overall, the findings suggest that MtHD in industrial design education is currently operationalised primarily as an epistemic shift rather than as a transformation of the entire design process. Across cases, immersion is effective for reframing but rarely translates into implementation. While immersion effectively destabilises anthropocentric assumptions, its translation into later-stage decision-making, feasibility evaluation, and production considerations remains underdeveloped.

3.3 Reflective focus rather than systematic assessment

A second pattern concerns the methodological traditions underlying MtHD pedagogical research. The majority of the papers are strongly practice-based, reflective, and exploratory in nature. They document studio-based experiments, teaching interventions, workshops, or pedagogical reflections in which educators describe how MtHD perspectives were introduced and interpreted within specific course contexts.

In our corpus, only ten papers report explicit data collection methods, and only seven describe a data analysis strategy. This suggests that knowledge is often generated through situated practice, reflective inquiry, and iterative experimentation. Design projects (i.e., studio assignments or workshops) provide fertile ground for testing new concepts, reframing design problems, and encouraging students to engage with unfamiliar perspectives. As a result, many papers emphasise pedagogical experimentation and conceptual exploration as valuable outcomes in themselves, often presenting experiences as cases without being methodologically grounded in formal case study approaches.

This orientation also reveals a limited level of systematic assessment of educational outcomes. Few studies employ structured evaluation frameworks, and assessment is typically limited to reflective or qualitative feedback rather than comparative or performance-based measures. None of the studies in the corpus report comparative pedagogical research or longitudinal tracking of student learning. Evidence of impact is typically inferred from project descriptions [e.g., 18], instructor reflections [e.g., 2], outcome documentation [e.g., 17], or student feedback [e.g., 9] rather than from formalised assessment strategies or clearly defined learning metrics.

This methodological tendency suggests that MtHD pedagogy is currently in an exploratory stage characterised by strong pedagogical innovation but limited empirical consolidation. The reviewed studies demonstrate considerable interest in integrating more-than-human perspectives into design education, yet they rarely attempt to evaluate the long-term effectiveness, transferability, or scalability of these approaches.

Finally, MtHD pedagogies are rarely discussed at the level of broader curriculum design. Most implementations appear as individual studio projects, workshops, or short-term course modules rather

than as integrated curricular strategies spanning multiple semesters or program structures. This suggests a need for scaffolded integration across courses, where MthD principles are revisited at increasing levels of technical and methodological complexity.

4 CONCLUSION

This study examined how Mth perspectives are currently being introduced and operationalised in industrial design education through a systematic review. The critical review of the corpus indicates a strong reliance on perspective-shifting methods and systems-level analysis as primary means for communicating entanglements and incorporating MthD into design pedagogy. Educators frequently employ observation, role-playing, and speculative exercises to operationalise Mth perspectives within the design process. However, these efforts are largely concentrated in the immersion phases of design and rarely extend to later stages such as prototyping and testing. When combined with the limited use of systematic assessment methods, this raises concerns about the long-term impact and transferability of MthD pedagogies across educational contexts.

These findings highlight the need to extend MthD beyond immersion and conceptual reframing into later design stages. This includes considering how Mth principles might inform later stages of design development, decision-making, and implementation, as well as how they intersect with production constraints, business models, and broader socio-technical systems.

Building on these findings, we outline a preliminary trajectory for integrating MthD across the industrial design process. First immersion-based framing should be translated into design criteria, where nonhuman perspectives inform requirements and decision making. Second, prototyping should extend beyond discursive exploration toward materially and technically situated experimentation, incorporating constraints such as fabrication, lifecycle considerations, and system interactions. Third, testing should include comparative and performance-based evaluation, not only reflective learning outcomes. Finally, these stages should be distributed across curricula rather than being isolated within individual studios. This trajectory does not prescribe specific methods but proposes how MthD can extend beyond early-stage engagement toward implementation within industrial design education.

Future research should build on this trajectory by developing assessment frameworks capable of measuring MthD learning outcomes, conducting longitudinal studies of student development, and examining how Mth perspectives intersect with industrial practice, including questions of feasibility and industry engagement. By synthesising current pedagogical approaches and identifying key gaps, this review argues for a more systematic and transferable development of MthD pedagogies within industrial design education.

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USER-CENTRED DESIGN OF THERAPEUTIC DEVICES FOR MOUNTED EQUINE-ASSISTED THERAPY WITH CHILDREN WITH INTELLECTUAL AND MOTOR DISABILITIES

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ABSTRACT

Equine-assisted therapy (EAT) offers significant physical, cognitive, and emotional benefits for children with intellectual disabilities who also experience motor challenges. However, many therapeutic centres lack specialised devices that enhance intervention quality once the child is mounted on the horse, where posture control, engagement, and coordinated movement become critical. This study reports on a semester-long design project in which product design students developed two therapeutic devices to support mounted activities at FICAE Foundation in Monterrey, Mexico. The investigation followed a user-centred design approach. Students conducted targeted research on intellectual disability and motor impairment, combined with interviews and field observations during EAT sessions. These insights highlighted key therapeutic challenges: maintaining trunk stability, promoting bilateral coordination, and sustaining attention during mounted exercises. Based on this understanding, students generated initial sketches and low-fidelity prototypes, which were iteratively tested and refined through feedback from therapeutic specialists. Through cycles of making, testing, and redesign, both teams progressed toward high-fidelity functional prototypes tailored to the dynamic and safety-critical context of EAT. The resulting devices supported activities aimed at improving balance, posture, motor planning, and engagement, while also reducing therapist workload during mounted exercises. This project demonstrates the potential of integrating real-world therapeutic contexts into product design education, fostering student competencies in participatory design, prototyping, and evidence-based decision-making. It also contributes a replicable approach for designing context-specific therapeutic devices that address the needs of children with intellectual and motor disabilities participating in equine-assisted therapy.

Keywords: Equine-assisted therapy, disability, user-centred design, higher education, educative innovation

1 INTRODUCTION

Equine-assisted therapy (EAT), also referred to as therapeutic horseback riding or hippotherapy, has been recognised as a complementary intervention for children with intellectual disabilities and motor impairments. The three-dimensional and rhythmic movement of the horse resembles human gait, promoting postural adjustments that stimulate trunk control, pelvic mobility, balance, and neuromotor coordination [1], [2].

Trunk control is fundamental for functional motor development, directly influencing upper-limb coordination, head stability, and bilateral motor planning [3]. Previous studies have documented improvements in trunk stability, postural symmetry, and muscle activation after equine-assisted interventions in children with neuromotor disorders [1], [2]. Beyond motor outcomes, EAT has also demonstrated psychosocial and cognitive benefits, particularly in children with autism spectrum disorder (ASD) and intellectual disabilities. Reported outcomes include improvements in social communication, adaptive behaviour, attention, and emotional regulation [4–6]. The sensory inputs generated during mounted activities—particularly vestibular, proprioceptive, and tactile stimulation—may additionally support sensory integration and self-regulation processes [7–9]. However, the effectiveness of such stimulation depends on carefully structured interventions.

Despite the therapeutic benefits of EAT, innovation in this field has primarily focused on mounting systems, saddles, and protective equipment, while comparatively less attention has been given to therapeutic devices used once the child is already mounted. In practice, therapists frequently rely on improvised tools to stimulate reaching, trunk activation, and engagement, but these are rarely developed through systematic ergonomic or user-centred approaches. User-Centred Design (UCD) offers a relevant framework for addressing this gap by emphasising iterative development grounded in stakeholder needs, real contexts, and continuous evaluation [10], [11]. In healthcare and assistive product development, participatory and co-creative approaches have demonstrated improvements in usability, safety, and adoption [12], while inclusive design principles advocate for solutions responsive to functional diversity [13].

Within higher education, embedding authentic healthcare challenges into product design education can strengthen empathy, systems thinking, and socially responsible innovation [14]. Design-Based Research (DBR) and Research-through-Design (RtD) provide complementary methodological approaches for developing and evaluating solutions in real-world contexts while generating transferable design knowledge [15], [16].

In response to the lack of mounted therapeutic devices designed specifically for equine-assisted interventions, this study reports a semester-long user-centred design project conducted in collaboration with FICAE Foundation in Monterrey, Mexico. Product design students developed two mounted therapeutic devices—Towi and Spike—to support trunk stability, bilateral coordination, and cognitive engagement during therapy sessions.

This paper contributes by documenting the integration of UCD, DBR, and RtD methodologies in the development of mounted therapeutic devices for children with intellectual and motor disabilities, while proposing a replicable educational model for socially engaged product design practice.

2 METHODOLOGIES

2.1 Research Design Framework

This study adopted an integrated methodological framework combining Design-Based Research (DBR), User-Centred Design (UCD), and Research-through-Design (RtD). This triangulated approach allowed the project to operate simultaneously as a pedagogical intervention and as applied design research within a real therapeutic context.

Design-Based Research is characterised by iterative cycles of analysis, design, implementation, and refinement conducted in authentic environments [17]. Rather than isolating variables under laboratory conditions, DBR seeks ecological validity while generating transferable design principles [18]. Given that equine-assisted therapy occurs in dynamic, safety-critical conditions, DBR was particularly appropriate for structuring the development of mounted therapeutic devices.

User-Centred Design principles ensured systematic stakeholder involvement throughout the process. According to ISO 9241-210, UCD requires explicit understanding of users, tasks, and environments, iterative prototyping, and evaluation against user requirements [10]. Norman emphasises that usability and contextual fit emerge through continuous feedback and iteration rather than linear development processes [11]. These principles guided all design decisions.

Additionally, the study aligns with Research-through-Design approaches, in which knowledge is generated through the creation and critical reflection on artefacts [16]. In this project, the prototypes (Towi and Spike) functioned as epistemic artefacts that revealed insights about mounted therapeutic interaction, trunk engagement dynamics, and cognitive-motor integration.

2.2 Contextual Inquiry and Stakeholder Engagement

The research began with a contextual inquiry phase conducted at FICAE Foundation. Following participatory design principles [12], therapists were actively involved as expert stakeholders throughout the process. Data collection methods included: (1) non-participant observation of mounted therapy sessions, (2) Semi-structured interviews with therapists [19], (3) Task decomposition analysis of mounted exercises and (4) Documentation of existing improvised therapeutic tools

Observation focused particularly on trunk alignment instability, bilateral reaching limitations, attention fluctuation, and therapist physical workload. These aspects are consistent with the importance of trunk stability in motor development [3] and documented therapeutic goals in hippotherapy research [2]. Children were not directly involved in co-design workshops due to ethical and safety considerations.

However, behavioural responses during sessions informed design refinements indirectly through therapist feedback.

2.3 Problem Framing and Requirement Definition

Field data were synthesised into structured design requirements during a formal problem-framing phase. Following DBR guidelines [17], the initial qualitative findings were translated into operational criteria: (1) Adjustable saddle integration, (2) non-rigid structural surfaces, (3) Lightweight configuration, (4) Quick-release safety mechanisms, (5) Modular adaptability (6) Easy sanitation.

Safety constraints were prioritised due to the unpredictable dynamics of equine movement. As documented in therapeutic riding literature, trunk instability and fatigue can alter postural alignment rapidly [2], requiring devices that support without rigid immobilisation.

2.4 Iterative Prototyping Cycles

The development phase consisted of four iterative cycles structured according to DBR principles [18] (see Table 1), and each cycle incorporated structured feedback loops consistent with iterative UCD practice [10] and co-creation models [12],[20].

Table 1. Cycles of prototyping

Cycle	Description
1 – Concept Exploration	Sketch development and low-fidelity cardboard modelling to explore reach zones and saddle compatibility.
2 – Low-Fidelity Testing	Foam prototypes tested in simulated mounted positions to assess: (1) Balance interference, (2) Ergonomic reach, and (3) Therapist accessibility
3 – Mid-Fidelity Functional Prototypes	Introduction of EVA foams, reinforced textiles, and modular connectors. Therapists evaluated usability and therapeutic applicability during controlled mounted simulations.
4 – High-Fidelity Refinement	Structural optimisation of attachment systems, weight distribution, and edge geometry. Final prototypes were evaluated for: (1) Safety compliance, (2) Installation time, (3) Cleaning feasibility, and (4) Therapeutic task integration

2.5 Evaluation Strategy

The evaluation approach was qualitative but systematically structured. Criteria were organised into five categories as you can see in Table 2:

Table 2. Evaluation Criteria

Category	Evaluation Focus
Safety	Secure fixation, absence of rigid protrusions, rapid detachment
Ergonomics	Reach range compatibility, trunk alignment facilitation
Therapeutic Function	Promotion of bilateral coordination and active postural correction
Usability	Installation time, therapist handling effort
Engagement	Sustained attention and task participation

Although quantitative biomechanical measurements were beyond the scope of this academic studio, therapist assessments provided practice-based validation aligned with rehabilitation research models [3].

2.6 Knowledge Generation Through Design

Consistent with Research-through-Design methodology [16], knowledge emerged through reflective analysis of iterative artefact development. Three preliminary design principles were identified: (1) Controlled instability enhances trunk activation, rather than rigid stabilisation. (2) Modular tactile interaction improves mounted attention span, particularly in children with sensory processing variability. (3) Embedded task-structure reduces therapist improvisational workload, increasing session consistency. These findings contribute initial transferable guidelines for the design of mounted therapeutic devices in equine-assisted contexts.

3 RESULTS

The design process resulted in two fully functional high-fidelity prototypes: Towi and Spike. Although both devices emerged from the same methodological framework, they addressed distinct therapeutic dimensions within mounted equine-assisted therapy: postural-motor stabilisation and cognitive-motor engagement. In Table 3, you can see a comparison between both projects with nine Dimensions.

Table 3. Comparative evaluation of mounted therapeutic devices

Evaluation Dimension	Towi	Spike
Therapeutic Objective	Enhancement of trunk stability and bilateral motor activation	Enhancement of cognitive-motor engagement and attention structuring
Targeted Functional Deficit	Postural instability and limited midline crossing	Attention fluctuation and difficulties in task sequencing
Interaction Mechanism	Controlled lateral instability requiring continuous postural adjustment	Embedded modular tasks combining tactile and visual stimuli
Postural Activation	Direct facilitation of upright alignment and trunk engagement	Indirect activation through task-oriented movement
Bilateral Coordination	Promotes symmetrical reaching and midline crossing	Promotes alternating-hand interaction and motor planning
Attention and Engagement	Moderate increase through motor activation	High increase through structured task sequencing
Therapist Interaction Demand	Reduces need for manual trunk stabilisation	Reduces need for task improvisation and guidance
Adaptability and Modularity	Adjustable level of instability and support	Reconfigurable task modules with progressive complexity
Design Strategy (RtD Insight)	Dynamic stabilisation through controlled instability	Cognitive structuring through embedded task architecture

The comparison presented in Table 3 is structured based on the evaluation criteria defined during the design process (Table 2), expanded to include interaction mechanisms and design insights derived through Research-through-Design. This allows for a systematic comparison of both therapeutic performance and design contribution.

In the case of Towi, although no quantitative biomechanical measurement tools were used, structured therapist feedback identified: (1) Faster task initiation, (2) Improved bilateral coordination during object transfer, and (3) More consistent postural alignment across session duration. Importantly, no interference with reins, therapist positioning, or horse movement was observed.

In the case of Spike, therapists reported that alternating-hand task sequences improved bilateral coordination and motor planning. This supports sensory integration frameworks suggesting that structured proprioceptive and tactile input can reinforce motor planning processes [8], [9]. Importantly, the modular reconfiguration capability allowed progressive task complexity without changing the base device. While both devices improved mounted task structure, their primary contributions differed:

- Towi enhanced postural activation and trunk engagement.
- Spike enhanced attention regulation and cognitive sequencing within motor tasks.

Towi's impact was primarily biomechanical, addressing trunk alignment and midline crossing. Spike's impact was primarily cognitive-sensory, structuring task engagement and attention span. Together, they illustrate complementary design strategies within the same therapeutic ecosystem.

4 DISCUSSION

The results suggest that mounted therapeutic devices developed through an integrated human-centred and design-based framework can enhance equine-assisted therapy without disrupting its underlying biomechanical principles [1], [2].

Towi primarily amplified postural-motor engagement. By introducing controlled instability rather than rigid stabilisation, it promoted active trunk correction, aligning with evidence that trunk improvements in hippotherapy emerge from dynamic neuromotor activation [1], [2]. Given the foundational role of trunk control in coordinated motor function [3], the observed improvements in midline crossing and

bilateral activation indicate that context-sensitive design can extend established therapeutic mechanisms. Spike, in contrast, enhanced cognitive-motor engagement. Increased attention and task consistency align with findings that equine-assisted interventions support behavioural regulation in children with ASD [4–6]. However, this study suggests that embedding task structure directly into the artefact can intensify these effects. The modular tactile configuration reflects sensory integration principles, where structured multisensory input supports motor planning and self-regulation [7–9].

Together, both devices illustrate complementary strategies: biomechanical amplification through controlled instability (Towi) and cognitive structuring through embedded task architecture (Spike). From a design perspective, three implications emerge. First, therapeutic stabilisation should prioritise dynamic engagement over immobilisation. Second, embedding task logic into artefacts enhances repeatability and reduces therapist workload, consistent with user-centred design principles [10], [11]. Third, modularity enables adaptability to functional diversity, aligning with inclusive design approaches [13].

Methodologically, the integration of Design-Based Research and User-Centred Design enabled iterative refinement within a real therapeutic context, ensuring ecological validity [17], [18] and stakeholder alignment [12]. Through Research-through-Design, the prototypes functioned as knowledge-generating artefacts, extending their contribution beyond functional performance [16].

Overall, this study positions product design as an active mediator within therapeutic ecosystems. By integrating biomechanical and cognitive dimensions into mounted artefacts, design can amplify both motor and engagement outcomes in equine-assisted therapy.

5 CONCLUSIONS

This study explored the development of mounted therapeutic devices within equine-assisted therapy through an integrated framework combining Human-Centred Design, Design-Based Research, and Research-through-Design. Conducted in collaboration with a therapeutic foundation, the project resulted in two functional prototypes—Towi and Spike—addressing complementary therapeutic dimensions: trunk stability and cognitive-motor engagement.

The findings suggest that product design can meaningfully enhance therapeutic interaction without altering the fundamental biomechanical principles of equine-assisted therapy documented in prior research [1], [2]. Towi demonstrated that controlled instability can promote active trunk engagement rather than passive stabilisation, reinforcing the foundational role of postural control in coordinated motor performance [3]. Spike illustrated that embedding structured cognitive tasks into mounted artefacts can increase sustained attention and sequencing consistency, aligning with documented regulatory benefits of equine-assisted interventions in children with ASD [4–6].

Beyond device-specific outcomes, the study contributes three broader insights. First, therapeutic stabilisation strategies should prioritise dynamic activation over rigid immobilisation. Second, embedding task architecture directly into physical artefacts enhances repeatability and reduces therapist workload. Third, modular and adaptable systems are essential in addressing functional diversity in disability contexts.

Methodologically, the integration of Design-Based Research [17], [18] with User-Centred Design principles [10], [11] proved effective in maintaining ecological validity while generating transferable design knowledge. Through Research-through-Design [16], the prototypes functioned not only as solutions but as epistemic artefacts, revealing design principles applicable to broader therapeutic product development. Educationally, the project demonstrates the value of embedding authentic healthcare challenges within product design curricula. Students engaged with real safety constraints, interdisciplinary collaboration, and iterative refinement cycles, fostering socially responsible innovation grounded in contextual understanding.

While further quantitative validation is required to measure long-term clinical impact, the study positions design as an active mediator within therapeutic ecosystems. Mounted therapeutic devices, when developed through rigorous user-centred and iterative methodologies, can act as amplifiers of both motor and cognitive engagement in equine-assisted therapy.

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MAPPING REGENERATION: SYSTEMIC THINKING AND DIVERSITY IN DESIGN EDUCATION THROUGH GIGAMAPS IN MEXICO'S SIERRA GORDA

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ABSTRACT

This paper examines how Gigamapping can support systemic and regenerative thinking in design education through a place-based pedagogical experience developed in the School of Architecture and Design. The study was conducted within a sixth-semester Regenerative Design concentration in collaboration with rural communities in Mexico's Sierra Gorda. Students engaged in ethnographic observation, participatory process, and iterative analogue and digital Gigamapping to explore socio-ecological relationships across multiple scales.

The pedagogical framework combined principles of regenerative design, System-Oriented Design (SOD), and systemic visualisation methods to support students in moving beyond isolated problem-solving toward interconnected socio-ecological and cultural understanding of the place. In this study, Gigamapping is understood as a systemic visualisation practice that enables participants to externalise, connect, and iteratively reframe complex relationships among human and non-human actors.

Data were collected from two student cohorts through pre-post surveys on regenerative awareness and a post-course Systemic-Regenerative Learning Scale assessing five dimensions: system boundary expansion, relational complexity, epistemic diversity recognition, reflexivity, and leverage point identification. Survey findings were triangulated with comparative analysis of analogue and digital Gigamaps.

Results show that Gigamapping fostered more relational and systemic ways of thinking. It also served as an integrative tool for systemic reflection and interpretation in place-based regenerative learning. In this article, "regeneration mapping" describes the use of Gigamapping to visualise regenerative socio-ecological and cultural dynamics.

Keywords: Professional education, educational innovation, systemic design, regenerative design education, diversity, Gigamaps, co-creation, ethnography, design pedagogy

1 INTRODUCTION

Humanity is currently facing an escalating socio-ecological crisis in which human activities are destabilising the environmental systems that sustain life. Recent assessments indicate that six of the nine planetary boundaries have already been transgressed, revealing the limitations of development models centred on extraction and short-term growth [2]. Within this context, regenerative perspectives have emerged as alternatives that seek not only to reduce harm, but also to restore and strengthen socio-ecological systems over time [2][3][4].

Regenerative design proposes that human systems should co-evolve with natural systems through long-term relational approaches. Beyond sustainability understood as impact reduction, regenerative design seeks to restore and strengthen ecological, cultural, and territorial relationships over time [2][3][4]. Recent research highlights the importance of systems thinking, transdisciplinary collaboration, and situated learning in addressing complex socio-ecological transitions [1][3][9][10].

Systemic design offers methodological approaches for engaging such complexity by integrating systems thinking with design practice [5]. Within this field, System-Oriented Design (SOD) emphasises relational analysis, systemic and relational visualisation, and iterative reframing processes to support intervention within complex socio-ecological systems [6].

A central method within SOD is Gigamapping. In this study, Gigamapping is understood as a systemic visualisation practice used to externalise and explore relationships among actors, infrastructures,

ecological processes, and institutional dynamics [6][7]. Unlike conventional mapping approaches focused on static representation, Gigamapping enables the visualisation of multi-scalar interdependencies, feedback loops, and non-linear relationships while integrating diverse forms of knowledge within a shared visual environment.

This relational perspective becomes particularly relevant in place-based learning contexts characterised by ecological, cultural, and epistemic diversity. Complexity emerges not only from the number of interacting variables, but also from the coexistence of multiple ways of understanding territory and sustainability [1]. Design education therefore plays a critical role in preparing future practitioners to engage regenerative transitions through more reflexive and systemic forms of learning.

This paper investigates how Gigamapping can support systemic and regenerative learning within a place-based educational context developed in collaboration with rural communities in Mexico's Sierra Gorda. Through ethnographic fieldwork, participatory engagement, and iterative analogue and digital Gigamapping, students explored socio-ecological relationships across different territorial scales.

More specifically, the study examines the extent to which Gigamapping contributed to the development of regenerative learning skills, including expanding the boundaries of the system, recognising relational complexity, integrating epistemic diversity, developing reflective awareness, and identifying points of influence for regenerative intervention.

2 METHODOLOGIES

2.1 Research Design

This study adopted a practice-based pedagogical research approach combining educational intervention with reflective evaluation of learning outcomes. The objective was to examine how Gigamapping, integrated within a place-based regenerative design course, supported students in developing systemic and regenerative ways of understanding territory. Figure 1 shows the Methodological framework used for this study.

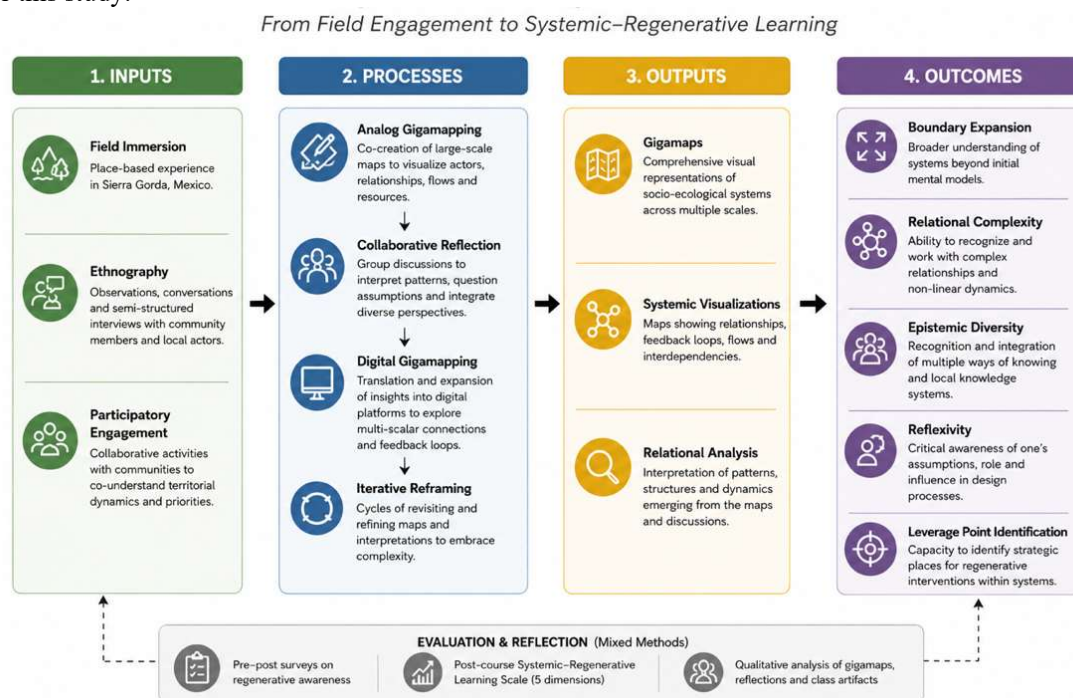


Figure 1. Methodological Framework

The study was conducted across two iterations of a sixth-semester Regenerative Design Concentration at the School of Architecture and Design, of Tecnológico de Monterrey, campus Querétaro, for 5 months. Both cohorts (2024: 9 students; 2025: 14 students) collaborated with 2 rural communities in Mexico's Sierra Gorda (Ejido La Barranca and San Gaspar) through field immersion activities involving ethnographic observation, participatory engagement, and systemic visualisation. The pedagogical framework integrated three complementary dimensions (Figure 2):

1. Regenerative Design Principles [3][4]
2. System-Oriented Design approaches to complexity [6]
3. Gigamapping as a systemic visualisation and reflexive learning practice [5][6]

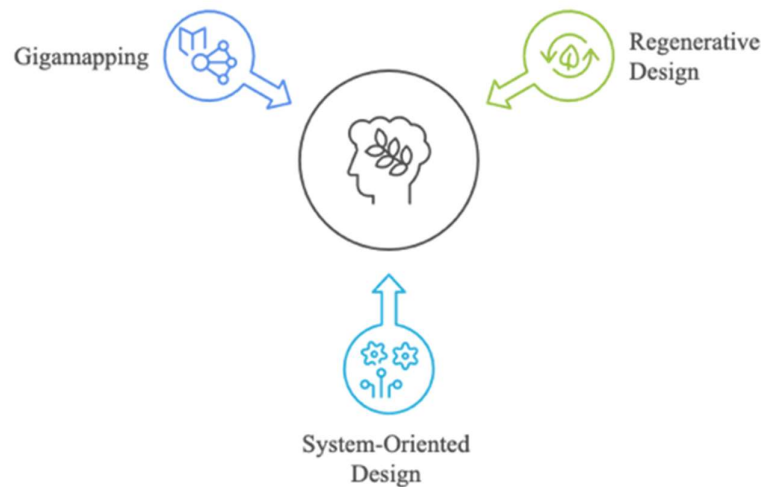


Figure 2. Pedagogical framework integrating Regenerative Design, System-Oriented Design, and Gigamapping within a place-based learning process

2.2 Pedagogical Process and Gigamapping

The pedagogical process was structured as practice-based pedagogical action research in which students progressively expanded their understanding of territory through observation, participation, and systemic visualisation. Rather than treating mapping as a final representational output, the course positioned Gigamapping as an iterative process for organising complexity, questioning assumptions, and identifying relationships across scales, as shown in Table 1.

Table 1. Comparison between Mapping and Gigamapping

TRADITIONAL MAPPING	GIGAMAPPING
Static representation	Dynamic system
Single scale	Multi-scale
Human Actors	Human + Non-human Actors
Linear	Non-linear / loops

Fieldwork was conducted in collaboration with rural communities in Mexico's Sierra Gorda. Students engaged in ethnographic observation, informal conversations, participatory activities, and territorial documentation to identify ecological, social, institutional, and cultural dynamics embedded in the local context, as regenerative understanding of place.

Gigamapping was implemented in two sequential phases (Figure 3). During field immersion, students collaboratively developed large-format analogue maps to externalise observations, actors, and emerging relationships. These maps were later translated into digital Gigamaps using the Kumu platform, enabling greater relational density, feedback visualisation, and multi-scalar analysis across micro, meso, macro, and bio-regional levels [7]. The transition from analogue to digital mapping functioned as a reflexive reframing process through which students reconsidered system boundaries and identified leverage points for regenerative intervention.

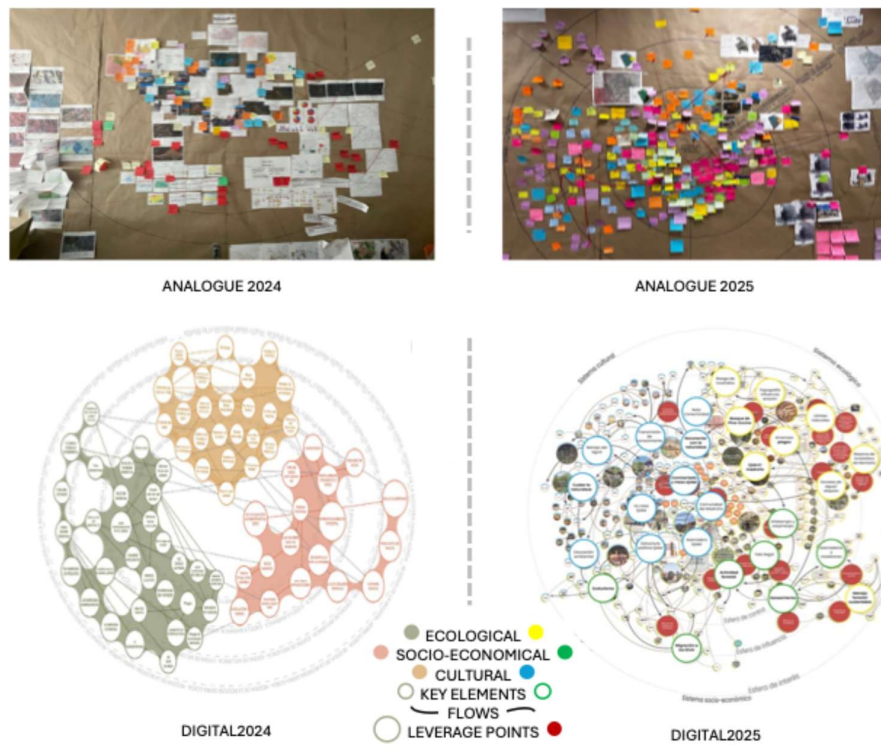


Figure 3. Evolution from analogue to digital Gigamaps across the 2024 and 2025 cohorts

2.3 Instruments and Data Analysis

Two complementary instruments were used to assess learning outcomes. First, students completed pre-post surveys measuring perceived knowledge of regenerative design principles and the perceived importance of integrating regenerative design into professional formation. Second, a post-course Systemic-Regenerative Learning Scale assessed five dimensions: system boundary expansion, relational complexity, epistemic diversity recognition, reflexivity, and leverage point identification. Survey data were analysed descriptively due to the small cohort sizes. Findings were triangulated with comparative analysis of analogue and digital Gigamaps to identify recurring learning patterns across both course iterations.

The study is exploratory in nature and relies primarily on self-reported data. However, consistency across two consecutive cohorts and convergence between survey responses and visual artifacts provide preliminary evidence supporting the pedagogical value of Gigamapping within systemic-regenerative learning contexts.

3 RESULTS AND LEARNING PATTERNS

Findings integrate three sources of evidence across two consecutive iterations of the Regenerative Design concentration (FJ2024 and FJ2025): (1) evolution of analogue and digital Gigamaps, (2) pre-post responses to Questions 18 and 19 on regenerative awareness, and (3) a post-course Systemic Learning Scale assessing perceived development of systemic thinking capacities.

Across both cohorts, students progressively shifted from localised and linear interpretations of territory toward broader systemic understandings. Initial analogue maps focused primarily on visible local challenges and immediate actors, whereas digital Gigamaps incorporated ecological systems, institutional dynamics, feedback relationships, and non-human actors, revealing greater relational complexity and multi-scalar awareness.

The transition from analogue to digital mapping also supported reflexive reframing processes. Students reconsidered initial assumptions, reorganised categories, and increasingly integrated local knowledge, ecological processes, and community perspectives into their interpretations of territory. Survey responses reinforced these patterns, indicating stronger awareness of interdependence, epistemic diversity, and reflexive thinking following the Gigamapping process (Figure 4).

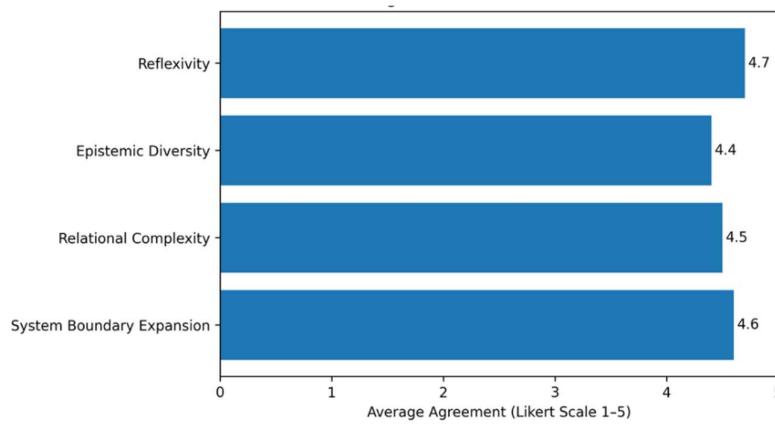


Figure 4. Comparative synthesis of students' perceived development across four systemic-regenerative learning dimensions following the Gigamapping process

Survey data additionally indicated increased perceived knowledge of regenerative design principles across both cohorts, while the perceived importance of regenerative design remained consistently high before and after the course (Figure 5). These findings suggest that the pedagogical process contributed primarily to expanding students' systemic-regenerative understanding rather than altering their initial valuation of sustainability-related issues.

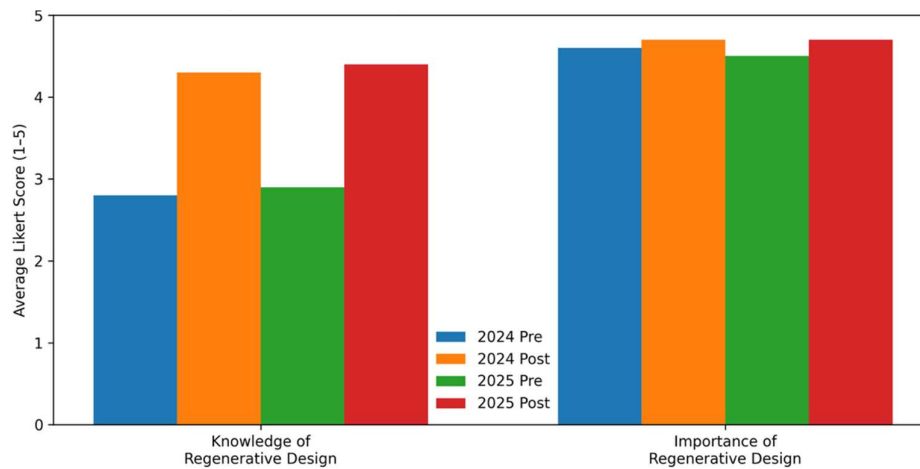


Figure 5. Pre-Post comparison of students' perceived knowledge and perceived importance of regenerative design across the 2024 and 2025 cohorts

Overall, findings across surveys and visual mapping artifacts suggest that Gigamapping functioned as a reflexive and integrative mechanism supporting systemic interpretation, relational synthesis, and regenerative awareness within place-based design education contexts.

4 DISCUSSION AND CONCLUSIONS

The findings suggest that systemic and regenerative learning emerged through the interaction of multiple pedagogical components, including field immersion, participatory engagement, ethnographic observation, and iterative reflection. Therefore, the study does not claim that Gigamapping alone produced the observed learning outcomes. Rather, the mapping process functioned within a broader place-based pedagogical ecology that supported students in interpreting territorial complexity through relational and systemic perspectives.

However, evidence across both cohorts indicates that Gigamapping functioned as a central integrative mechanism within the broader pedagogical process. The maps enabled students to externalise observations, visualise relationships across scales, compare perspectives, and iteratively reframe their understanding of territory. The progression from analogue to digital Gigamaps revealed increasing

relational density, incorporation of non-human actors, and greater recognition of ecological, institutional, and cultural interdependencies.

The study also highlights the importance of epistemic diversity within systemic design education. Students progressively integrated local knowledge, ecological processes, and community perspectives into their interpretations of territory, reinforcing the value of place-based learning in regenerative education contexts.

Although developed within a specific territorial context, the pedagogical approach presented in this study can be applied to other contexts through immersion in place, collaborative visualisation, iterative reframing, multiscale analysis, and epistemic plurality, generating more reflective and relational forms of learning that can help students address socio-ecological complexity.

Even though exploratory and limited in scale, self-reporting bias, lack of a control group, and difficulty in isolating the effects of Gigamapping, the recurrence of similar patterns across two consecutive cohorts suggests that Gigamapping may support the development of systemic literacy and regenerative agency in future designers.

By integrating regenerative design, System-Oriented Design, and place-based learning through systemic visualisation practices, this paper contributes a transferable pedagogical model for systemic-regenerative learning in higher education design contexts.

5 FUTURE WORK

Future research could expand this study across institutions, disciplinary contexts, and territorial settings to evaluate the transferability of the pedagogical model, further examine the specific contribution of Gigamapping within place-based learning approaches, and develop validated instruments for assessing reflexivity and systemic reasoning in design education.

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UNIVERSAL DESIGN – EVOLUTION OR REVOLUTION? AN INTERROGATION OF UNIVERSAL DESIGN AS A CATALYST FOR EQUITY, DIVERSITY AND INCLUSION THROUGH THE LENS OF PRODUCT DESIGN THEORY, PHILOSOPHY AND PRACTICE

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ABSTRACT

This paper interrogates Universal Design (UD) as a theoretical and philosophical framework to encourage diversity and inclusion within Product Design. Moving beyond its origins as a response to accessibility, UD is contextualised here as a critical design positionality that challenges assumptions about users and abilities. Through an examination of Product Design theory, this study explores how it disrupts the notion of an 'ideal' or 'average' user by advocating for a more diverse understanding of the human experience. Drawing on phenomenology, design ethics and critical disability studies, the paper situates UD as a vehicle for reimagining design not merely as a means of producing artefacts, but as a practice of social engagement and ethical responsibility. By exploring diversity as an intrinsic and intuitive design value, it aligns with a contemporary, participatory and socially sustainable design approach. The paper further critiques the limitations of purely functionalist interpretations of UD, proposing instead a philosophical synthesis that embraces ambiguity, cultural diversity, resilience and the fluidity of human needs. Ultimately, the authors argue that UD extends Product Design beyond form or function and reframes design as a moral and epistemological act that transforms both the discourse and the practice of Product Design toward diversity, equity, empathy and shared human dignity. The paper is further supported by student reflections from the Design Theory and Universal Design discourse on the BSc in Product Design in Technological University Dublin (TU Dublin).

1 INTRODUCTION

Universal Design has traditionally been framed as a methodology for accessibility. Originating within late twentieth-century architectural discourse, it proposed that environments should be usable by the widest possible range of people without adaptation. However, within contemporary Product Design theory, UD increasingly operates not merely as a technical strategy but as a philosophical orientation. It challenges assumptions about who design is for, how users are conceptualised and how ability is normalised.

This paper interrogates whether Universal Design represents an evolutionary development within Product Design practice or a revolutionary epistemological shift. It argues that while UD may appear methodologically evolutionary, extending user-centred and inclusive approaches, it constitutes a deeper reorientation of Product Design as an ethical and socially situated practice. Drawing on disability studies, phenomenology, feminist epistemology and participatory design theory, the paper positions UD as a framework that recognises diversity as intrinsic to human experience rather than exceptional deviation from a norm.

2 FROM ACCESSIBILITY TO UNIVERSAL DESIGN

Universal Design is most closely associated with the work of Ronald L. Mace, who defined it as the design of products and environments usable “by all people, to the greatest extent possible, without the need for adaptation or specialised design” [1]. The Center for UD formalised this through the Seven Principles of UD in 1997 [2].

Emerging from the disability rights movement and legislative frameworks such as the Americans with Disabilities Act, early accessibility strategies were frequently compliance driven. As Steinfeld and Maisel argue, Universal Design marked a shift from reactive adaptation toward anticipatory inclusion [3]. Rather than adding assistive features retrospectively, UD proposed embedding inclusivity at the conceptual stage. However, critiques have emerged. Imrie questions whether UD's universalist ambitions risk masking socio-cultural specificity [4]. Hamraie further demonstrates that accessibility discourse historically codified certain bodies as normative while positioning others as deviations [5]. These critiques suggest that UD's transformative potential lies not in its principles alone, but in its challenge to assumptions about ability and normality.

Within Product Design, this transition signals a move away from designing for statistical averages toward acknowledging embodied diversity as fundamental.

3 PRODUCT DESIGN AND THE CONSTRUCTION OF THE AVERAGE USER

Industrial Product Design developed alongside modernist commitments to standardisation, optimisation and efficiency. As Forty demonstrates, design historically constructed consumer identities aligned with industrial rationality [6]. Ergonomics and anthropometrics reinforced the notion of an average body. Norman's influential usability framework retained this orientation, albeit with greater emphasis on cognitive and behavioural compatibility [7]. Yet, as Akrich observes, designers inscribe scripts into artefacts that configure expected users and behaviours [8]. The user is not discovered but constructed. Universal Design de-stabilises this construction. Rosemarie Garland-Thomson introduces the concept of 'misfit' to describe how disability emerges relationally between bodies and environments [9]. This reframes exclusion as a design failure rather than bodily deficiency. Krippendorff's 'semantic turn' in Design Theory further supports this repositioning by emphasising meaning-making over functional determinism [10]. UD extends this insight by foregrounding plural embodiment as a primary design condition. Diversity is not a market segment; it is an ontological constant. In this context, UD represents a disruption of the epistemic authority of the average.

4 PHENOMENOLOGY AND EMBODIED EXPERIENCE

The philosophical depth of Universal Design becomes apparent through phenomenology. Maurice Merleau-Ponty argues that perception is embodied and relational [11]. We engage the world through situated bodily experience; therefore, products mediate lived reality. Ihde's post phenomenology demonstrates how technologies shape and transform human-world relations [12]. A poorly designed artefact can restrict agency; San inclusive one can expand it. UD therefore becomes a commitment to supporting multiple modes of embodiment.

The social model of disability, articulated by Oliver, further shifts focus from impairment to environmental barriers [13]. Design is therefore implicated in the production of disability. Feminist ethics and epistemology deepen this analysis. Gilligan's ethics of care foregrounds relational responsibility [14], while Haraway critiques claims of neutral objectivity and advocates for situated knowledges [15]. In design, this translates to acknowledging that all artefacts embody values and perspectives.

Through these theoretical lenses, Universal Design becomes not merely a technical method but a philosophical orientation toward plural lived experiences.

5 UNIVERSAL DESIGN AS ETHICAL REORIENTATION

If design mediates experience, it is inherently ethical. Victor Papanek famously argued that designers bear responsibility for social and environmental consequences [16]. Universal Design extends this responsibility toward embodied diversity. Design Justice frameworks, such as those articulated by Costanza-Chock, advocate participatory processes that centre marginalised communities [17]. While distinct from UD, they share its commitment to redistributing design power. UD therefore operates as an epistemological shift. It challenges the neutral product and reframes Product Design as moral practice. Inclusion becomes intrinsic rather than supplementary. At this level, UD appears revolutionary.

6 PARTICIPATION, SOCIAL SUSTAINABILITY AND PRACTICE

Universal Design aligns with participatory and co-design methodologies. Sanders and Stappers describe co-creation as expanding creativity across stakeholders [18]. Björgvinsson et al. link participatory

design to democratic innovation processes [19]. Such approaches acknowledge the limits of designer foresight. Engaging diverse communities reveals experiential knowledge otherwise excluded. Social sustainability further intersects with UD. Manzini envisions design as enabling resilient, adaptive communities [20]. Products inspired by disability-led innovation, such as inclusive kitchen tools, demonstrate how designing for specific needs often benefits broader populations. However, tensions remain. Designing for everyone risks oversimplification. The challenge lies in embracing adaptability rather than static universality.

7 CRITIQUES AND LIMITATIONS

Universal Design is not without limitations. Hamraie cautions that universality may conceal Western assumptions about independence and productivity [5]. Cultural context shapes conceptions of ability. Market appropriation presents further risk. Inclusion rhetoric may become branding strategy rather than structural change. Additionally, critics argue that universal strategies must coexist with targeted interventions. Identity-specific design remains necessary where structural inequities persist. These critiques suggest that UD requires philosophical refinement. Rather than uniform solutions, it must embrace plurality, ambiguity and contextual sensitivity.

8 CASE STUDY

Through both complementary theoretical and project-based lenses, the third-year Design Theory module on the BSc Product Design at TU Dublin explicitly thematises Universal Design and Equity, Diversity and Inclusion (EDI). The module encourages students to not just critically challenge UD and EDI as discrete or isolated considerations but as fundamental part of a holistically considered design practice that recognises these frameworks as integral to meaningful and responsible Product Design.

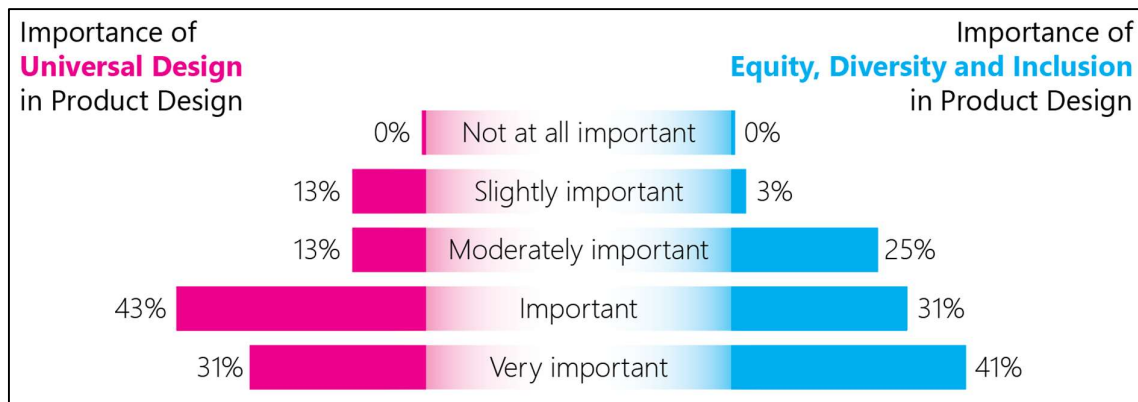


Figure 1. Quantitative results from surveying 39 third year students

39 students were tasked to reflect about UD and EDI after participating in the module. The quantitative results from the survey are displayed above in the info graphic in Figure 1, which clearly displays a strong overall recognition of the importance of both, UD and EDI. The following student reflections offer more detailed insight into how the dual theoretical–practical learning approach influenced their perceptions of inclusive design.

When asked about how Universal Design as well as Equity, Diversity and Inclusion integrated into your overall product design education, the findings indicate that UD and EDI are widely perceived as embedded within the product design programme at TU Dublin, particularly in later years, though inconsistently across modules. Many students described it as “very well integrated,” “very ingrained into the course,” and “core to design,” with several noting that “each product/assignment has always tried to reach multiple users.” Third year emerged as a pivotal stage, where UD and EDI became “everywhere” and “really clear,” particularly through the Design Theory module, which offered “interesting projects to explore it.” However, earlier years were only “touched on,” “less so,” or “not integrated enough overall.” Some students felt the content was concentrated in one area, stating, “they are only well integrated in the Design Theory module” and “it’s in one module.” Overall, while endorsement is strong, students recommend earlier and more consistent integration across all years.

When asked about the Design Theory module specifically, UD and EDI are seen as strongly embedded and influential. Students described the module as “accurate and well-integrated” and credited it with helping them “think differently” and better communicate inclusive principles. The emphasis on designing “not...for disabled people but rather...for everyone” was particularly impactful. Nonetheless, respondents called for refinements in pacing and clarity, suggesting it “could have been executed at a faster pace” and that clearer distinctions are needed between “universal versus inclusive versus adaptable design,” as “the line between these areas are blurry.” Gaps were also identified in cultural representation and exposure to examples “where design isn’t inclusive.”

Students overwhelmingly associate Universal Design with inclusivity, accessibility and “good design.” It is described as “designing for everyone” and ensuring that “no matter conditions,” users can engage equally. Many consider UD “synonymous with good design” and “what product design really should be.” Empathy is central, with students highlighting “designing with empathy and awareness of diversity” and “not just designing for people exactly like yourself.” Usability and simplicity were recurring themes, with value placed on products that are “easily understandable/intuitive” and that “avoid unnecessary complexity.” UD is also seen as socially impactful, helping to “bridge the gap of those who feel more vulnerable in society.”

Similarly, EDI is viewed as a core ethical responsibility. Students described it as “very important to me as a designer” and “an ethical principle that should be in every designer’s mind,” arguing that exclusion is “morally wrong.” EDI was closely linked to fairness and non-judgement, with emphasis on creating designs that “don’t discriminate,” “don’t make anyone feel inferior/vulnerable,” and ensure “no one would ever want to feel left out.” Awareness of social diversity, “a mix of cultures, beliefs, ethnicities,” was considered essential, alongside empathy and representation, including “acknowledging diverse users... and giving them a voice.” While some noted tensions, such as potential impacts on aesthetics or the reality that “you can’t do it all,” overall commitment remained strong.

When students were asked about how Universal Design influences their identity as product designers, it was clear that they saw it as significantly shaping their professional identity. It fosters an “open minded” and reflective approach, encouraging them to “include everyone and everything in the design choices you make.” Students connect UD and EDI to equality, asserting that “everyone deserves to...live equally with no bias” and that “no design or product should be only accessible to a certain group.” These principles guide decision-making and reinforce their identity as ethical, inclusive and socially responsible product designers committed to creating accessible and impactful solutions.

In summary, this case study illustrates how embedding Universal Design within design education can meaningfully shift students’ perceptions of responsibility, identity and practice. Exposure to UD and EDI as interconnected philosophical commitments rather than optional technical add-ons, encouraged students to critically examine their own assumptions, broaden their understanding of users and recognise inclusion as a foundational design value. While students highlighted inconsistencies across the curriculum, they also demonstrated growing reflexivity, empathy and ethical awareness when UD was explicitly thematised. The findings suggest that early, continuous and integrated engagement with UD strengthens students’ capacity to navigate complexity, embrace diversity and design with social responsibility. Ultimately, the case study confirms that teaching UD as a core design ethos provides the potential to facilitate more thoughtful, inclusive and socially attuned designers.

9 CONCLUSIONS

Universal Design can be understood as both evolution and revolution within Product Design. On the surface UD appears evolutionary in method, as it builds on what designers already do - human-centred design, ergonomics and participatory practice. Yet the arguments advanced in this paper; supported by phenomenology, critical disability studies, critical epistemology and student reflections from TU Dublin, indicate a deeper shift. UD rejects the myth of an ‘average user,’ treats disability as something that arises in the interaction between people and products and frames design as an ethical mediation of serving plural lifeworld’s. In this respect, UD is revolutionary: inclusion is not a mere optimisation task at the end of a design process, it’s a core criterion of validity starting at problem framing, evidence gathering, meaning-making and evaluating.

The case study demonstrates that when UD is taught as a philosophical positionality, it has the potential to reshape professional identity. Students reported becoming more reflexive about bias, more explicit in stakeholder mapping and more comfortable with aesthetic pluralism as well as contextual ambiguity. They also recognised the practical tensions where universality cannot be absolute. Trade-offs are real;

and targeted solutions will still be required where structural inequities persist. This pragmatic stance does not dilute UD's ambition; it clarifies where universality ends and adaptability begins, encouraging designers to build for change, contingency and difference over time.

Three implications follow. For pedagogy, UD should be threaded longitudinally into the whole curriculum, across studio work, project briefs and assessments. Students should learn how universal, inclusive and adaptable design relate to each other but are not the same. For professional practice, UD calls for participatory governance of design decisions, treating 'edge case' testing as a standard part of prototyping and transparent documentation where equity compromises occur. For policy, procurement rules and standards should reward design processes that evidence inclusion from the very beginning, not just products that meet minimum accessibility compliance at the end.

Ultimately, UD is best understood as a moral and epistemological commitment that expands what counts as good design: not only artefacts that function and delight, but systems that recognise, respect and redistribute the conditions of participation. If the aim of Design Theory is to make explicit the values already shaping practice, then the most successful outcome of this discourse would be to render separate references to 'UD' and 'EDI' unnecessary because design, done well, is already universal.

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PROFESSIONAL PRACTICE – REFLEXIVITY AND EDI

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ABSTRACT

This paper critically examines identity construction in design education through the Professional Practice module on the BSc Product Design at Technological University Dublin (TU Dublin), situating it within contemporary debates on Equity, Diversity and Inclusion (EDI). The module foregrounds transformative and reflective practice facilitated through transdisciplinary discourse. It positions professional identity as a fluid, negotiated and contextually situated construct informed by socialisation, ethical reflection and worldview formation. From this perspective, professional identity formation reveals how dominant disciplinary narratives can marginalise alternative epistemologies and lived experiences. By emphasising reflective and student-centred pedagogies, the module cultivates reflexivity as a core element of professional development, enabling students to interrogate the diverse values, voices and needs that inform design practice. Through structured critical dialogue, conventional hierarchies are challenged, advancing a pluralistic model of design professionalism that embraces EDI as integral to creative and ethical practice. The paper argues that this Professional Practice module offers a framework for reimagining professional identity as inclusive, dynamic and ethically grounded. It reconceives design education not merely as accommodating diversity, but as embedding equity and inclusion within the epistemological and moral fabric of students' future professional selves.

Keywords: Professional identity, design theory, design education, reflexivity, diversity, equity and inclusion

1 INTRODUCTION

Across Engineering and Product Design education, the development of professional identity is increasingly linked to wider debates about Equity, Diversity and Inclusion. While design programmes have traditionally prioritised technical competence and creativity, scholars emphasise that designers' worldviews, values and social positions shape the ways they frame problems, recognise stakeholders and evaluate possible solutions [1–3]. Professional identity is not a fixed or neutral construct but emerges through participation in educational practices, institutional cultures, social discourses and critical reflection [4,5]. Consequently, design education is not only about skills and techniques; it is also a socialising force that orients students toward particular norms, paradigms and ethical positions [6,7].

The subject of this research is the student reflections on debates around the topic of EDI that are part of the Professional Practice module delivered in the final semester of their four-year BSc Product Design at TU Dublin. At this point in the programme the students have embedded both breadth and depth into their knowledge of design-based discourse. It should be noted that all these students have engaged in modules covering Universal Design in earlier years and therefore have both insight and vocabulary around the subject. This paper draws on the reflections of the thirty-two students who engaged in the discussions on EDI and is part of a much broader five-year longitudinal study of identity formation through debate and reflective practice.

This case study of classroom discussion reveals both scepticism and endorsement of EDI, generating productive tensions that contribute to students' professional identity formation.

Three key arguments structure this paper. First, reflexivity as a sustained critical awareness of self, context and power helps support students in reframing EDI as an epistemic lens that shapes design processes. Second, the designer's role can be understood as that of a translator and mediator, whose work benefits from diverse voices and perspectives. Third, embedding EDI within learning environments facilitates a pluralistic conception of design professionalism that positions inclusion as an ethical and creative imperative. The paper contributes to pedagogical literature by linking professional

identity formation to EDI-oriented reflexivity and by offering practical implications for educators seeking to embed inclusion within professional practice curricula.

2 BACKGROUND AND LITERATURE

2.1 Professional Identity in Design Education

Professional identity describes how individuals see themselves in relation to their profession, encompassing skills, values, ethical commitments and ways of belonging [4]. In design education, identity emerges through rituals of critique, iterative project work, collaboration and immersion in studio culture [2]. Learning is situated and relational: designers develop their identity through interactions with peers, tutors, clients and communities, all which shape what they come to view as legitimate knowledge or good practice [7,8].

Schön's concept of the reflective practitioner [1] is foundational here, emphasising reflection-in-action and reflection-on-action as mechanisms through which professionals navigate ambiguous problems. At the same time, dominant disciplinary norms such as commitments to universality, objectivity or minimalist aesthetics, can limit the visibility of alternative knowledge systems, especially when homogeneity in academic settings reinforces narrow standards of legitimacy [6,3]. Recognising professional identity as fluid and negotiated, highlights the importance of reflexive pedagogies that engage students with ethics, inclusion and socio-cultural complexity.

2.2 Reflexivity and Critical Pedagogy

Reflexivity involves situating oneself within broader social structures and questioning how positionality shapes perception and decision-making [9,10]. It requires students not only to reflect on their actions but also to interrogate assumptions, power relations and the interests served by particular design approaches. Freire's critical pedagogy [11] underscores the role of dialogue and co-constructed knowledge in developing critical consciousness. This perspective is echoed in contemporary design education approaches that emphasise iterative critique, peer learning and cross-disciplinary engagement [12,13].

Reflexive practice strengthens technical knowledge by situating it within complex ethical and social contexts. It enables students to recognise how biases, disciplinary assumptions and institutional norms shape what designers notice or ignore. In this way, reflexivity is foundational to inclusive design practice.

2.3 EDI as an Epistemic and Methodological Orientation

Although EDI is often framed in organisations as a recruitment or hiring concern, design research shows that inclusion directly affects innovation by influencing problem framing and decision-making [3,14]. Human-centred and co-design methods promote participatory engagement and contextual sensitivity [15,16], while design justice frameworks explicitly foreground power redistribution and community leadership [3]. Inclusive and Universal Design approaches extend considerations of human variation and environmental fit [17,18]. EDI therefore functions as both a design constraint and a creative driver. It constrains by requiring attention to people who have historically been marginalised and also drives innovation by revealing latent needs and broadening the scope of possible solutions [19]. From this viewpoint, EDI becomes part of design epistemology itself.

2.4 Meritocracy, Equity and Structural Inequality

Debates about quotas and meritocracy often assume that selection environments are neutral. Research demonstrates that systemic inequalities which range from educational access to networking opportunities can distort perceptions of merit [20]. Studies across sectors reveal persistent implicit and explicit biases in hiring [21,22], challenging claims that current practices reliably identify the most capable candidates. EDI initiatives seek not to lower standards but to counterbalance accumulated disadvantages and broaden pathways to excellence.

Design classrooms provide important spaces to critically engage these tensions. Grappling with competing values such as individual fairness versus systemic fairness enables students to develop ethical reasoning skills central to professional identity formation [5].

3 PEDAGOGICAL APPROACHES: PROFESSIONAL PRACTICE AT TU DUBLIN

The Professional Practice module position's identity work and reflexivity as essential to developing design professionalism. Its aims include fostering critical self-awareness, embedding EDI as a defining component of design professionalism, developing communication and mediation skills and enabling students to challenge homogenising narratives in design culture.

The module employs a flipped classroom methodology that combines pre-class engagement with theory through curated readings and critical prompts. Active in-class participation, structured reflection and the effective use of technology creates a comprehensive and dynamic learning environment.

Through a structured critical dialogue, students examine assumptions about meritocracy, cultural representation, bias, stakeholder power and the responsibilities of designers in diverse contexts. This flipped classroom approach uses a café format as the debating metaphor. [23]

Using Mezirow's theory of transformative learning for the design of this café format and discussions, proved to enable students negotiate and reframe their positionality. A central tenet of this particular flipped classroom intervention is the student reflection which not only deepens the students' understanding of the course materials but also informs and consolidates their emergent personal and professional identity. It fosters critical self-reflection, personal growth, a clearer sense of identity and responsible citizenship, making it a convincing model for contemporary education.

Drawing from design theory, sociology, ethics, philosophy and organisational studies, the module's transdisciplinary approach encourages students to connect micro-level design decisions with macro-level structural factors [9,12]. This integrative pedagogy supports long-term, reflexive identity development. The module draws upon established literature on cultivating reflective practice, identity construction and epistemic pluralism. Students engage in situated reflexivity [8,10], practice dialogic learning through facilitated debate [11], explore multiple ways of knowing including lived experience and community knowledge [7,3] and translate this into ethically grounded design action informed by user-centred and inclusive design standards [15,17,18].

4 CASE STUDY AND THEMATIC ANALYSIS

4.1 Case Study Overview

A focal classroom debate on EDI provided insight into students' developing identities and assumptions. Discussion explored EDI beyond employment and recruitment issues to include design methods, aesthetic norms, cultural representation, systemic bias and the designer's role. Student contributions ranged from scepticism, particularly around perceived threats to merit, to strong support for EDI as integral to ethical design. The thematic analysis below (Figure 1) synthesises recurring patterns in the discussion.

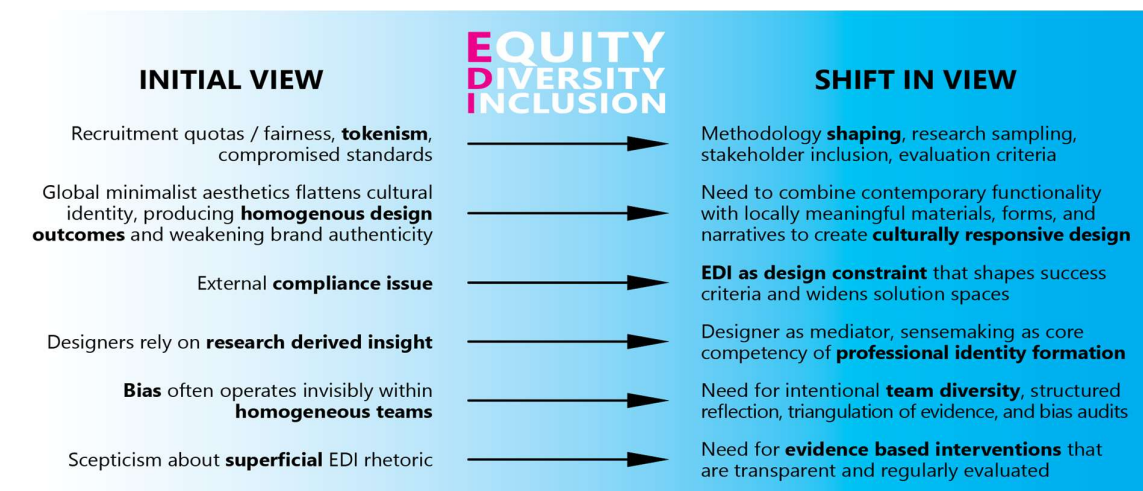


Figure 1. Shift in students' views of EDI after exploring deeper impact of EDI within design practice

4.2 EDI Debates

The following insights have been gathered from the written reflections on the student's own experience and learning from the classroom debates on EDI. Initially, many students associated EDI primarily with recruitment quotas and recruitment fairness. This narrow interpretation mirrored common organisational narratives and generated concerns about tokenism or compromised standards. As dialogue progressed, students began reframing EDI as a design methodology shaping question formation, research sampling, stakeholder inclusion and evaluation criteria. This 'upstream' perspective helped students recognise that inclusion affects the very definition of design problems and the validity of findings. The shift from recruitment focused EDI to process focused EDI marked a significant conceptual development.

Debates around meritocracy revealed conflicting intuitions. Some students viewed quotas as potentially unfair or undermining competence. Others emphasised that merit is socially shaped, not objectively measured and that structural inequalities distort who appears most capable [20]. Through facilitated discussion, students developed more nuanced views: equity measures can be legitimate tools in specific contexts, provided they are transparent, competency-based and designed to avoid tokenism. This exercise supported ethical-practical reasoning about competing contexts. [22].

Students articulated concerns that global minimalist aesthetics flatten cultural identity, producing homogenous design outcomes and weakening brand authenticity. They explored possibilities for combining contemporary functionality with locally meaningful materials, forms and narratives, aligning with situated and culturally responsive design scholarship [7,8]. These reflections highlighted the importance of aesthetic pluralism as an expression of inclusive design practice.

Students increasingly saw EDI not as an external compliance issue but as a design constraint that shapes success criteria and widens solution spaces. They recognised that many supposedly Universal Design principles reflect western or normative assumptions that may not transfer across cultures or user groups [18]. Inclusive and Universal Design were understood as directional commitments rather than absolute goals, with attention to edge cases often generating innovations beneficial to broader populations [17,19].

Students debated whether diverse user groups must be directly represented in design teams or whether designers can rely on research-derived insights. Most concluded that lived experiences and professional translation skills are complementary. Designers act as mediators who synthesise diverse insights into coherent requirements and testable design propositions [1,14]. These reframing positions communication and sensemaking as core competencies of professional identity.

Students acknowledged that bias often operates invisibly within homogeneous teams, contributing to group thinking and missed insights. Strategies such as intentional team diversity, structured reflection, triangulation of evidence and bias audits were proposed as mechanisms for surfacing blind spots [18]. While some expressed scepticism about superficial EDI rhetoric, most accepted the need for evidence-based interventions that are transparent and regularly evaluated [21].

Students recognised that early-career professionals may have limited influence over organisational policy but still identified pathways for contributing to change, including building alliances, pursuing incremental improvements and developing policy literacy. This pragmatism aligns with research that conceives professional identity as a long-term, context-responsive process supported by reflexive habits [1,4].

5 DISCUSSION AND OBSERVATIONS

5.1 From Accommodation to Epistemic Integration

A central insight emerging from the module is students' shift from viewing EDI as an accommodation, simply making space for difference within existing structures, to epistemic integration, where inclusion informs foundational decisions about what counts as knowledge, evidence and success. Embedding EDI upstream remodels design reasoning in ways consistent with situated and participatory design paradigms [7,14]. The classroom debate provided students with opportunities to recognise this reorientation.

5.2 Negotiating Merit and Equity Without Tokenism

The merit versus equity debate illustrated a widespread misconception: that fairness to individuals and fairness within systems are mutually exclusive. When structural inequalities shape access to resources and opportunities, meritocratic outcomes cannot be achieved without corrective measures [6,24]. The pedagogical challenge is to help students distinguish critiques of specific mechanisms, such as quotas,

from blanket rejections of inclusion. Developing policy literacy supports ethically grounded professional judgement [22].

5.3 Mediation as Core Professional Competence and Reflexivity as Ongoing Praxis

Reconceptualising the designer as mediator integrates technical, communicative and ethical skills. This aligns with Schön's reflective practitioner model [1] and Wenger's theory of participation [2]. Communication, translation and synthesis increasingly emerge as first-order competencies in inclusive design toolkits [18]. This identity orientation helps prepare students for complex, multi-stakeholder contexts.

Reflexivity is not just a discrete learning activity but an ongoing professional commitment. The flipped classroom supports this by providing iterative opportunities for dialogue, counter-examples and structured reflection. Students noted that meaningful influence requires strategic patience and collaborative action. Reflexive identity work equips graduates to adapt responsibly under conditions of uncertainty [9,10].

6 LIMITATIONS AND FUTURE WORK

Professional Identity formation is an important part of the educational journey of product design students. The case study outlined in this paper represents one element of a five-year longitudinal study which looks at identity formation and ways to support students in shaping their professional values and beliefs to prepare them for their professional careers.

This analysis is based on one classroom intervention from a single module within one institutional context, limiting generalisability. Classroom discussions may include social desirability effects and inform both individuals and groups through socially constructed reflective narrative. Future work could involve longitudinal studies tracking graduates' application of reflexive EDI practices in workplace settings and comparative research across programmes and institutions could illuminate contextual effects. Additional empirical work using coded reflection journals or learning analytics could further investigate how reflexive engagement contributes to improved design outcomes and team performance. This case is based on outputs from year three of a five-year longitudinal study on identity formation and further findings will be published in the future. This study was structured from early pedagogic research work undertaken by one of the authors. [25]

7 CONCLUSIONS

The Professional Practice module at TU Dublin demonstrates how reflexivity can reorient students' understanding of EDI from a narrow HR-focused issue to an epistemic and methodological foundation of design professionalism. Discussions about meritocracy, cultural identity, bias and the designer's mediating role highlight the complexity of embedding EDI within real design practice. Rather than providing definitive answers, the module equips students to navigate this complexity with ethical awareness and creative agency.

A pluralistic model of design professionalism, grounded in reflexivity, evidence-based reasoning and aesthetic diversity, provides a robust foundation for contemporary design practice. In this model, professional identity becomes dynamic, inclusive and ethically grounded and design education evolves from simply accommodating diversity to embedding equity and inclusion within the ways designers learn, decide and act.

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CRAFT EDUCATION AS A CATALYST FOR CULTURAL SUSTAINABILITY IN SAUDI DESIGN CURRICULA: A CASE STUDY OF DESIGN STUDENTS AT IMAM ABDULRAHMAN BIN FAISAL UNIVERISTY

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ABSTRACT

Design majors in Saudi Arabia often prioritise global and technological educational methods, which can limit the diversity of learning resources students can encounter. As traditional crafts embody cultural diversity, manual skills, sensory knowledge and community identity, which should be valued in design learning as a rich source of inspiration and cultural continuity. This study investigates how integrating craft-related courses influences students' cultural sustainability, their connection with local craftspeople, and the impact on their design practice.

Utilising a mixed-method approach – survey, semi-structured interviews, and a case study analysis of student design projects - the study compares students who completed craft-related courses with those who did not. Results show both groups demonstrated high interest in crafts but only moderate practical engagement with traditional crafts, indicating that appreciation does not always translate to sustained involvement. Students who had completed craft-related courses were more likely to integrate craft elements into their designs, although often driven by course obligation. Indeed, case study analysis shows that integration tended to reflect conceptual or aesthetic intentions rather than cultural embedment. Engagement with craftspeople remained limited overall, reflecting broader constraints. Qualitative insights highlighted barriers limiting deeper engagement, including limited time, insufficient exposure, and difficulty accessing artisans.

Findings highlight the importance of integrating craft-related subjects within design curricula to promote diverse knowledge systems, enabling access to cultural resources. It recommends more immersive and meaningful educational strategies to help students build lasting connections with local craft communities and develop culturally grounded design practices.

Keywords: Cultural sustainability, craft education, design curriculum, craft community, cultural diversity

1 INTRODUCTION

Cultural sustainability, a key dimension of social sustainability, reflects the preservation and connection to cultural beliefs and traditions. Handicrafts contribute to these cultural and social dimensions by carrying embodied skills and community knowledge, making their presence within design education relevant to broader discussions on inclusive and culturally responsive learning. Although craft-related courses are included in the design curriculum, limited research examines how this learning influences students' cultural sustainability and how students engage with diverse forms of knowledge.

Accordingly, the study aims to evaluate how teaching craft-related courses affects students' by assessing their ability to adapt traditional crafting skills within modern design practices and their interaction with handicraft community. It examines how this exposure shapes students' connection to cultural heritage, their willingness to incorporate it in their design work, and the depth of their engagement with craftspeople, which provides insight into students' access to different cultural contexts and practices.

The research hypothesis implies that integrating craft learning into design curricula strengthens cultural sustainability by enhancing students' connection with crafts, encouraging the modern application of

traditional skills and fostering a deeper connection to cultural identity while supporting more inclusive and socially aware design practices. The study targets students from different design majors, including industrial, interior, and graphic design programmes, which differ in the extent to which craft-related courses are embedded in their curricula, allowing for a comparison between students who have completed these courses and those who have not.

2 LITERATURE REVIEW

Craft education plays a significant role in supporting students' cultural sustainability through meaningful engagement, and skill development. Craft practices serve in preserving cultural identity while also fostering inclusivity and social cohesion within communities [1]. Research show that craft education plays a role in transmitting cultural knowledge and ensuring the continuity of heritage across generations. [2] [3]craft practicing in informal settings created a platform of social inclusion. Research also highlights that such environments encourage community building regardless of the language barriers and had led to meaningful engagement. [4]. Moreover, it was found that craft-based economy projects significantly contribute to preserving cultural identity, migrant integration, and cross-cultural connections. While migrant integration does not represent a social challenge in Saudi Arabia, such literature highlights the broader inclusive potential of craft practices. In this regard, studies emphasise the significances of collaborative workshops and entrepreneurship since they encourage knowledge exchange and intercultural relationships, contributing to the long-term sustainability of cultural heritage [5]. Such activities and the creation of cultural products was seen to increase market attractiveness, leading to more preservation of heritage and transmission of culture [6]

Craft spaces and workshops serve as inclusive environments for engagement, dialogue, and skill development, where cultural values and perceptions can be negotiated through hands-on practice [7]. Research indicates that craft education enhances technical skills, deepens awareness of cultural heritage, and supports the transmission of traditional knowledge when integrated into educational curricula [8], [9]. Moreover, inclusive pedagogical approaches that address diverse learner needs, connect student projects to market opportunities, and promote cross-institutional collaboration contribute to reducing structural barriers and building broader communities of practice [10].

To conclude, crafts behold a great cultural value, and though crafts, heritage may be preserved and cultural practices continue and sustain. Moreover, craft education was seen to open door for inclusive communication and meaningful engagement. The role of educational institutions stands as a platform for social inclusion, engagement, and skill exchange.

3 METHODOLOGIES

3.1 Research Design

This study adopted a mixed-method framework combining quantitative and qualitative approaches to examine the impact of craft education on design students' knowledge, exposure, engagement, and design practices. A non-probability sampling method was used, to access the defined population of female students enrolled in the College of Design at Imam Abdulrahman bin Faisal University. The general sample included 157 students across three majors-Graphic Design (n=68), Industrial Design (n=54), and Interior Design (n=35)- ranging from first year to graduation level. For comparative purposes, participants were divided into two groups based on their educational background: students who had studied craft-related courses (n=78) and those who had not (n=79). This grouping enabled the study to assess how formal craft education shapes cultural sustainability outcomes.

3.2 Data Collection

Data was collected using three complementary tools. First, a digital survey distributed to the full sample, to gather quantitative data on students' knowledge of crafts, interest level, exposure through events and social media, engagement with craftspeople, and the integration of craft techniques into their design projects. Second, semi-structured interviews were conducted with 20 students, face-to-face and via Zoom. These interviews provided deeper qualitative insights into students' experiences, communication barriers with artisans, and motivations behind incorporating crafts in their design projects. The third tool was a case study analysis of 23 randomly selected students' graduation design projects. It examined how students translated craft knowledge and values into actual design outcomes. Ethical approval was granted by the IRB of Imam Abdulrahman bin Faisal University. Participation was voluntary, informed consent was obtained, and responses were kept confidential for academic use only.

3.3 Data Analysis

Data analysis was conducted in several stages, with various techniques. Survey data were analysed using descriptive, cross-tabulation and correlation analysis to explore relationships between key variables. Additionally, to capture the multidimensional nature of engagement, a composite Engagement Index was developed integrating cognitive, affective and behavioural dimensions. Variables were normalised and weighted based on theoretical relevance, with greater emphasis placed on behavioural engagement due to its role in embedding practice. To ensure validity, internal coherence was examined through positive associations among the three dimensions. Engagement levels were categorised into low, moderate, and high based on equal intervals of the engagement index (0-1 scale). Interview transcripts were analysed thematically to identify recurring patterns related to communication barriers, motivations, and perceptions of cultural sustainability. Finally, the case study projects were evaluated using predefined criteria related to craft integration, execution, and cultural sustainability. These criteria allowed the analysis to assess the depth of craft knowledge and embedment rather than surface-level aesthetic use. To ensure consistency, two researchers reviewed the projects, and inter-rater reliability confirmed agreement. Findings from all tools were then triangulated to produce a comprehensive understanding of how craft education contributes to cultural sustainability in design education.

4 ANALYSIS & DISCUSSION

4.1 Knowledge and Interest of Crafts

A central pattern that emerged is the gap between knowledge of crafts and interest in crafts. Overall students reported relatively higher levels of interest in crafts ($M=3.71/5$, $SD=1.13$) while knowledge levels were relatively lower ($M=3.3/5$, $SD=0.97$). Knowledge was moderately impacted by study of related courses ($r=.20$) and the intensity of courses ($r=.34$), though interest demonstrated no association to study ($r=.02$). Also, there is a moderate positive correlation between knowledge and interest indicating that exposure enhances understanding and enthusiasm.

Further, interview insights clarify these patterns, particularly in relation to how and why students would be exposed to the educational opportunities. Students explained that their motivation to take craft-related courses often depended on whether the course was mandatory, aligned with their specialisation, or manageable as an academic workload. These structural constraints help explain why interest levels exceed knowledge levels, especially in majors where the course is perceived as less relevant.

Table 1. Correlation matrix of study key variables related to knowledge, interest, exposure, design integration and overall engagement

	1	2	3	4	5	6	7	8	9
1. Craft-Course Enrolment	-	<u>.61</u>	<u>.20</u>	.02	.06	.10	-.04	.14	<u>.17</u>
2. Course Intensity	<u>.61</u>	-	<u>.34</u>	-.01	.02	-.05	.15	-.11	.14
3. Craft Knowledge Score	<u>.20</u>	<u>.34</u>	-	<u>.35</u>	<u>.24</u>	.18	.02	.18	<u>.67</u>
4. Craft Interest Score	.02	-.01	<u>.35</u>	-	<u>.26</u>	<u>.31</u>	-.01	<u>.23</u>	<u>.79</u>
5. Event Attendance Frequency	.06	.02	<u>.24</u>	<u>.26</u>	-	.04	.01	<u>.39</u>	<u>.46</u>
6. Design Integration Score	.10	-.05	.18	<u>.31</u>	.04	-	-.11	.14	<u>.55</u>
7. Craftspeople Contact Frequency	-.04	.15	.02	-.01	.01	-.11	-	-.05	-.03
8. Craft Social Media Following	.14	-.11	.18	<u>.23</u>	<u>.39</u>	.14	-.05	-	<u>.45</u>
9. Composite Engagement Index	<u>.17</u>	.14	<u>.67</u>	<u>.79</u>	<u>.46</u>	<u>.55</u>	-.03	<u>.45</u>	-

Note: Cell background colour indicates correlation strength; formatting indicates significance (bold<.05, bold+underline<.01, bold+underline+italics<.001). Pearson's r , $N=157$

4.2 Exposure to Crafts

Exposure through events was modest and uneven, where many students attended only one or two craft-related events, and participation was far less common than attendance. Differences appeared between groups: students who studied craft-related courses were more likely to attend educational courses (19% vs. 11.4%), and craftsmen's meetings (20.3% vs. 7.6%), while attendance at festivals was similar across

groups (49.4 vs. 48.1%). Festival attendance therefore seems to function as an introductory gate to crafts awareness which can create a path to more active forms of engagement. These patterns indicate that formal study encourages exposure to more learning-oriented and practitioner-focused events, though overall experiential engagement remains limited. This aligns with interview comments where students described their exposure as mostly observational “I enjoyed viewing their work” and “I participated once in pottery work,” highlighting why exposure scores remain moderate despite high interest. Additionally, students in the Industrial Design programme—where craft-related courses are more intensively embedded—showed 15-20% higher participation rates in craft-related events and activities compared to the other disciplines, whose curricula include fewer craft-related requirements, where students majorly attended events without active participation.

4.3 Design Integration of Crafts

Design students show a moderate frequency of integrating crafts in their projects ($M=2.5/5$) indicating that crafts appear in design work but not as a regular practice. What clarifies this pattern is the relationship between variables: interest shows a stronger correlation with design integration ($r=.31$) than knowledge does ($r=.18$). This suggests that students’ interest in crafts is the primary driver of whether they use them, while knowledge plays indirect role supporting integration by reinforcing interest.

Motivations of design integration further support this interpretation. Result shows that students mostly apply craft elements to support their design concepts (66%), and for aesthetical reasons (61%), while cultural preservation and supporting craftsmen community appears less (51%) and (27%) respectively. Thus, cultural value is acknowledged, but it is not the leading driver for students to bring crafts into their work. Taken together, these findings show that students value crafts, but primarily for their conceptual and aesthetic contribution rather than for cultural continuity.

The case analysis of design projects further clarifies this. Across all measured dimensions, Graphic Design projects demonstrated the highest overall incorporation ($M=2.9/5$), followed by Interior Design ($M=2.4/5$), while Industrial Design projects demonstrated lower integration ($M=1.7/5$). Notably, even in the criterion of Execution and Making Techniques, Industrial Design project did not exceed other disciplines despite having mandatory crafts course. The strongest scores in all programmes are for Cultural and Sustainability Impact ($M=3.1/5$), suggesting that crafts are often framed conceptually. This goes with the earlier note that interest, rather than curricular exposure, is the primary driver of integration.

4.3.1 Saudi Craft Integration in Student Outcomes

Several students incorporated Saudi craft practices and cultural narratives into their design outcomes. In Interior Design, one student developed the *Saudi Visual Arts Centre in AlUla*, integrating locally inspired materials and storytelling within a contemporary setting. Graphic Design students created culturally driven work using visual storytelling, printed interaction tools, and social media content; for example, *Wataf* project strengthened intergenerational relationships around elderly care through culturally inspired communication materials. In Industrial Design, a student developed an interactive storytelling application that integrated Saudi oral heritage through digital and physical interaction. These projects demonstrate how students reinterpret local heritage through contemporary design methods.

However, the findings show that craft references were often integrated conceptually rather than through deeper material experimentation and making processes. This reflects a gap between craft practices and educational structures, where fast-paced academic systems restrict sustained hands-on engagement and craft development. Although practical components exist, students often choose not to integrate crafts in major design projects, relying instead on conceptual or visual references.

4.4 Engagement with Craftspeople

Students’ actual contact with craftspeople is limited, uneven and largely functional. On average, students contacted a craftsman almost once a year ($M=1.15$) with substantial variability among them ($SD=2.04$). The highest reason for contact is design project implementation (49%), followed by learning and skill development (46%), then personal project implementation (33%). This pattern indicates that almost half students only contacted craftspeople when a course requirement pushes to do so, while far fewer students had initiate contact for personal exploration. Interestingly, the study of crafts-related courses influences the contact, but not uniformly. Students who studied craft-related courses show higher contact for design projects (59% vs 40%) but lower contact for personal projects (26% vs. 40%). The learning and

development were similar for both groups (46% vs 49%). This suggests that coursework encourages students to contact craftspeople when required but does not necessarily establish a long-term relationship. Interview data further illustrate this as many students stated they “have not communicated artisans,” or that “access is not always easy,” and some noting “do not know how to reach them.” Students’ digital engagement with craftspeople is noticeably higher than their direct interaction. Results show that students follow, on average, around 7 craft-related accounts, using social media as primary channel. While this expands exposure, it remains observational, offering inspiration but not hands-on knowledge that comes from working with craftspeople. This digital approach of engagement reinforces the gap between interest and actual cultural exchange.

4.5 Composite Engagement Index:

The engagement index was strongly correlated with interest in craft ($r = .79$) and knowledge of crafts ($r = .68$), indicating that affective and cognitive dimensions substantially contribute to the overall engagement. Moderate correlations with design practice integration ($r = .56$) and event attendance ($r = .46$) suggest that behavioural dimensions play a meaningful but secondary role. These correlation results support the construct validity of the index, as it aligns with the theoretical expectations. However, one notable deviation emerged as formal curriculum exposure showed a weak association with the index ($r = .17$), still a programme-level comparison revealed that students enrolled in the programme where craft-related coursework was mandatory demonstrated a 10% higher proportion of high-engagement scores compared to programmes where such courses were elective or partially related. This suggests that structural curricular embedding may elevate overall engagement distribution, even if individual-level correlations remain weak. Indeed, interview insights support this pattern where students who studied craft-related courses described increased awareness “it enhanced my appreciation for handcrafts” and more exposure “it encouraged me to attend exhibitions.”

5 CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

This study highlights the meaningful yet incomplete role of craft education in advancing cultural sustainability within design programmes. Students across majors’ express strong appreciation for traditional crafts and recognise their cultural and aesthetic value, yet this appreciation does not reflect in their practice. Knowledge levels remain moderate, and design integration is selective, with interest showing a stronger impact on application than knowledge. This suggests that emotional and creative attraction to crafts motivates use more than informational understanding alone.

Exposure to crafts is present but limited, with event attendance being modest and participation being rare, and most encounters are observational rather than hands-on. Yet, the impact of studying craft-related courses is evident, where students who studied these courses were more likely to attend educational workshops and craftsmen’s meetings, indicating that formal study encourages deeper forms on exposure. However, engagement with craftspeople remain the weakest link: interactions are infrequent, often driven by project requirements, and hindered by communication barriers and limited access. As a result, crafts are being used primarily as aesthetic or conceptual elements. This pattern reflects concerns raised in existing craft-education literature, where students often value traditional crafts symbolically but struggle translating this appreciation into sustained practical engagement.

5.2 Interpretation of Findings

These findings partially support the study’s hypothesis. Craft education increases awareness and expands exposure, but it does not yet lead to a sustainable relationship with craftspeople or cultural integration within design practices. Strengthening the structural and relational components of craft education is therefore essential. This study expands upon previous research by identifying a gap between students’ interest in crafts and their actual practice. It explains the reasons for this persistent gap, highlighting structural constraints, as well as limited interaction with artisans. Unlike earlier studies focus on heritage preservation or curriculum content, this study positions craft education as a relational and experiential process, emphasising the importance of sustained student-artisan interaction for achieving cultural sustainability within Saudi design programmes.

5.3 Recommendations

A set of improvements is needed to strengthen the role of craft education in cultural sustainability. First, the craft-related courses should be redesigned so that cultural identity, heritage and traditions are clearly embedded in its content, ensuring meaningful students' engagement. Also, tailoring the course to the need of each design specialisation would increase relevance and strengthen students' motivation. Additionally, longer-term and process-oriented craft engagement should be encouraged across multiple courses and academic levels, to support sustained practice and more inclusive learning. Second, universities should establish structured opportunities for direct interaction-through formal communication channel, workshops, co-teaching, field visits, or collaborative project briefs-to provide students with direct access to artisans' tacit knowledge. This responds to students' difficulty in approaching craftspeople individually; such institutional structures can ease communication barriers and create more supported interaction. Finally, expanding research and collaboration across institutions would help capture variations in craft traditions and build a broader network linking design programmes with craft communities and market opportunities. This would support a more sustainable and culturally grounded integration of crafts in Saudi design education while contributing to broader discussions on diversity and inclusion in design education.

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BRIDGING DISCIPLINES: COOPERATIVE EDUCATION OUTCOMES IN INDUSTRIAL DESIGN AND MECHANICAL ENGINEERING

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ABSTRACT

This paper examines outcomes of a structured cooperative education model embedded in an undergraduate curriculum in which students alternate between campus-based study and workplace placements. Focusing on industrial design and mechanical engineering students participating in the same institutional model, the study investigates four dimensions: collaboration self-efficacy, reflective learning (including transfer), professional readiness/employability, and workplace integration quality (mentoring, feedback, task ownership, interdisciplinary exposure). A cross-sectional survey (N=85) was administered to students who had completed multiple placements; composite scales showed good to excellent internal consistency (Cronbach's $\alpha=.85-.95$). To add explanatory depth, semi-structured interviews were conducted with 28 students (14 per department). Survey results indicate moderately positive perceived outcomes across all four dimensions, with no statistically significant differences by gender or department (all $p>.05$). Interview findings highlight that learning is amplified when placements provide responsibility, access to communication channels, and timely feedback, and that boundary crossing often depends on translating work through concrete artefacts (e.g., documentation, explanatory presentations) that make intent and constraints legible across roles.

Keywords: Cooperative education, work-integrated learning (WIL), interdisciplinary learning, industrial design education, engineering education, reflective learning, employability

1 INTRODUCTION

University-business collaboration-based applied education models aim to develop students' professional knowledge and skills not only in the classroom/studio environment but also within real work processes. Cooperative education and work-integrated learning (WIL) are widely used in design and engineering programmes to strengthen students' transition into professional practice through repeated workplace exposure. However, outcomes are not guaranteed by placement alone; learning depends on how students are integrated into workplace activity systems and how academic programmes scaffold reflection and transfer.

The paper discusses the results of co-operative education within an institutional model where all students undertake multiple work placements with external organisations. This study compares industrial design and mechanical engineering students along four perceived outcome dimensions: collaboration self-efficacy, reflective learning (including transfer), professional readiness/employability, and workplace integration quality. The survey results are further explained through interviews that provide insights into how students experience boundary crossing and professional identity development in practice.

'Cooperative education' in this paper is used to describe a structured cooperation between the university and host organisations that is based on repeated workplace placements embedded in the curriculum. The study does not assume that design and engineering students are always co-located in the same placement teams and compares students from the two departments within the same model.

While cooperative education is commonly framed as a 'bridge' between education and employment, evidence suggests that benefits depend on the conditions of participation—what students are allowed to do, who supports them, and how workplace experiences are connected back to academic learning.

Accordingly, this paper asks: (i) how do students in two adjacent disciplines perceive cooperative education outcomes across collaboration, reflection/transfer, professional readiness, and integration

quality; and (ii) what qualitative mechanisms help explain variation in experiences within the same model?

2 BACKGROUNDS

Work-integrated learning (WIL) conceptualises placements as curriculum components that are intentionally designed to link academic learning and workplace practice through supervision, assessment and support. The learning outcomes are influenced by the quality of mentoring, feedback, authentic participation and inclusive opportunities for meaningful task ownership.

Interdisciplinary learning can be conceptualised as boundary crossing, where learning occurs as participants negotiate differences in language, norms, and criteria across communities and practices. In design–engineering contexts, coordination is often mediated by artefacts such as sketches, prototypes, documentation, and presentations that render work legible across disciplinary perspectives.

Reflective practice is the process by which experience becomes learning through feedback and reflection on action and supports transfer between contexts. Professional identity formation entails continuing identity work on the basis of participation and recognition in professional communities. Placements can help refine preferred trajectories and hybrid roles (e.g., coordination-oriented identities).

Boundary crossing provides a useful lens for interdisciplinary learning because it foregrounds practical frictions—terminology gaps, mismatched quality criteria, and role ambiguity—and the coordination work required to resolve them. In design–engineering settings, artefacts such as sketches, CAD drawings, prototypes, documentation, and presentations can function as boundary objects that support alignment by externalising intent and constraints [1,5].

Across placements, identity work is often revealed through preference clarification (‘what I want to do’ vs ‘what I do not want’), and for some students, a transition to hybrid roles such as coordination and planning. Usually, these identity signals are created through recognition and legitimacy in the workplace community and through the degree of authentic participation afforded to the interns [4,6].

3 METHOD

Design: A convergent mixed-methods design combined a cross-sectional survey with semi-structured interviews and brief written reflections to capture both outcome patterns and contextual explanations of students’ cooperative education experiences.

Context: The model of cooperative education examined in this study can be viewed as a work-integrated learning (WIL) implementation that institutionalises repeated engagement in the workplace within the undergraduate curriculum. This setup allows to compare perceived outcomes for two disciplines located side by side in the same model.

Sample: Survey participants were undergraduate students from industrial design and mechanical engineering (N = 85; Industrial Design n = 43; Mechanical Engineering n = 39; missing department n = 3). Interviews were conducted with 28 students (14 per department).

Quantitative instrument: The survey instrument comprised four dimensions: (1) collaboration self-efficacy, (2) reflective learning and learning transfer, (3) professional readiness/employability, and (4) workplace integration quality (mentor support, feedback, task ownership, interdisciplinary exposure). Items used a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree). Example items included “I was able to work effectively with people from different disciplines” and “I used feedback to improve how I work.”

Qualitative reflections: Interviews (≈20 minutes) elicited critical incidents of cross-disciplinary collaboration, reflection triggers, identity insights, breakdowns in collaboration, and programme-level improvement suggestions. To retain focus while producing analysable accounts, participants were also asked to provide brief incident-focused reflections during or immediately after the interview.

Data analysis: Quantitative analyses included descriptive statistics and internal consistency (Cronbach’s α). Group comparisons by gender and department were examined using independent-samples t-tests. Qualitative data were analysed using a structured thematic approach aligned to four analytic categories (boundary crossing, reflective learning/transfer, identity work, integration conditions), and representative quotations were selected for reporting in a space-constrained conference format (Table 2).

Ethical considerations: Participation was voluntary and based on informed consent. Interviews were conducted in Turkish; quotations were translated into English for reporting. Identifying details

(people/organisations) were removed and participants are referenced by anonymised codes (e.g., ID07, ME12).

4 RESULTS

The composite scales showed good to excellent internal consistency (Cronbach's $\alpha = .85-.95$). Overall composite scores were moderately positive across all four dimensions (Table 1).

Independent-samples t-tests indicated no statistically significant differences in factor scores by gender or department (all $p > .05$).

The qualitative interviews show that the perceived outcomes are mainly affected by the affordances and boundary conditions of the workplace. Students reported learning gains when placements offered clear task ownership and timely feedback and students had access to appropriate communication channels, but limited responsibility or restricted access constrained participation and reduced confidence.

In both departments, boundary crossing often involved translating work into concrete artefacts (e.g. explanatory presentations, drawings, documentation) to align expectations and reduce terminology gaps. Identity work regularly took the form of making clear “what I want to do” vs. “what I do not want,” and in some cases a shift toward hybrid coordination roles (e.g., project planning and cross-functional alignment).

For example, one participant contrasted placements by noting: “In one placement I was not given responsibility; in another I could participate directly in lab work.” (ME07).

Another described boundary crossing as making work legible: “I prioritised being understood and prepared explanatory presentations.” (ID07).

Table 1. Scale reliability and descriptive statistics for composite survey scores

Scale	Items (k)	Cronbach's α	N	Mean	SD
Collaboration self-efficacy	7	0.854	82	3.830	0.807
Reflective learning + transfer	7	0.887	82	3.873	0.832
Professional readiness / employability	11	0.940	82	3.987	0.835
Workplace integration quality	10	0.950	82	3.959	0.989

Table 2. Summary of interview themes and illustrative quotations (anonymised)

Scale	Items (k)	Cronbach's α	N	Mean	SD
Collaboration self-efficacy	7	0.854	82	3.830	0.807
Reflective learning + transfer	7	0.887	82	3.873	0.832
Professional readiness / employability	11	0.940	82	3.987	0.835
Workplace integration quality	10	0.950	82	3.959	0.989

Qualitative theme	What it shows	Illustrative quote (anonymised)
Integration quality & agency	Responsibility, access, and mentoring enable learning; lack of responsibility constrains participation.	“In one placement I was not given responsibility; in another I could participate directly in lab work.” (ME07)
Artefact-mediated boundary crossing	Students ‘translate’ across disciplines via presentations, drawings, and documentation.	“I prioritised being understood and prepared explanatory presentations.” (ID07)

Legitimacy and role recognition	Intern status/title can shape whether collaboration is possible.	“Interns have no title... I first had to prove what I could contribute.” (ME12)
Hybrid identity through coordination	Some students shift toward coordination and planning roles as meaningful professional practice.	“My work shifted toward project coordination—building schedules and plans.” (ID09)

5 DISCUSSIONS

Survey findings suggest broadly similar perceived outcomes across gender and departmental groups, with interviews helping explain how variation is often driven by placement conditions rather than disciplinary labels alone. That is, the same institutional model can produce different learning experiences depending on the extent to which students are allowed authentic participation.

Workplace integration quality (mentoring, feedback, access to communication channels, and meaningful task ownership) emerged across cases as a practical lever for strengthening reflective learning and transfer. Students who were given responsibility and access and treated as legitimate contributors reported greater confidence, clearer transfer of learning, and greater willingness to collaborate cross-functionally.

Boundary crossing was often achieved by artefacts that made design intent or engineering constraints explicit (e.g. explanatory presentations, drawings, documentation). These artefacts supported shared understanding by reducing gaps in terminology and by externalising decisions in forms that could be evaluated and negotiated by other roles (technicians, engineers, managers).

From an education design perspective, these findings speak to low-cost programme levers: (i) setting minimum expectations for host organisations (role clarity, assigned mentor, feedback cadence, and at least one deliverable with ownership); (ii) embedding lightweight reflection prompts and debriefs to link workplace episodes back to coursework; and (iii) aligning assessment criteria so that workplace learning (tools, documentation, coordination practices) is recognised rather than considered peripheral.

Finally, qualitative accounts illustrate that professional identity development is often expressed as preference clarification (“what I want to do” vs “what I do not want”) and, for some students, a shift toward hybrid coordination-oriented roles (e.g., planning, alignment work). For design and engineering educators, this suggests that cooperative education can be used deliberately to support identity work and interdisciplinary readiness, not only technical skill acquisition.

Limitations include reliance on self-reported perceptions and a single institutional model. Future work could model placement characteristics (e.g., sector, repeat placements, team composition) as predictors of outcomes and investigate longer-term trajectories after graduation.

6 CONCLUSION & IMPLICATIONS FOR DESIGN/ENGINEERING EDUCATION

Cooperative education can provide a common developmental framework across design and engineering students, but placements that offer authentic participation, feedback and clear structures for integration enhance learning.

Implications for programme design include: (i) strengthening mentor and feedback structures; (ii) embedding short guided reflections and debriefs to support learning transfer; (iii) designing opportunities for cross-functional interaction; and (iv) aligning assessment criteria so that workplace learning (including tools, documentation, and coordination practices) can be recognised and transferred into studio/engineering coursework.

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INFLUENCES OF PEER CRITIQUE, COLLABORATION AND ITERATION ON TEAM DYNAMICS AND HUMAN-CENTERED DESIGN OUTCOMES IN PRODUCT DESIGN STUDIOS

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ABSTRACT

Studio-based learning is the foundation of product design education and includes practices like peer collaboration, iterative making processes, tutor critiques and peer-to-peer critique sessions. However, the contributions of peer critique sessions to students' teamwork dynamics and their application of human-centred design (HCD) principles remain under-examined. This study examines how this core studio practice shapes students' ability to work effectively in teams and apply HCD principles in their design decisions. Adopting a mixed-method approach across multiple product design studio courses, the research integrates pre- and post-survey data, structured observations of peer critique sessions, coded transcripts of student-to-student feedback, and longitudinal analysis of project artefacts. Quantitative measures assess teamwork quality, psychological safety, and HCD application, while qualitative data analyses reveal how peer discourse and shared problem framing influence design reasoning. Preliminary hypothesis proposes that well-structured peer critiques-especially those emphasising user needs-enhance collaborative cohesion, deepen empathic understanding, and improve HCD outcomes across iteration cycles. By illuminating how peer-driven critique and collaborative studio practices most effectively foster empathy-driven decision making and cohesive team dynamics, the results of this study provide evidence-based strategies for product design educators seeking to strengthen reflective, empathetic, and team-oriented product design education.

Keywords: Peer critiques, collaborative learning, iterative learning, Human-Centred Design, design pedagogy

1 INTRODUCTION

Hands-on learning has traditionally proven to be very effective method of teaching where students learn by thinking, doing, and working with others [1,2,3] and it is especially more so in the case of product design education. Product Design has always employed the studio-based learning as studio spaces let students combine hand-on technical knowledge with creative exploration while getting feedback on their designs. Students learn various aspects of design through iterative making, reflective dialogue, and critique, which helps them develop problem solving skills and design thinking skills [1,3,5]. The critique is a very important aspect of product design education as it is a tool that allows students to share ideas, discuss and evaluate each other's work thereby learning through reflection as opposed to just instruction [1,7].

Traditionally, critique sessions are mostly led by the tutor, where they are positioned as experts imparting knowledge and students on the receiving end [1,8]. This arrangement gives valuable guidance and helps students learn effectively, but studies show it can also reinforce concepts of hierarchy, heighten anxiety, and inhibit self-expression and opportunities to learn from each other [8,9]. Critique sessions are significant in how they have an effect on students' confidence, willingness to participate and take creative risks [9]. Alternatively, peer critique transfers some evaluative authority to the students. This enables them to share their ideas more freely and opens up avenues for collective discussions [7,10].

Product design programmes, nowadays, stress upon the importance of teamwork, interdisciplinary collaboration and user-centred innovation. In addition to having a deep understanding of users' needs, design graduates are expected to work effectively with others [3,5,6,11]. But students often are unable to

integrate their learnings about their users beyond the initial stages of design even though human-centred design (HCD) provides applicable frameworks. Despite peer critiques being used in product design education, its role in encouraging teamwork, fostering psychological safety and incorporating HCD remains under-examined [4,7,10].

This paper addresses this gap by examining how peer critique can become an effective teaching tool by studying how it affects the above factors and thereby adds empirical data to discussions about product design education [3,11].

2 REVIEWS OF LITERATURE

Design education is at a critical juncture. With the advent of new technology and changes in the way we interact with it, design education needs to also keep with all these changes. This literature review reflects on the changing trends and shifts in contemporary design pedagogy and charts its trajectory into the future.

2.1 Studio-based Learning in Product Design Education

Studio-based learning is based upon experiential and constructivist theories that emphasise that knowledge is shaped through action, reflection and engaging with others. Schon's reflective model highlights the significance of reflection-in-action and reflection-on-action where learning comes through problem finding and solution finding, and the analysis thereof, while Kolb's experiential learning model posits learning through a continuous cycle of experience, reflection, conceptualisation and action [1,2]. The design studio provides the environment for nurturing professional identity and developing sound design judgement [3].

2.2 Critique and Peer Learning

Critique in design education has traditionally been a tutor-led activity. Recent research has shed light on students experiencing emotional stress due to the associated power dynamics [8,9]. Peer critique is emerging as a pedagogical mechanism that reduces hesitation thereby fostering active participation and encouraging students to be more vocal, clearer design thinking and more accepting of alternate views, and better shared understanding among them [7,10].

2.3 Teamwork and Psychological Safety

Projects are a common aspect in product design curricula and most projects have some assignments, if not all, that are group projects. Group projects help students learn to work together towards a common goal and face critique with more confidence as they explain their contribution towards the team effort. As such psychological safety becomes a critical factor to ensure productive collaboration [4].

2.4 Human-Centred Design (HCD) in Education

HCD is a problem-solving approach that places the user's needs and experiences at the centre of the design process its incorporation in design curricula is widespread. However, students find it difficult to implement HCD principles beyond the initial stages of the design process [5,6]. Peer critique sessions may become an important asset as it allows open discussion on user's perspective and hence help in shaping better user-centred design decisions.

3 RESEARCH METHODOLOGY

A mixed method data collection and analysis method was employed for this study in which data was collected in two phases. In phase one, publicly available course data was collected from universities offering product design programme. Course content and syllabi were obtained from institutional websites and analysed to identify open discussions as mode of teaching, along with commonly covered topics. Qualitative content analysis was employed to draw out prevalence of peer learning inclusion. In phase two, detailed semi-structured interviews were carried out with product design students to understand how their design studios were conducted. The participants selected were a homogenous group belonging to different institutes and selected through snowball sampling. Out of the 78 students approached, 56 agreed to participate in the interview, comprising of 25 males and 31 females. Participants were asked for their consent before and most of them were interviewed in person. The interviews were focussed on studio courses in product design that included individual and group assignments, and explored topics such as critique and peer learning, teamwork, psychological safety and

importance of HCD in design education. To better assess these factors, pre- and post-course surveys were administered and all items were measured on a 5-point Likert scale. Structured observations of peer critique sessions were also conducted looking at participation patterns and nature of feedback. The analysis also examined how feedback from critique sessions influenced the final output.

4 FINDINGS

Peer learning or peer critiques have been in use for some time now but in recent years we see an emergence and also a widespread acceptance by universities and schools as a formal teaching tool. Data collected in phase one, on universities, indicate the importance of formal and informal peer interactions in studio environments. RMIT University in Australia introduced a structured peer-learning model within its core Art and Design programmes relying on student-led peer reviews to promote learning. In fact, RMIT has developed and introduced a range of tools to support access and structure in peer learning [12]. Aalto University in Finland encourages students from different disciplines to collaborate on projects and facilitate feedback from peers and industry professionals. Aalto has implemented this model across all its campuses underscoring the educational value in creating sensitive, rounded designers [13]. Observational analysis revealed that peer critique sessions resulted in joint problem-solving rather than judgement. This created a shared sense of ownership of their design solutions.

4.1 Teamwork and Psychological Safety

To examine students' perception of teamwork and co-operation, they were asked to fill out a questionnaire with a few statements that focussed on key teamwork constructs like collaboration, coordination, shared responsibility and communication. Table 1 below lists the statements.

Table 1. Teamwork Quality Statements

No.	Statement
T1	Team members communicated effectively with each other during the design process
T2	Responsibilities within my team were clearly understood and distributed
T3	My team was able to resolve disagreements constructively
T4	Team members were committed to shared project goals
T5	Collaboration within my team improved the quality of our designs
T6	I felt accountable to my team for my contributions

Figure 1 shows a comparative analysis of mean calculations based on all the responses received from participants from both the pre- and post-course surveys. Improvements were seen across all six testing parameters as evidenced by the visible increase in mean values. Notably, visible increase was seen in T3, T4 and T5 suggesting that students reported improvement particularly in collaborative contribution and shared responsibility in the team.

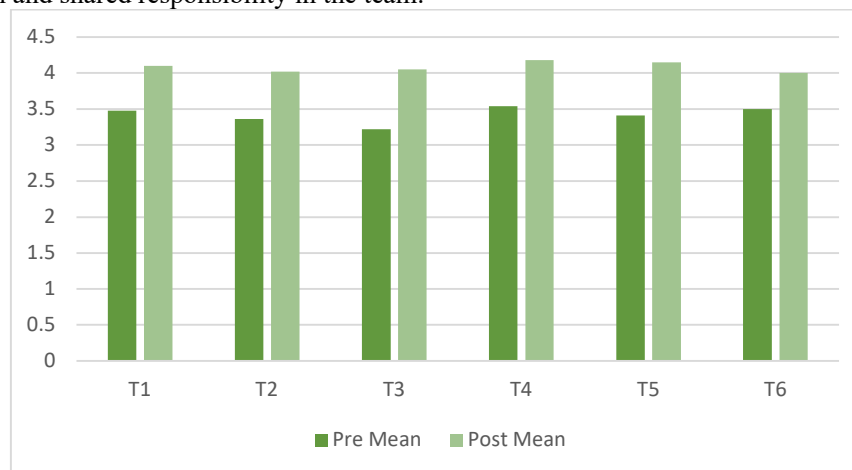


Figure 1. Teamwork Quality Index

The questionnaire included statements that focussed on key psychological safety constructs like openness, trust during critiques and interpersonal risk-taking. Table 2 below lists the statements.

Table 2. Psychological Safety Statements

No.	Statement
P1	I felt comfortable expressing my ideas during peer critique sessions
P2	I could ask questions or seek clarification without fear of negative judgement
P3	Mistakes were treated as learning opportunities in my team
P4	I felt safe giving honest feedback to my peers
P5	Different opinions were respected during critique discussions
P6	Peer critique sessions encouraged open and respectful dialogue

Figure 2 shows a comparative analysis of mean calculations based on all the responses received from participants from both the pre- and post-course surveys. Improvements were seen across all six testing parameters again, as evidenced by the visible increase in mean values. Notably visible increase was seen in P1, P4 and P6 suggesting that students reported reduced hesitation in expressing ideas, giving feedback and engaging in discussions during peer critique sessions.

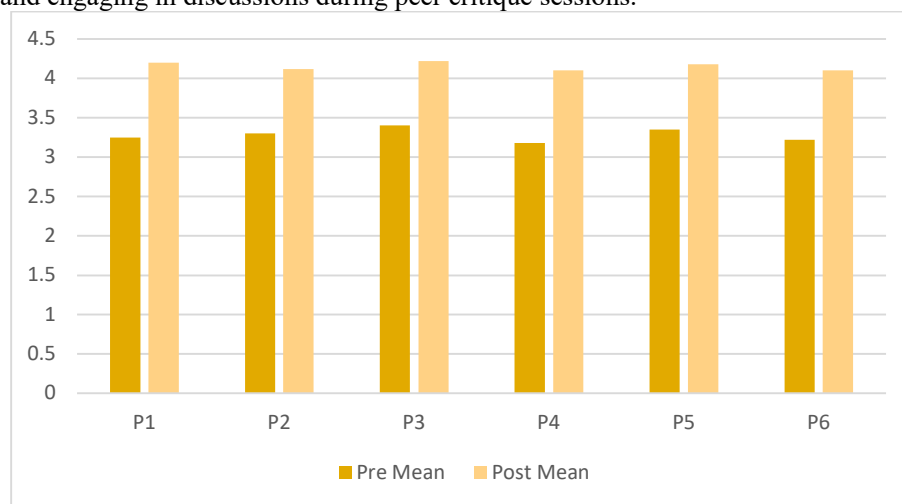


Figure 2. Psychological Safety Index

According to the survey results, at the end of the course, students reported improvement in interpersonal dynamics leading to improved teamwork and psychological safety. Observational data indicate that peer critique sessions improved active participation that tutor-led sessions.

4.2 Impact on HCD Application

To examine students' perception of HCD and its integration into their designs, the questionnaire included a few statements that focussed on key HCD competence constructs like empathising with the user and understanding user needs, incorporating user insights into design process. Table 3 below lists the statements.

Table 3. HCD Application Statements

No.	Statement
H1	I am confident in identifying and articulating user needs
H2	User research meaningfully informed my design decisions
H3	I considered users' emotional and experiential needs during design development
H4	Peer feedback helped me better understand the user perspective
H5	I can justify my design decisions based on user insights

H6	My ability to apply HCD principles improved during this course
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Figure 3 shows a comparative analysis of mean calculations based on all the responses received from participants from both the pre- and post-course surveys. Improvements were seen across all six testing parameters as evidenced by the visible increase in mean values. Notably, visible increase was seen in H2, H4 and H5 suggesting that students reported improvement particularly in meaningful translation of user awareness and insights into constructive design decisions.

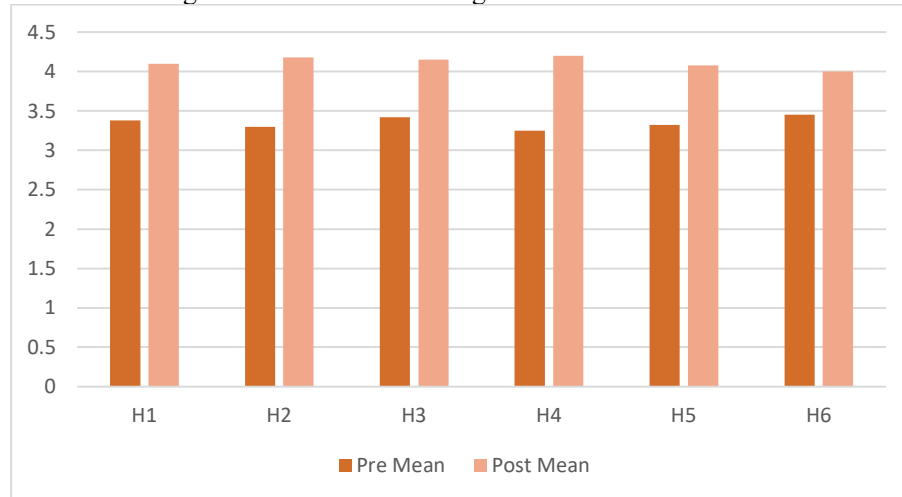


Figure 3. HCD Application Index

Table 4. Mapping of survey questionnaire items to analysed outcomes and findings reported in the study

Questionnaire Item	Construct Measured	Reported Outcome
Teamwork Quality	Team communication and shared goals	Improved teamwork quality
	Role clarity and accountability	Increased team coordination
	Conflict resolution	Constructive collaboration
Psychological Safety	Comfort expressing ideas and giving feedback	Increased psychological safety
	Respect for differing opinions	Open dialogue during critiques
	Learning from mistakes	Reflective learning <u>behaviour</u>
HCD Competence	Articulation of user needs	Stronger user justification
	Use of user research	Deeper HCD integration
	Empathy and experiential reasoning	Empathy-driven design decisions

5 DISCUSSION AND IMPLICATIONS

The results generated from the analysis of university course conduct and available syllabi and that resulted from the interviews of product design students show significant benefits behind incorporating peer critique as not only a mode of evaluation but also as a key pedagogical mechanism that plays a pivotal role in helping students build understanding, distribute evaluative responsibility and integrate user insights into all stages of the design process while aligning with constructivist learning theories [1,3,7]. Psychological safety plays a very important part as an enabler for a productive peer critique session. Students participate more willingly and actively when they are facing their own peers in a more informal environment. When they know that their ideas will not be judged, students are able to share their ideas more freely and be more open to constructive criticism and feedback. HCD principles were

also seen to be implemented more frequently by students as a result of employing peer critique sessions. They started to look at user needs and insights more closely as a result and incorporated in their design discussions. The findings suggest that peer critique should be seen, not as an informal studio activity, but as a critical part of design teaching. The implications it holds for design educators are:

- Structuring peer critique through prompts to address user needs.
 - Assigning rotating peer roles to widen perspectives and deepen sensitisation.
 - Requiring reports illustrating critique feedback to design changes.
 - Aligning assessment rubrics with collaborative and human-centred learning outcomes.
- These strategies help make the product design curriculum more robust and help educators mould their students into empathetic designers with technical competence and collaborative skills.

6 CONCLUSIONS

The integration of peer learning mechanisms is necessary in product design education to build effective teamwork, promote psychological safety and ensure meaningful application of HCD principles in design process. Incorporating peer critique sessions mindfully, results in protected psychological safety, and places evaluative authority with students thereby encouraging honest conversations about design and sensitisation about user insights. This also aids students to respond constructively to critique and helps them in openly participating in the design process. For educators, peer critique sessions provide a forum for open discussion and identifying and honing skillsets. It helps students by exposing and preparing them to the rigors of working in a professional, collaborative environment thereby underscoring the importance of peer critique as more than just an assessment tool. This study provides empirical evidence linking everyday studio interactions to social and cognitive aspects of learning. While this study focuses on undergraduate product design education, its learnings might be applicable to disciplinary variations and other applications in the future. By intentionally integrating peer critique into studio culture, product design education can better equip students to handle the social and professional dynamics in their design careers.

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TRANSITIONING TO REGENERATIVE DESIGN: LEARNING BEYOND TRADITIONAL EDUCATION

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ABSTRACT

Young designers face significant challenges transitioning from academia to professional practice, particularly in the demanding and increasingly vital field of regenerative design. This paper presents a collaborative design practice where students tackled a real-world challenge beyond the traditional educational setting, transforming the experience into both their thesis work and subsequent professional projects. The framework was provided by an open call for the Biennial of Design 27 (BIO27) in Ljubljana, which offered students critical insights and practical knowledge for their future careers. Their project, centred on the complex and unfamiliar topic of water, motivated them to develop a method combining natural processes, vernacular principles, and new technologies into a cohesive solution. This established method was not a one-time effort but continues to guide their navigation of diverse and complex projects through multiple iterations in their professional work. By integrating ecological, technological, and vernacular diversity into a single learning framework, the project demonstrates how alternative educational approaches can equip future designers with the competencies necessary to navigate complex social and ecological realities. It suggests that embracing diverse modes of knowledge production—scientific, local, experiential, and more-than-human—can enrich engineering and product design education, and support students in developing the resilience, sensitivity, and adaptability required for contemporary design practice.

Keywords: Regenerative design, diversity, vernacular knowledge, new technology, natural process

1 INTRODUCTION

Education emerges not merely as a cornerstone of social cohesion and knowledge acquisition, but as a dynamic axis for cultivating competencies that underpin sustainable societies [1]. Within the context of product design and engineering education, this role becomes particularly critical, as design curricula increasingly engage with complex socio-ecological challenges that exceed purely technical problem-solving [2]. A recurring challenge, however, lies in translating these imperatives into pedagogical structures that move beyond conceptual exploration towards situated, practice-based engagement. As Meyer and Norman (2020) delineate, design education unfolds across at least two institutional archetypes: autonomous design academies and departments nested within research universities [3]. The latter, embodying traditional product design paradigms as articulated by Yavuzcan and Gür (2020), privilege faculty-driven research and disciplinary advancement, with studio practices typically commencing in theoretical lectures before practice-based exploration, often culminating in conceptual prototypes that rarely transcend ideation [4].

At the University of Ljubljana, Academy of Fine Arts and Design (UL ALUO), this model is reflected in a range of research-oriented and industrial design projects presented via posters and 3D models in exhibitions. While such formats support creative exploration and disciplinary experimentation, they are often constrained by academic timeframes and controlled conditions, typically spanning approximately three months and aligning with the ideation phase of the Double Diamond process [5]. These structural limitations can restrict students' exposure to extended project development, interdisciplinary collaboration, and iterative prototyping under real-world pressures. This gap becomes particularly evident in the context of regenerative design, where design outcomes are expected to respond to ecological systems, local contexts, and long-term environmental impacts rather than isolated problem definitions.

A growing body of literature suggests that, despite the increasing presence of regenerative and sustainability-oriented discourse in design education, such approaches are frequently invoked at a conceptual level without being fully operationalised through life-cycle thinking, field-based research, or adaptive design methodologies [6]. In this context, contemporary designers are increasingly called upon to adopt systemic perspectives, prioritising resilience, sensitivity, and adaptability in response to planetary boundaries.

In response to these pedagogical challenges, this paper examines an alternative educational trajectory through a case study of a student-led project initiated via an international open call for the Biennial of Design 27 (BIO27). The study draws on practice-based research methods, combining fieldwork, interviews, iterative prototyping, and reflective analysis to examine learning processes in Master's-level product design education. Unlike conventional studio assignments, the open call functioned as an externally situated learning framework, introducing real-world constraints, public accountability, and interdisciplinary collaboration into the educational process.

Open to a broad international audience, the call foregrounded the theme of “super vernacular” design, encouraging participants to engage with local knowledge systems, material cultures, and ecological conditions. For the participating students, this context enabled a form of situated learning in which regenerative principles were explored through sustained research, fieldwork, and iterative prototyping beyond the boundaries of a standard academic course.

Guided by the research question, *How can open calls enable regenerative design learning processes in product design education?* this paper analyses the BIO27 case to examine the pedagogical characteristics of open-call-driven projects. The study further asks:

- (1) How do open-call frameworks differ from conventional studio formats in structuring learning processes?
- (2) Which real-world constraints and interdisciplinary interactions most significantly shape students' engagement with regenerative design?
- (3) What aspects of this approach hold potential for adaptation within higher design education curricula?

By situating the case within broader debates on regenerative design education, the paper reframes student projects not merely as isolated academic outputs, but as extended learning processes capable of fostering reflective practice, methodological adaptability, and professional readiness. In doing so, it contributes to ongoing discussions on how design education might better bridge the gap between conceptual regenerative discourse and situated, practice-based learning. While the study does not aim to quantitatively measure learning outcomes, it offers an in-depth qualitative analysis of learning processes and pedagogical structures enabled through an open-call framework, grounded in fieldwork, interviews, and iterative prototyping developed through the BIO27 project.

2 RESEARCH, EXPERIMENTATION, AND EXHIBITION OF CASE STUDY

The BIO27 project extended over seven months (December to June), functioning as an extended, practice-based learning case comparable to a prolonged academic semester. Unlike conventional studio formats, which often confine students to ideation within academic semesters, this structure fostered situated, practice-led learning by integrating real-world timelines, external accountability, and iterative phases, from research and brief formulation to prototyping and international exhibition, bringing together local and global designers, thinkers, and artists [7]. Through this extended structure, the project enabled a regenerative design learning trajectory grounded in iterative research, field engagement, and reflective practice. This progression cultivated key competencies in systemic thinking and adaptive methodologies, directly addressing gaps in translating regenerative discourse into operational practice. The research phase diverged from theoretical lectures by embedding students in interdisciplinary fieldwork, a core pedagogical shift toward experiential knowledge construction. Through collaborations with microbiologists, ecologists, chemists, physicists, artists, and local stakeholders, students conducted 10 qualitative semi-structured interviews with scientists, park staff, and residents, gaining holistic insights into Slovenia's water challenges. These engagements identified water pollution in Triglav National Park (TNP), a symbolically pristine alpine site threatened by farming and tourism [8], as a key focus. Fieldwork further included three structured site visits with TNP staff: an initial exploratory visit, a data collection visit involving water sampling and resident dialogues, and a final documentation visit linked to exhibition preparation (Figure 1). This sequence developed competencies in empirical rigour

and stakeholder dialogue, enabling students to operationalise regenerative principles via place-based data collection.



Figure 1. Triglav National Park visit and water sampling (Pjorkkala, 2022)

A partnership with Microbium, a pioneer in portable *E. coli* analysers, further exemplified the role of open calls in resource convergence, loaning equipment for on-site assays that bypassed laboratory constraints. Such alliances underscore how open calls catalyse resource convergence, mirroring regenerative models where design education interfaces with industrial innovation to bypass traditional barriers.

Building on this, the experimentation phase emphasised iterative, hands-on prototyping as both a research method and a learning process, through which students developed methodological adaptability by acquiring technical skills during the design process itself. In this phase, they taught themselves xylem-based [9] and ceramic filtration technique [10], including manual clay mixing, despite having no prior experience. Leveraging open-call funds, they introduced clay 3D printing in Slovenia (Figure 2). This sped up design iterations and demonstrated how funding can make digital tools more accessible in education.



Figure 2. Experimentation with 3D clay printing (Bor Cvetko, 2022)

Three semi-public milestones—pitches, research unveilings, and critiques—instilled reflexive communication competencies, refining abstract findings into professional narratives for diverse audiences. The BIO27 exhibition then culminated these dynamics, prioritising process documentation over final products (Figure 3), with students designing project presentations featuring fieldwork visuals, experimentation results, and prototypes. This fostered curatorial agency and professional readiness, transforming real-world frictions into meta-skills like resilience and adaptability.

Taken together, extended timelines, interdisciplinary embeds, iterative reflexivity, and public accountability offer a scalable open call framework for design education. This framework bridges conceptual regenerative design and practice, promoting competencies transferable to standard curricula, such as modular fieldwork modules or industry partnerships, to enhance regenerative learning impacts.



Figure 3. The presentation of work at BIO27 (Urban Cerjak, 2022)

3 ITERATIONS OF THE CASE STUDY

Post-BIO27, the project developed into a master's thesis and a series of international field iterations in Georgia (2022) and France (2023), transforming the initial student project into a longitudinal learning trajectory. Rather than functioning as mere project extensions, these post-BIO27 iterations operated as pedagogical mechanisms for testing, adapting, and reflecting on regenerative design methods across diverse socio-ecological contexts. These iterations served as real-world validation of both methodological transferability and material adaptability.

The first iteration, conducted in Tbilisi, Georgia, in collaboration with Floating University, confronted students with conditions of extreme water contamination and limited site accessibility along the Mtkvari River. This context required rapid methodological adaptation, particularly in filter deployment and on-site prototyping, while simultaneously foregrounding issues of water precarity and community engagement. As a learning outcome, students developed competencies in situated problem framing, stakeholder dialogue, and reflective decision-making under real-world constraints, illustrating how regenerative design learning is shaped through exposure to uncertainty and systemic complexity.

The second iteration, developed in Cognac, France (Figure 4), shifted the pedagogical focus towards material localisation and circular resource thinking. By replacing sawdust with local cognac waste (grape pomace and stems), students tested the adaptability of the filtration method while maintaining comparable bacterial reduction performance. This iteration strengthened learning outcomes related to material experimentation, vernacular resource integration, and professional communication with local industry stakeholders, reinforcing the regenerative principle of working within, rather than against, local material ecosystems.

Across these iterations, the project transitioned from a student-led educational exercise into a transferable design methodology capable of responding to diverse realities. From an educational perspective, the iterative structure enabled longitudinal learning rarely accessible within standard studio courses. Students were required to reflect on previous decisions, identify which aspects of the method were essential and which were contingent, and reconfigure their approach accordingly. This process cultivated a form of methodological literacy central to regenerative design education: the ability to design not fixed solutions, but adaptable systems that evolve through context-specific feedback.



Figure 4. Iteration development and bio-waste in Cognac, France (Pjorkkala, 2023)

4 DISCUSSIONS

The BIO27 open-call framework reveals transformative potential for regenerative design education by restructuring learning beyond conventional studios. From a methodological perspective, the case demonstrates how extended, open-call-based projects can function as learning laboratories, where design education, research, and professional practice intersect. Key benefits include authentic professionalisation through super vernacular themes, which integrate real-world constraints such as extended timelines and public accountability. These elements foster competencies absent in ideation-focused courses, including prototyping, interdisciplinary collaboration, and reflexivity, while also enabling the formation of enduring networks with experts and communities (Microbium, TNP staff). Iterations in Georgia and France further demonstrate scalability, supporting the transferability of adaptive methodologies across contexts.

Taken together, these observations foreground three interconnected pedagogical contributions of open-call-based learning in regenerative design education: iteration as a structured learning mechanism rather than mere project continuation; open calls as externally situated frameworks that support students' transition from academic settings into professional practice; and regenerative design as a method learned through contextual adaptation and iterative feedback rather than predefined solutions.

Challenges remain, however. The study does not quantitatively assess learning outcomes or compare the open-call framework with alternative studio formats, which constrains the evidential basis for claims about enhanced learning or long-term impact. In addition, the study is based on a single case, which limits generalisability and calls for further comparative research across different institutional and cultural contexts. Open calls are competitive and often unpaid, which creates barriers for early-career designers, while the additional demands placed alongside academic workloads can generate significant stress. These issues reflect broader tensions within practice-based learning, underscoring the need for stronger institutional support and mentorship structures. Recognising these limitations, the paper refrains from presenting the BIO27 case as a definitive model and instead positions it as an example from which others can adapt elements, rather than replicate the entire framework, within their own contexts.

This case study therefore advocates embedding open-call elements into curricula through a modular approach. Open-call frameworks function as discrete, transferable pedagogical units such as fieldwork, external briefs or industry collaborations that can be integrated into existing curricula without structural overhaul. These modules retain key features of the open-call format, including external accountability, real-world constraints and interdisciplinary collaboration, while remaining adaptable to institutional contexts and fostering cross-disciplinary skills and regenerative expertise. For product design and engineering education, this approach highlights how technical experimentation, material research and systems thinking can be integrated with regenerative and contextual design frameworks. By bridging conceptual discourse and situated practice, it contributes scalable models for design education confronting planetary challenges and positions academies as hubs for systemic change.

5 CONCLUSIONS

This paper presents an open-call-based approach as a practice-based educational and research methodology for developing advanced student projects in design education. The BIO27 case shows how such an approach can strengthen product design curricula by integrating scientific research, local knowledge, and real-world practice. In doing so, it cultivates key skills and competencies, including resilience, sensitivity, and adaptability, which are essential for regenerative design. Crucially, the case illustrates how learning can extend beyond conceptual exploration towards sustained engagement with complex socio-ecological realities.

The approach proved effective across iterations in Slovenia, Georgia, and France. It combines nature-based, vernacular, and digital methods into a model capable of adapting to diverse contexts and global challenges. Rather than proposing a fixed educational model, the study suggests a transferable logic for structuring learning processes that support professional transition and long-term methodological development. Future work will explore how selected elements of this approach can be systematically integrated into standard curricula, contributing to ongoing efforts to operationalise regenerative design education and expand the pedagogical tools available to design educators.

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CAN I WORK WITH YOU? THE IMPACT OF GROUP ALLOCATION CONSTRAINTS AND THE OPPORTUNITY FOR STUDENTS TO WORK WITH ONE ANOTHER

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ABSTRACT

Engineering and Product Design units typically present one of the few opportunities for students to work with one another to design solutions to real-world problems. As a student in a cohort, you may want and/or feel you should have an equal opportunity to work with any other member in your cohort. However, there is increasing pressure to identify 'optimal' group allocations brought about by student preferences, engagement and the need to meet institutional policies such as no lone gender/home/overseas working. These are diametrically opposed and to understand the compromise that needs to be made, this paper reports a numerical study into the effects of constraints on group composition and the resulting opportunity for individual students within a cohort to work together. The results identify the significance of the compromise that needs to be made and highlights the need for more detailed and comprehensive of different combinations of constraints is required to understand their effect on the opportunity space.

Keywords: Group allocation, protected characteristics, constraints

1 INTRODUCTION

Engineering and product design education necessitates group activity as it is rarely the case that a design project for a complex problem is conducted in isolation. The also present one of the few opportunities' students will have throughout their degree programmes to work with one another. While their delivery is resource-intensive, they provide key contributions to the development of employability skills in graduates, such as teamwork, communication, planning, and decision-making [1, 2].

Group activities are also essential for the development of project management skills, such as the identification and distribution of tasks, design data management, negotiation and persuasion, conflict resolution and empathy with team members. It also engages the students in 360-degree constructive feedback methodologies and the need to work effectively as a team to deliver on a project's goals to achieve academic excellence over and beyond that of their personal academic excellence. Group activities also enable peer-to-peer learning that can complement the learning from the academics running the exercise [3]. The Accreditation of Higher Education Programmes (AHEP) framework set by the Engineering Council in the UK features specific Intended Learning Outcomes (ILOs) on Engineering and Project Management, Teamwork and Communication.

To conduct an activity, design educators must allocate students to groups. While seemingly trivial, group allocation remains a topic that dominates the start of many group activities. A default strategy an educating might take would be to simply select at random thereby providing everyone an equal opportunity to work with one another. However, students can be sensitive to personal characteristics, work ethic, academic capability, and social cliques that may drive their feelings on the suitability of the group allocation [4]. And institutional policies may require certain criteria to be satisfied such as a no-lone gender in a group.

The problem can be regarded as a constraint satisfaction problem where design educators must decide on a method that can satisfy known constraints while acknowledging unknown unknowns exist that might lead to one or more student's being dissatisfied with their allocation. Further, there can exist times where the Intended Learning Outcomes (ILOs) of a course may be in conflict with the constraints that individual students may want satisfied resulting in what colloquially might be termed a 'no win' scenario. This is where the students may be dissatisfied with a process that might prove to be more

beneficial to their learning and development in the long-term. In these situations, design educators need to provide clear justification and rationale for the allocation process, so students are on-boarded from the beginning.

With the context set, this paper contributes a study into the compromises that need to be made between ensuring fair opportunity for students to work with another while adhering to increasing number of constraints and large cohort sizes. This was achieved through the development of a numerical model that evaluated random selection against a constraint-based solver of no lone A/B working in a group constraint.

2 RELATED WORKS

There are an increasing number of considerations, strategies and metrics that design educators can deploy in making evidence-based decisions on their group allocation strategy. This section summarises some of the considerations and methods that design educators may consider when allocating groups.

[4] surveyed 165 first-year university students revealed that a major concern for cohorts with 1st and 2nd language English speakers was that the group work was assessed as a group rather than individually.

[5] studied the effects of five group allocation strategies based on grades and programmes of study. They found that groups allocated on grades and programmes of study performed better than self-selected groups. Self-selected groups resulted in poorer attitudes to the course, educators and their colleagues.

[6] used feedback from students on the engagement and contributions of their colleagues and used this to allocate students in subsequent projects. They proposed students with similar levels of engagement and contribution should work together. It resulted in positive feedback from the students and little change in the average scores across the unit. A positive correlation was observed from groups that engaged more with the activity.

[7] reviewed design group allocations highlighting that many students prefer self-selection as they can bring their own views on the performance of their peers to bare on the problem. The study also highlighted that many often stick with the same individuals from their very first exercises when randomly selection was used. This indicates a sense of community and comradeship was developed and that it provides the potential to work better together in future projects. [8] highlighted the importance of placing constraints on characteristics such as the 2010 Equality Act legally recognised nine protected characteristics – Age, Disability, Gender, Marriage and Civil Partnership, Pregnancy and Maternity, Race, Religion and Belief, Sex and Sexual Orientation. No-lone working policies are increasingly commonplace and [8] confirmed the benefits of individuals not feeling isolated based on these characteristics. [8] also showed that the introduction of a no-lone gender in groups within their design teaching showed marked improvement in engagement and student satisfaction.

The related work revealed there are a considerable number of objective and subjective factors that a design educator can include in their group allocation strategy, summarised in Table 1. The related work also suggested that no one technique has emerged as a dominant solution and that much of the reflection on the success of the group allocation has been on analysing changes in the distribution of marks awarded and/or student satisfaction in the group allocation strategy. Many also raise the point that if a managed group allocation process is involved and is driven by learning objectives such as inter-disciplinary and/or diverse teamworking, then the assessment should provide opportunities for groups to articulate how they achieved this so it can be assessed independently of the output. A potential gap identified by the authors is that none of the prior work reflects on how strategies influence the opportunity for any two students within a cohort to work together, which may result in unequal opportunities for student learning. We propose that this quantitative metric can provide insights into the group allocation strategies discussed in this section, and whether they are under or over constrained.

Table 1. Considerations, Strategies and Metrics for effective Group Allocation

#	Consideration	Description	Ref
1	Protected Characteristics	The 2010 Equality Act legally recognised nine protected characteristics – Age, Disability, Gender, Marriage and Civil Partnership, Pregnancy and Maternity, Race, Religion and Belief, Sex and Sexual Orientation – and our cohorts increasingly feature a diverse composition of these characteristics. In line with these characteristics, educational institutions may include policies that declare that groups should include two or more individuals of a protected characteristic. An example of this in practice is no lone gender within a group. That is to say no one female or male in a group of males or females. Rationale for such policies often relate to well-being and safeguarding.	[8, 9]

2	Academic Performance	Can be used by educators to either group similar performing students or have groups that feature a range of capabilities thereby providing students with a different learning environment and experience.	[5]
3	Academic Engagement	Can be used by educators to either group similarly engaged students or have groups that feature a range of engagement thereby providing students with a different learning environment and experience.	[6]
4	Peer Assessment	Students assess their peers that can be used to assess the ability to work with one another	[6]
5	Interests	Students provide their interests where educators can then form groups that provide the right combination of interests to complete the activity thereby avoiding conflicts in students all wanting to do the same element of the project.	
6	Programme of Study	Educators can use this to foster inter-disciplinary working practices	[5]
7	Language Proficiency	Communication can be a barrier in students being able to work together effectively. Equally overseas students often view educating in another country to improve their language skills and desire diversity in group allocation. Home students can also see this an opportunity but could also feel it may reduce productivity which they often negatively associate with achieving higher marks.	[4]
8	Resource Availability	Units have fixed resources to support groups and these need to be factored in when allocating groups. E.g., supervisors.	
#	Strategy	Description	Ref.
1	Random	This does not consider any of the considerations and typically uses a uniform distribution to allocate students to groups.	[10]
2	Self-Selection	Empowers the students to determine their own groups. Conflicts have to often be resolved by the students themselves. Students who do not mind or do not want to debate can be offered to be randomly allocated to a group	[7]
3	Constraint Satisfaction	Educators provide pro-formas that features one or more considerations for students to fill in and/or gathers the data from internal systems that is then fed into a constraint-based solver whose objective is to find the best fit group allocation.	
4	Buddy + Constraints	Combines self-selection and constraint satisfaction for a best of both approaches.	
#	Assessment Metrics	Description	Ref.
1	Student Satisfaction	Using post-unit surveys to gather student satisfaction on the reasoning and effectiveness of the group allocation strategy.	[5, 8]
2	Mark Distribution	Comparing marks following a group allocation strategy change to see the effect on the attainment.	[5]

3 STUDYING THE INTERPLAY BETWEEN OPPORTUNITY AND CONSTRAINTS

A study modelling the effect of introducing a generic no lone A-B policy on the probability of any two individuals working together within a design cohort was developed to investigate the trade-off between opportunity and constraint-based satisfaction. The no lone policy can be commonly found and could be based on a protected characteristic (e.g., gender) or any other characteristic where individuals in a cohort could identify or be characterised as either A or B.

The first step in the study was to generate a baseline for comparison. This was achieved by determining the probability of working together when individuals in a cohort are randomly allocated to groups. This was derived analytically and further validated by a numerical Monte-Carlo model.

The analytical model was derived by first considering a student from a cohort population, P , and determining the likelihood of another student being selected as part of that group. Considering a group cannot be considered a group if members are less than 2 then the likelihood of the other student being selected in the next available opportunity is:

$$p = \left(\frac{1}{P-1}\right) + \sum_{i=2}^n \left[\left(\prod_{j=1}^i \left(1 - \frac{1}{P-j}\right) \right) \left(\frac{1}{P-i}\right) \right] \quad (1)$$

where p is the probability of individuals working together, P is the cohort size and n is the group size. The numerical model created to validate the analytical model's logic used a list of integers with each integer value representing an individual. The list was then randomly shuffled and 'chunked' into the desired group sizes. The model then iterated through the groups where it checked whether individual '0' was in the same group as individual '1'. This was repeated 10,000 times to capture the probability of the two individuals working together and compared with the analytical model with least squares fit to determine whether they corroborated.

The second model introduced the concept of their being a mutually exclusive characteristic where individuals could identify as either 'A' or 'B' and that a policy existed where design educators ensured groups never contained exactly one individual with an 'A' or 'B' characteristic.

This was modelled using a function that accepted the number of 'A' and 'B' students and the desired group size. Integer IDs were then generated for the 'A' and 'B' populations, respectively,

autoincrementing to avoid ID conflicts. Two IDs from both populations were tracked as the groups were allocated.

The two populations were randomly shuffled, and individuals within the two populations were paired up to ensure the no-lone working conditions were satisfied. This also meant that the algorithm was only suitable for even sized cohorts and groups, and this was deemed satisfactory as the study was interested in the general trends across cohort sizes and distribution of individuals across the ‘A’ and ‘B’ populations.

The pairs were then combined into a single cohort list, shuffled and then allocated into groups based on their order within the shuffled list. The algorithm then checked whether the marked IDs (e., A1, A2, B1, B2) were within the same group. The algorithm then returned True or False conditions for the cases of whether A1-A2, A1-B1, and B1-B2 appeared in the same group.

A Monte-Carlo simulation was run 10,000 times for group sizes of 4 and 6 and population sizes of 60, 120 and 180 to gain insight into the probabilities of students working together. The values attained were compared to the random allocation to demonstrate the effect of introducing the policy had on the opportunity of students being able to work together.

4 RESULTS

Figure 1 presents the results from the analytical (dashed) and numerical (continuous) modelling of the random allocation of students to groups. It also shows the effect of group size and cohort size. The results show that the likelihood drops off either exponentially or by some power-law as the cohort size increases with group size translating the curve but with decreasing effect. The numerical modelling confirms the analytical model accurately captures the probability of students being able to work with one another.

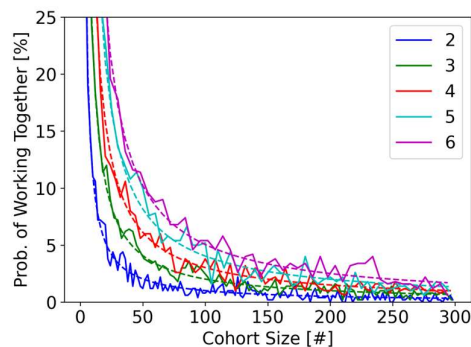


Figure 1. Probability of working with another individual across different population and group sizes

Figure 2 shows the probabilities of A and B students working together with the introduction of the no-lone working policy. All reveal the same pattern with the group size and cohort effectively translating the pattern across the probability range. When there is a population with low A then A-A becomes very likely, B-B tends to the same value as random selection and A-B is less likely than random selection. Moving to a 50-50 split of A and B makes the opportunity of A1-A2 and B1-B2 equivalent and higher than random and A1-B1 below random. A1-B1 remains constant across A-B ratios suggesting that the implemented algorithm trades A-B working for A-A and B-B working to conform to the no lone working constraint.

Increasing the group size for the same cohort population sizes increases the opportunity of individuals working together as one would expect given there emerges multiple opportunities for the individuals to be paired up. In contrast increasing the cohort size reduces the opportunity, flattens the curves around the 50-50 ratio and makes the biases more extreme where there are very low proportions of A or B (> 15%).

Figure 3 shows the same results but as a delta against the random selection value in order to quantify the difference. In the 4, 60 cases, a difference of 2% was observed between random and the opportunity of A1-B1 working together and a 2% increase in A1-A2 and B1-B2 when they are equally distributed. Much smaller differences are observed when the group and cohort sizes increase with a less than 1% difference in the 6, 180 for the majority of cases.

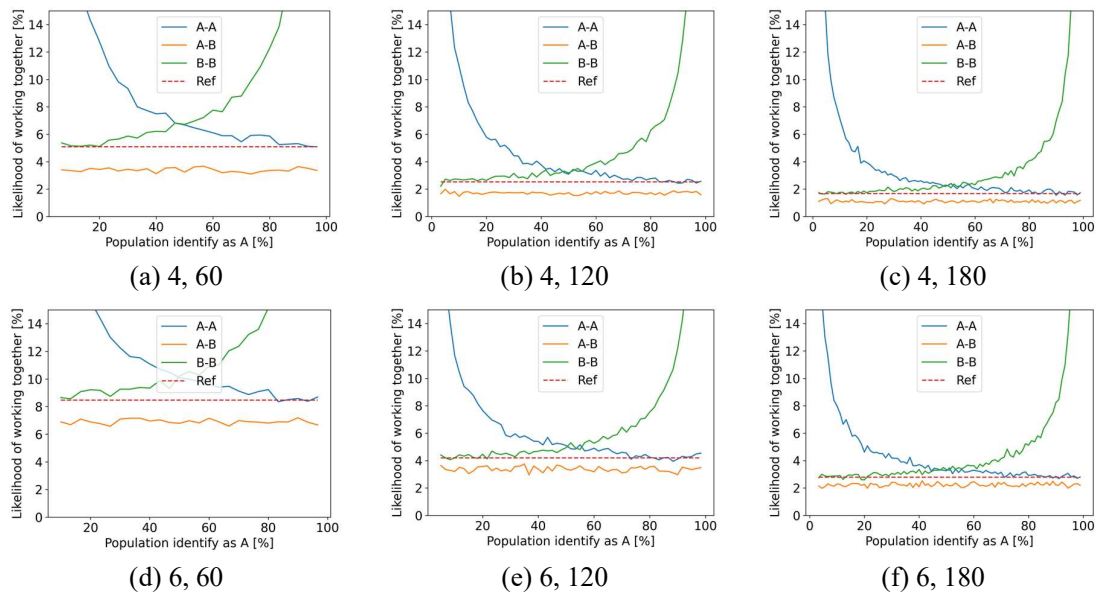


Figure 2. Opportunity for individuals working together

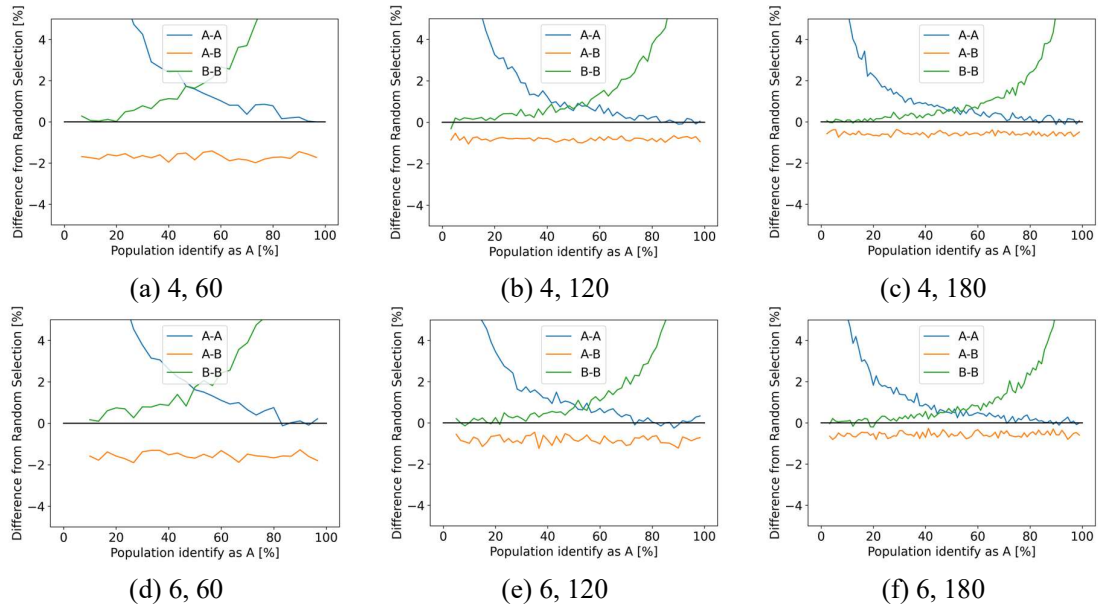


Figure 3. Difference in the opportunity for individuals to work together

5 DISCUSSIONS

The study has provided some additional metrics to complement existing work on group allocation strategies with a specific focus on how they affect the opportunity for students to work with another student within their cohort. The results have shown that constraint(s) can have a marked change on the opportunity for students to work together. The effects are more prevalent in smaller cohorts and group sizes. The study of the no lone-working constraint showed it effectively reduced the opportunity for a student to work with someone with a different characteristic. Larger cohort and group sizes are able to accommodate a greater number of constraints without significantly reducing the opportunities for any one student being able to work with another in the cohort, however this could incur other costs and complexities depending on the nature of the specific project and may not always be possible. This initial exploration into the potential effects of constraint-based group allocation has shown in a simple case that potentially significant reductions in inter-characteristic student working. As additional

constraints are added to the allocation process, it is likely that this effect will increase. Thus, it is important that this relationship is publicised to design educators, so that decisions in group allocation strategy can be made on a more informed basis.

Future work can expand this analysis to characterise the impact of multiple constraints and weighted constraints on the opportunity for any two students in a cohort to work with one another. The evidence generated from this work can accompany existing evidence on the effects of varying group allocation strategy (i.e. on safeguarding and student satisfaction) to help further inform and justify the group formation decisions made by design educators.

6 CONCLUSIONS

Group allocation is a critical step in design education where educators can configure and design the educational experience of the students. This paper has studied the effect of introducing a no-lone A-B policy for group sizes of 4 and 6, and cohort sizes of 60, 120, 180, and compared it to a random selection policy. The effects of the policy are largely felt at low cohort and group sizes with the opportunity of an A person working with a B person reduced by 2% in favour of increasing the opportunity of working with another from their respective populations. The increase followed a power-law behaviour with it increasingly significantly as their size becomes small in the relation to the cohort size. While the addition of single constraints may not shift the opportunities of students working together to a great degree, the compound effect may become profound when multiple constraints are considered and is an area of future work to be studied to ensure design educators have the information available to make further informed decisions on their group allocation strategies.

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SERVICE DESIGN FOR AND WITH CHILDREN: A COLLABORATIVE STUDIO EXPERIENCE

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ABSTRACT

Despite the prevalence of service design solutions for children in everyday life, “service design” and “design for and with children” are rarely introduced together in design education. This paper presents a scholarship of teaching and learning study that examines how service design can be integrated with designing for and with children in an undergraduate collaborative studio. The analysis draws on a reflective evaluation of two iterations of a studio course, a review of student submissions, and verbal feedback collected during studio sessions. The findings suggest that service design can function as a mediating pedagogical framework when teaching design for and with children. Service design tools, such as stakeholder mapping and service blueprints, act as boundary objects that help students coordinate different disciplinary perspectives while navigating the complexity of multi-stakeholder service systems. The coherence required to develop a service design solution with multiple touchpoints also encourages students to move beyond approaches based primarily on intuition toward more systematic investigation. Using the studio experience as a basis for discussion, this paper aims to initiate dialogue in design education by highlighting the pedagogical potential of integrating service design with child-centred design contexts and showing how this integration can contribute to a more holistic understanding of designing for and with children.

Keywords: Service design, designing for and with children, design pedagogy, collaboration, studio

1 INTRODUCTION

Service design solutions developed for and with children are common in everyday life. Public libraries around the world offer literacy-based engagement programmes for children [1], while educational institutions provide developmental services such as the use of Scratch, a visual programming language, in both schools and after-school programmes [13]. Similarly, companies and healthcare organisations increasingly develop service-based solutions that address children’s needs, such as Ollie, a system developed to support children during MRI scans [17].

Despite the prevalence of such solutions in practice, service design and child-centred design have developed largely in parallel, with limited pedagogical integration. These two areas are rarely introduced together in design education. Instead, they are often taught as separate subjects through lecture-based courses or independent studio projects. This separation is not entirely surprising, as the two domains require different forms of expertise. Service design challenges designers to adopt systems thinking, including attention to stakeholders, interactions, and processes across time and space, as well as the infrastructures that support them [12]. Designing for and with children, on the other hand, requires sensitivity to developmental differences across age groups, including cognitive, emotional, and sensorimotor capabilities [2].

These distinct knowledge requirements may explain why the two domains are rarely combined within studio-based educational settings. However, integrating them can offer important pedagogical benefits. Designing for and with children inherently involves multiple stakeholders, such as parents, teachers, caregivers, and institutional actors. Service design is well suited to addressing such multi-stakeholder relationships and interactions. In this context, service design can function as a mediating framework, with service design tools such as stakeholder maps and service blueprints acting as boundary objects that support collaboration among team members in the development of child-centred service solutions. This paper presents pedagogical insights from an undergraduate collaborative studio in which industrial design and communication design students worked together on service design projects focused on children. The study is structured around a research question that also informed the course design: How

can service design be introduced alongside designing for and with children to support collaboration among student teams? Through reflective analysis, a review of student submissions, and verbal feedback collected during the studio course, the paper examines how service design can mediate interdisciplinary collaboration as students navigate the complexities of designing for and with children.

2 SERVICE DESIGN FOR AND WITH CHILDREN

Designing for and with children is often associated with creativity, playfulness, curiosity, and imagination. While these qualities may suggest that developing design solutions for children is straightforward, the process is in fact complex and demanding [2]. Adults frequently struggle to accurately understand how children think, behave, and interpret the world, as these perspectives are shaped by developmental stages that adults have long moved beyond. In addition, children undergo rapid physical, cognitive, and emotional development, with changes occurring initially over months and later over years. These developmental dynamics mean that design solutions intended for children must account for age-specific needs and capabilities. As a result, designing for and with children often requires specialised knowledge and methods, which is reflected in the emergence of dedicated research communities such as Interaction Design and Children (IDC) [18] community and initiatives like FabLearn [19].

This area of design research and practice is particularly significant because early interactions with designed artifacts and services can have lasting impacts on children's development. As digital media [8], interactive technologies [4], and child-computer interaction [6] have become increasingly embedded in everyday life, the importance of child-centred design solutions has gained growing attention. At the same time, discussions around children's rights, agency, and participation have shifted the focus from designing for children toward designing with children [3]. Participatory design and co-design approaches have therefore become increasingly influential in research and practice involving children.

In addition to these changing dynamics, the design of child-centred solutions has always involved multiple stakeholders. Parents, caregivers, teachers, and other actors frequently mediate children's interactions with designed systems. Depending on the context, these stakeholders may play active or passive roles in shaping how children experience products and services. Parental mediation theory [9], for example, illustrates how parental involvement can range from active engagement to more indirect forms of guidance that nevertheless influence children's interactions with technologies and services.

The inherently multi-stakeholder nature of designing for and with children therefore calls for a systems-oriented perspective. Service design represents another area within design that similarly requires systemic thinking. As a field, service design focuses on coordinating the steps, tasks, stakeholders, physical and digital artifacts, and environments that together constitute a complete service experience. It considers how interactions between users, service providers, and other stakeholders unfold across time and space, requiring designers to understand the end-to-end relationships and value exchanges within a service ecosystem [11].

To address this complexity, service design employs a range of methods and tools [15], such as stakeholder mapping, journey mapping, and service blueprints. While these methods support the development of new service concepts, they also play an important role in facilitating communication and coordination among different actors involved in the design process. In this sense, service design tools can function as boundary objects in the sense described by Star and Griesemer [14], providing both flexibility and shared structure that enable individuals from different disciplines to collaborate effectively. These characteristics of service design can help designers who are new to designing for and with children navigate the complexities of this practice more effectively.

Despite these conceptual overlaps, service design and designing for and with children have largely developed as separate bodies of research with only a few exceptions [e.g., 5, 7, 10]. As a result, limited work has examined how these two areas intersect. This is especially true of their application in design education. To the best of my knowledge, no prior work has examined this intersection or provided pedagogical insights on the topic. This paper addresses this gap by exploring how service design can be integrated with designing for and with children in an interdisciplinary studio context.

3 A PEDAGOGICAL EXPERIENCE

The content presented in this paper falls within the wisdom-of-practice category and the personal narrative type of Weimer's [16] classification scheme for scholarship of teaching and learning studies.

The study draws on reflections from two consecutive years of teaching a studio course on service design for and with children. Reflective analysis is complemented by a review of student submissions and verbal feedback collected from students during the course.

The course was offered as a collaborative studio for fourth-year undergraduate students in industrial design and communication design. Students were tasked with developing service design solutions, along with their key touchpoints, to support children's play, education, health, and wellbeing. Over the two iterations of the course, 33 students participated and developed ten child-centred service design proposals. These proposals addressed a variety of contexts, including a public library service encouraging families to harvest and learn about food production, a subscription-based service teaching financial literacy to children, a photo-based diary service designed to support children's self-esteem, and interactive activities at farmers' markets aimed at helping children understand food sources and their physical and emotional effects.

Across the two iterations of the course, the studio structure was also adjusted. In the first iteration, students were introduced to general service design concepts before transitioning to designing for and with children. In the second iteration, this sequence was reversed and the course began by foregrounding child-centred design. This adjustment appeared to help students adopt a child-centred mindset earlier in the semester and engage more deeply with research and stakeholder perspectives than in the previous iteration.

The studio followed a four-phase structure: 1) immersion in the project space, 2) designing the overall service, 3) developing individual touchpoints, and 4) revisiting the service proposal based on insights gained during touchpoint design (Figure 1).



Figure 1. Course structure

During the first session, students were introduced to the concept of service design and its distinctions from product design. This session was followed by a two-week immersion phase focused on designing for and with children. The aim of this phase was to help students adopt a child-centred perspective through a range of activities. During this period, students participated in field visits, including trips to a local museum's creativity centre for children and the children's section of a public library. They also engaged in play-based exercises exploring differences between free play and structured play. At the same time, students conducted research on existing design solutions for children by identifying iconic products developed over the years. Secondary research was also conducted to understand the developmental stages of childhood and related physical, cognitive, and emotional considerations.

To transition from designing for and with children to service design for and with children, students conducted a service benchmarking exercise in which they defined and analysed two existing service solutions targeting children. The product design examples that students identified as iconic (e.g., L.O.L. Surprise collectible toys, Lite-Brite illuminated art toy, Scratch visual programming language and online community) along with the service benchmarking results (e.g., KiwiCo monthly STEAM subscription boxes, Cincinnati Public Library Summer Reading Program) remained visible in the studio space throughout the semester and served as reference points for discussion and comparison (Figure 2).



Figure 2. Collaborative analysis of product (left) and service solutions for children (right)

Following this immersion phase, students formed interdisciplinary teams based on shared areas of interest (i.e., education, play, health, entertainment, wellbeing, or others defined by students) and specific target age groups (i.e., babies, toddlers, preschoolers, grade school children, and teenagers). Each team included both industrial design and communication design students.

Teams then began developing initial service concepts. During this phase, students were introduced to service design tools such as ecosystem maps, user journey maps, service blueprints, and business model canvases. They also conducted secondary and primary research with children and relevant stakeholders (e.g., parents, teachers, doctors). Their primary research involved interviews and observations. During their interviews with children, students also used a probe specifically designed to help children further express their needs and wants on the topic being studied. These interactions led each team to develop a service proposal aligned with their research insights. As part of their service proposal, around the sixth week of the fourteen-week semester, teams identified key service touchpoints, and each team member developed one touchpoint while ensuring alignment with the broader service system. Feedback sessions with children and other stakeholders were also conducted during this stage (Figure 3).



Figure 3. Photographs from a feedback session with on touchpoint designs

In the final two weeks of the semester, teams revisited their service proposals and refined them based on insights gained through touchpoint development and stakeholder feedback. The semester concluded with expert review sessions in which local practitioners working in service design or child-centred design provided feedback on the projects.

3.1 Student feedback

Although students generally reported positive experiences in the course, they often described the process as demanding and complex. This tension is reflected in students' definitions of service design collected during an in-class exercise. Two main patterns emerged in these definitions. First, several students emphasised that service design extends beyond isolated products. For example, one student described service design as "a way to deliver an experience beyond just a product," while another defined it as "a cohesive system of products and interactions that serve people in a continuous service loop."

A second group of responses focused on the importance of considering multiple stakeholders. One student explained that service design "considers everyone including stakeholders, customers, and employees."

Interestingly, the same characteristics that students identified as central to service design - its systemic nature and multi-stakeholder scope - also emerged as sources of frustration. Students described the process as "looking at everything at once," involving "lots of components," and being "a complex process" with "many moving parts." At the same time, the context of designing for children was frequently described as motivating and engaging. One student commented that "service design can be fun when it is for kids."

Students also noted the challenges of understanding children's perspectives. Some expressed uncertainty about fully grasping how children think. Nevertheless, many highlighted the value of perspective-taking, noting that designing for children allowed them to "see a new perspective when designing," "reconnect with inner child," or "pretend like a kid again and step into their shoes."

4 DISCUSSIONS

The pedagogical experience described in this study highlights the potential value of integrating service design with designing for and with children in studio-based design education. While these two areas have largely developed as separate bodies of research and practice, the findings from this course suggest that they share important conceptual commonalities that make their integration pedagogically productive.

The studio experience described in this paper highlights three valuable aspects of using service design to introduce students to designing for and with children. Although designing for children requires careful attention to developmental differences and children's physical, cognitive, and emotional capabilities, students may initially rely on their own experiences or childhood memories when developing design solutions. Service design methods and tools encourage students to conduct primary research with children and other stakeholders and to evaluate design options from multiple perspectives. These multiple perspectives were evident in students' verbal feedback as well as in their final presentations, in which they situated their service solutions in relation to multiple stakeholders. This required students to move beyond their own childhood experiences and develop a more holistic understanding of their project topics. In this way, service design helped shift students away from intuition-based design approaches toward more systematic investigation and stakeholder-informed decision-making.

Another important observation relates to the role of multi-stakeholder and ecosystem maps in service design. Prior work on parental mediation highlights how parents and caregivers shape children's interactions with media and technology through different forms of guidance and involvement [9]. Similar dynamics emerged in the studio projects, where students recognised that children's experiences with services are often shaped not only by children themselves but also by parents, teachers, and institutional actors. This multi-stakeholder structure required students to consider relationships between actors rather than focusing solely on children as individual users. Such considerations challenged students to broaden their understanding and engage with the nature of designing for and with children more realistically.

Lastly, service design methods played a particularly important role in helping students collaborate and navigate the complexity of designing for and with children. Tools such as stakeholder maps, journey maps, and service blueprints enabled students to visualise relationships between actors, touchpoints, and environments. In addition to supporting the development of service proposals, these tools also facilitated communication among students working from different disciplinary perspectives. In this role, service design tools aligned with the theoretical description of boundary objects [14]. They provided shared structures that enabled collaboration between industrial design and communication design students.

Student feedback further illustrates two pedagogical tensions inherent in this process. First, many students described service design as valuable but challenging. They emphasised that it required them to consider a large number of interconnected elements. These observations reflect broader characteristics of service design practice, which often involves coordinating complex interactions between stakeholders, artifacts, and environments [15]. Second, while students found service design challenging, they found designing for and with children enjoyable. Students frequently described designing for children as motivating and engaging, suggesting that the child-centred context helped make the complexity of service design more meaningful. Designing for children required students to engage in perspective-taking and empathy, reinforcing the importance of research and observation in the design process.

Across the two iterations of the studio experience discussed in this paper, the second iteration, in which designing for and with children was introduced first, appeared to be strategically useful in helping students consider child-centred solutions from the beginning. However, this sequencing also changed the orientation of the project. While learning service design was more central to the project in the first iteration, in the second iteration, service design became more of a supporting framework for a project centred on designing for and with children.

5 CONCLUSIONS

Taken together, these findings suggest that service design and designing for and with children can be effectively introduced together in design education. The developmental and participatory aspects of child-centred design encourage students to move beyond product-focused thinking, while the systemic orientation of service design provides tools for organising and understanding the complexity of multi-

stakeholder interactions. Their integration within studio education can support a more holistic understanding of design processes that involve complex social and experiential systems. This study represents a small-scale pedagogical reflection based on two iterations of a single studio course. Future research could extend this work by examining similar pedagogical approaches in other design programmes and by developing more systematic methods for evaluating learning outcomes in design studios. Further exploration of how service design methods support collaboration in child-centred design contexts can also contribute to broader discussions of systems-oriented design education.

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URBAN GARDEN AS A TOOLKIT FOR UNDERSTANDING DIVERSITY IN DESIGN EDUCATION

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ABSTRACT

This paper advocates for a fundamental paradigm shift in design education, moving from a focus on mass consumerism and technical rationality toward ethical and ecological stewardship. Utilising the Futures Triangle methodology, the research analyses the tension between historical pedagogical models and the urgent environmental pressures of the present. By examining the historical weight of industrial productivity and the contemporary push of ecological crises, the study identifies pathways toward a more inclusive, empathetic, and socially just design practice. Central to this proposal is the conceptual framework of “design as gardening,” which reimagines urban gardens as “living laboratories” and “bioregions”. This approach moves beyond anthropocentric design models, encouraging students to engage with more-than-human agencies and local material conditions. By grounding pedagogical practice in a logic of care and bioregional diversity, the paper suggests how design education can cultivate the ethical sensitivity and systemic thinking necessary to address complex socio-ecological challenges. Ultimately, this work repositions the designer's role as a facilitator of collective growth and regenerative futures.

Keywords: Design education, urban gardens, Futures Triangle, empathy

1 INTRODUCTION

In recent decades, the fields of design and engineering, once rooted in human-centred principles infused with profound empathy, have undergone a troubling shift—for example, from durable, repairable products characteristic of artisanal and modernist traditions to disposable, mass-produced items driven by fast fashion and planned obsolescence—prioritising consumerism and unchecked capitalism over human-centred and ecological stewardship. This shift from durable products to disposable, mass-produced items reflects what has been termed a “mining” logic of design—an extractive process that prioritises output over the long-term logic of care and ecological stewardship [1]. This paper critically interrogates the shortcomings of contemporary design and engineering education, which perpetuate this trajectory, and proposes an urgent paradigm shift: embedding a multifaceted understanding of empathy and diversity to restore ethical depth and inclusivity in pedagogical practices. Specifically, this research examines how urban gardens can serve as living laboratories to cultivate empathy and broaden perspectives on diversity, thereby challenging the conventional approaches within design education [2]. To address these challenges, this study employs the Futures Triangle as an analytical and pedagogical framework to explore the interplay of historical precedents, current pressures, and future possibilities in design education. Framed as a reflective, practice-based case study, the research uses urban gardens as a contextual and methodological anchor to investigate how empathy, care, and diversity can be reintegrated into design and engineering curricula.

2 METHODOLOGIES: THE FUTURES TRIANGLE

Within this study, the Futures Triangle functions as a reflective analytical and pedagogical framework rather than a predictive tool, structuring the examination of design education in relation to care and diversity. As articulated by Sohail Inayatullah in his seminal article, the Futures Triangle is a straightforward yet profound futures studies tool designed to map the dynamic interplay of three essential forces shaping any trajectory toward a plausible or preferred future: the *weight of history* (pull of the past), the *push of the present*, and the *pull of the future* [3].

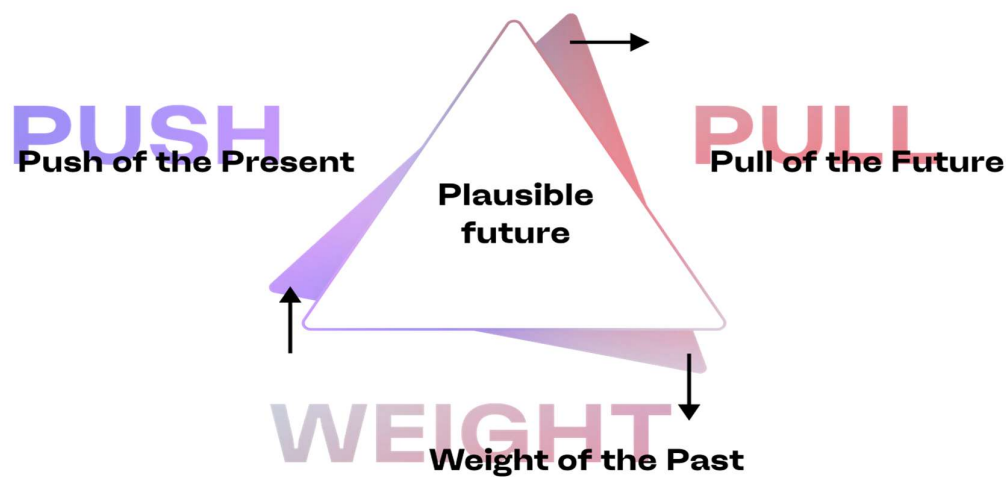


Figure 1. Futures Triangle (Andrija Mihailović, 2026)

The **weight of the past** encompasses entrenched structures, narratives, discourses, and cultural inertia that often resist change, anchoring current realities and constraining innovation. The **push of the present** refers to contemporary trends, disruptions, social forces, and systemic pressures—such as technological advancements or market demands—that propel movement forward, sometimes towards unintended outcomes. Finally, the **pull of the future** embodies aspirational visions, metaphors, or images of preferred futures that inspire action and provide direction, countering historical weights and harnessing present pushes [3].

In this paper, the Futures Triangle illuminates the evolution of design education through the urban garden metaphor, probing historical precedents of garden-inspired care and emancipation, present-day pushes from consumerism and anthropocentrism, and pulls towards empathetic, socio-ecological pedagogies. This framework offers a critical lens through which to analyse how urban gardens, as heterotopias of diverse, often competing visions, can disrupt binary utopian or dystopian views of design education and instead foster a more nuanced understanding of future possibilities.

Using the Futures Triangle, this paper develops a structured, qualitative reflection on design education. Its three dimensions—the weight of the past, push of the present, and pull of the future—provide an analytical framework for examining teaching practices, curriculum orientations, and student engagement in an urban garden-based learning context. Each section of the paper aligns with one dimension of the triangle, enabling a systematic exploration of tensions, constraints, and possibilities in contemporary design education.

3 THE WEIGHT OF THE PAST

The "weight of the past" refers to the enduring influence of historical pedagogical models that have profoundly shaped the epistemological foundations of design education. These models emerged in response to specific social, political, and industrial conditions, introducing radical innovations in how design was taught, practiced, and understood. However, their underlying emphasis on technical rationality, efficiency, and production-oriented problem-solving has narrowed the ethical and relational scope of design, privileging industrial productivity over care, situatedness, and social stewardship.

Among the most prominent institutions of the past in design education, the Bauhaus (1919–1933) stands as a foundational landmark that sought to bridge the gap between art, craft, and industry. It aimed to dissolve the distinction between the "fine artist" and the "craftsman," integrating artistic vision with industrial production [4]. For example, the Vorkurs was a mandatory introductory year where students entered specialised workshops that functioned as workplaces to commercialise Bauhaus-designed products, fostering a model of "learning by doing" [5], [6].

On the other side of the world Black Mountain College (1933–1957) in the United States emerged as a progressive educational experiment that similarly emphasised experiential learning and interdisciplinary collaboration. Unlike the increasingly technical schools in Europe, Black Mountain focused on the arts as the core of a liberal arts education, emphasising process and experimentation over industrial output [7]. While often seen as a successor of Bauhaus, Ulm School of Design (1953–1968) shifted the focus towards a more scientific and methodological approach to design, as the school moved toward a more technical and rational approach to address the complexities of post-war society. This shift best presents the move to a more present-type educational model [8]. Within the Futures Triangle framework, these

historical pedagogical models form the “weight of the past”, not due to any lack of value or innovation, but because their lasting influence continues to define what counts as legitimate knowledge, skills, and practices in design education. This persistence offers a foundation to build upon while also imposing constraints that must be critically navigated in envisioning alternative pedagogical futures.

4 THE PUSH OF THE PRESENT

The “push of the present” highlights contemporary forces, such as rapid technological advancements and urgent environmental crises, that necessitate a paradigm shift in design education to cultivate an ecological consciousness and foster interconnectedness between human and natural systems. There has been a clear disconnect between market requirements and societal needs, where marketability and product competitiveness often overshadow pressing demands for sustainability and broader systemic impacts [9]. This disconnect is also reflected in design education.

Specifically, there have been efforts to introduce sustainable practices and systems thinking into curricula, reflecting a broader transition that design and engineering educators are making to address the inadequacy of traditional, discipline-bound approaches in equipping students for a world beset by social and environmental crises. Within design education, these pressures and responses often result in curricular additions, such as sustainability modules or systems-thinking workshops, that remain marginal to the core pedagogical structure. As a result, ecological and social concerns are frequently addressed as thematic content rather than as foundational epistemological shifts, leaving dominant anthropocentric and consumerist design logics largely intact. These efforts, to introduce more sustainable approaches into curricula often encounter institutional resistance or remain superficial, failing to fundamentally challenge the dominant anthropocentric and consumerist paradigms that drive current design practice [10].

The push of the present thus provides a critical analytical lens for situational analysis based on teaching practice and observed tensions.

5 THE PULL OF THE FUTURE

To counter these entrenched paradigms, the “pull of the future” represents the aspirational visions and transformative potentialities that guide design education toward regenerative and socially just outcomes, drawing on alternative models that emphasise complexity, situatedness, and co-response-ability. The pull of the future is a speculative pedagogical framing that envisions possible futures not as fixed predictions, but as creative provocations to interrogate present trajectories and inspire alternative directions for learning and practice. This approach enables us to identify the essential competencies expected of graduates from design or engineering programmes, necessitating a shift towards curricula that are connective, systemic, and holistic.

6 PLAUSIBLE FUTURES

Within the Futures Triangle framework, a plausible future for design education emerges from negotiating historical constraints, present-day pressures, and aspirational yet situated pedagogical visions. Rather than envisioning a utopian outcome, this framing highlights feasible shifts in educational practices that recognise more-than-human agency and ecological interdependence in learning environments. Here, the pull of the future acts as a pedagogical compass, steering curriculum design, learning outcomes, and assessment methods toward relational thinking, ethical responsibility, and situated engagement, while respecting the practical and institutional realities of contemporary design education.

7 URBAN GARDENS AS A TOOLKIT FOR RETHINKING DIVERSITY: AN EXPLORATORY STUDY

This paper approaches urban gardens and community-based initiatives as exploratory pedagogical contexts through which regenerative imaginaries and future-oriented design practices can be examined [11]. Rather than presenting urban gardens as a definitive solution to the tensions discussed above, the study uses them as a grounded and situated context for reflecting on how design education might engage more directly with ecological interdependence, social diversity, and hands-on, community-oriented learning [12].

Using the Futures Triangle as a speculative exploratory tool, the section connects past influences, present forces, and future aspirations to reimagine design education through an unconventional metaphorical lens. This methodology is further developed through Fallan’s concept of “Epithelial Metaphors,” particularly his critique of design as “mining” and his proposal to rethink design practice

as “gardening”. In this sense, following Fallan, the urban garden is not treated merely as a site of cultivation, but as a pedagogical metaphor and methodological tool that supports a shift from extraction, production, and control toward care, maintenance, adaptation, and situated responsibility.[1]. Implementation of urban gardens as a pedagogical toolkit within a specific design curriculum, could therefore illustrate how living laboratories may support a transition from a paradigm of mining to one of gardening [1]. For this we need to interpret urban gardens not merely as static sites of cultivation but as bioregions. John Thackara conceptualises bioregions as spatial frameworks that reconnect human activity with ecological systems and local material conditions. Rather than defining space through administrative or political boundaries, bioregional thinking emphasises living systems as organising principles for spatial and social life. Thackara states, “A bioregion re-connects us with living systems, and each other, through the places where we live...” Bioregions thus serve as catalysts for social and ecological innovation by grounding design practice in the specificities of place and the interdependence of human and non-human systems [13]. This pedagogical shift requires students to engage in "learning to be affected" by the more-than-human, fostering an affective education where designers develop sensitivity to non-human agency and relational entanglements. This re-orientation transforms the design student into a "cultivator" or "gardener" of socio-ecological systems, fostering a sense of co-liberation and challenging dominant anthropocentric views prevalent in traditional design pedagogy [14]. This viewpoint holds particular significance in comprehending urban gardens not simply as green infrastructure, but as interconnected socio-ecological arenas where environmental dynamics and social activities intersect. It is also not necessary to limit this approach only to a physical realm of the bioregion but rather extend it to a methodological framework that informs how designers and engineers engage with complexity, adaptability, and the co-production of knowledge across diverse systems. This methodological extension is exemplified by the concept of "design as gardening," which applies a logic of care to the cultivation of conditions across all stages of design.

8 CONCLUSIONS

Using the Futures Triangle as a framework to reconstruct the past, present, and possible futures of design and engineering education helps to outline the key competencies anticipated from design and engineering graduates, calling for curricula that are interconnected, systemic, and holistic. By positioning urban gardens as exploratory pedagogical sites, this study suggests how immersive engagement with bioregional diversity may cultivate the necessary ethical sensitivity and collaborative capacity for addressing complex socio-ecological challenges. Rather than proposing a universal model, this paper positions urban gardens as one possible pedagogical toolkit through which design and engineering education can experiment with alternative values, epistemologies, and futures grounded in care, diversity, and ecological responsibility.

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AI-GENERATED FORMATIVE FEEDBACK FOR ENGINEERING LAB REPORTS

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ABSTRACT

This project examined the use of AI-generated formative feedback in a first-year undergraduate engineering unit, aiming to develop students' AI literacy and critical thinking. Students who opted in received feedback on draft laboratory reports from a locally deployed large language model. The feedback was discussed in small groups during an in-person workshop. It is hoped that, alongside peer review, this offers complementary opportunities for a diverse cohort to engage critically with feedback. Of 830 enrolled students, 390 submitted a draft and 374 opted in for AI feedback. Pass rates on the subsequent summative report were 70% for those receiving AI feedback versus 57% for those who did not. This difference remains confounded by known correlations between engagement with formative activities and overall attainment.

A deliberate design feature was the inclusion of one intentional inaccuracy in each student's feedback. This was explained to students beforehand and intended to promote scrutiny of feedback over passive acceptance of AI output. The activity was supported by a short presentation on responsible AI use and ethical considerations, informing discussions about trust, reliability, and the role of AI in education.

Survey responses were limited ($n = 32$), but 71% of respondents found the feedback useful and 89% revised their work as a result. Students valued clarity, speed, and rubric-based structure but expressed mixed views on the introduced inaccuracies. Findings highlight the importance of transparency, opt-in participation, and careful pedagogic framing when integrating AI tools into learning and assessment.

Keywords: AI, large language models, formative feedback, laboratory reports, large cohorts

1 BACKGROUND

1.1 Useful Feedback

Feedback is a strong contributor to student development, but more is not always better. Literature repeatedly shows that feedback can strongly influence achievement, yet effects vary depending on what the feedback contains, how it is presented and how students use it [1], [2]. A common explanation is that for feedback to be effective it must be a comparison to an understood standard and enable action towards improvement. In practice, staff often report a "feedback gap", where time is spent producing comments, but many students do not engage with them in ways that lead to longer-term [3], [4]. This has led to greater emphasis on student feedback literacy: the capacity to interpret feedback, make judgements about quality, manage affect and act on advice [5]. These challenges are amplified in large cohorts, where providing detailed feedback is difficult to sustain at scale. The problem is further sharpened in contexts such as lab report writing where iterative writing is essential when learning the skill for the first time. Peer review is one established way to increase feedback opportunities and learn through evaluation of others' work [6]. However, despite the pedagogical benefits of peer review, students often report greater trust in staff feedback, perceiving it as more authoritative or reliable than peer comments [7]

1.2 Generative AI to Support Feedback

Generative AI (Gen-AI), and large language models (LLMs) in particular, are increasingly being trialled as tools to support formative feedback. Recent reviews of Gen-AI for automated feedback in higher education report potential benefits such as rapid turnaround, scalability and rubric-aligned commentary, which may help address staff workload pressures [8], [9]. Evidence from writing-focused studies suggests that LLMs can provide usable early-draft feedback, but that expert human feedback often has better accuracy, prioritisation and specificity [10]. A further concern is over-trust: LLM outputs can be

fluent but wrong, and students may accept them uncritically unless activities are designed to encourage checking and judgement [11], [12]. Emerging work on engagement with LLM-generated feedback also indicates that students' revision behaviours may be superficial without explicit guidance and opportunities for dialogue [13].

2 PROJECT OVERVIEW AND AIMS

This paper reports on a case study from a first-year engineering unit teaching experimental practice and lab report writing to a large first-year engineering undergraduate cohort ($n = 830$). Within this project students could opt in to receive AI-generated formative feedback on a draft laboratory report. This feedback was tightly structured around the marking rubric and produced by a locally deployed (i.e., run on a computer on campus) LLM. The feedback was reviewed by students in small groups during an in-person workshop immediately after giving peer feedback. This facilitated session created the opportunity for student-student and student-staff discussion about the different sources of feedback and how best to use them productively. It also exposed students to the real-world challenge of reviewing and using different sources of potentially conflicting feedback. A key design feature was the inclusion of one/two intentional inaccuracies in each student's feedback. This was disclosed in advance to students and aimed to position the AI output as something to evaluate rather than accept. The activity was also supported by a short presentation on responsible AI use and ethical considerations, informing discussions about trust, reliability, and the role of AI in education. It should be noted that most published examples of AI-generated feedback involve students using an LLM 'chat bot' to generate their own feedback [8]. In contrast, this project generated feedback with a staff controlled LLM system implemented by the authors – this provided consistency in feedback quality and placed the live session's emphasis on critically reviewing the provided feedback.

This project aimed to (1) explore whether LLMs could produce useful, rubric-based formative feedback at scale, and (2) use the feedback and live session to encourage development of students' critical evaluation and AI literacy. The remainder of the paper outlines the unit context, details the intervention and summarises student perceptions from a short post-activity survey.

3 INTERVENTION DESIGN

3.1 Unit Context

This project was situated within a University of Bristol undergraduate engineering unit called "Engineering Communication, Measurement and Data Analysis" (ECMDA). This unit is taken by almost all first-year engineering students, resulting in a cohort of 830 in 2024/25 when the intervention was first implemented. ECMDA covers the fundamentals of experimental practice, data analysis in Python and lab report writing. The teaching and learning of lab report writing skills (which this project is focused on augmenting) is primarily carried out in flat bed teaching space shown in Fig. 1a, timetabled for a sixth of the cohort at a time (~140 students), sat in groups of ~3 in the room.

As described fully in previous work [6] and summarised in Fig. 1b, ECMDA relies heavily on an iterative peer review process to scaffold students learning towards a final summative lab report submission. A series of formative lab reports are submitted by students throughout the year, each of which is accompanied by a facilitated live peer review session where students review their colleagues' reports in small groups. This same peer review session is conducted for students' draft submission of their final summative lab report. The currently considered intervention was conducted within this final live session: in the second hour of the session the students were given the AI-generated feedback (as described in Section 3.2) and supported to review in groups (as discussed in Section 3.3).

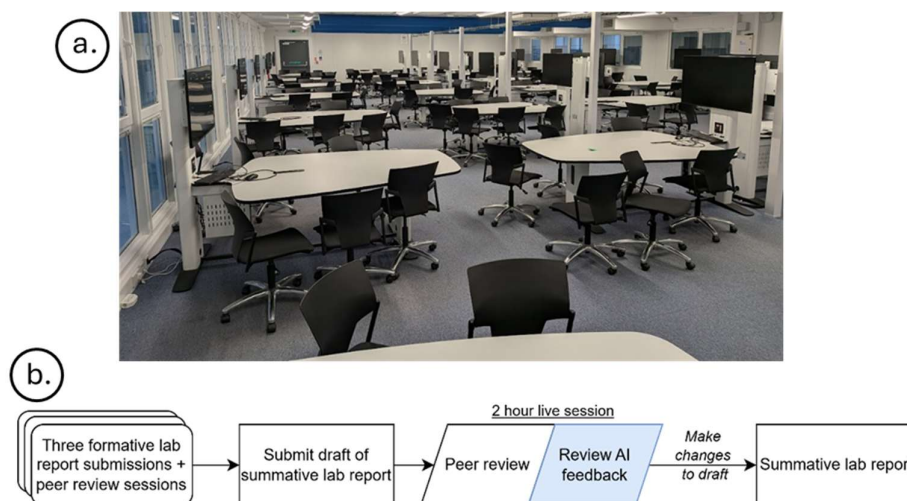


Figure 1. a) A photograph of the ECMDA teaching space used for peer and AI feedback review sessions (G.01, Ivy Gate, University of Bristol) and b) a diagram of the overall formative scaffold

3.2 Creating AI-Generated Feedback

We defined three design requirements for our AI-generated feedback:

Timely – Generation with a <24hr turnaround, for 400+ students (half the cohort as sessions were split across two weeks) with minimal human intervention.

Local compute – All computation should be local, using institution-controlled hardware, to ensure data privacy and, potentially, to reduce environmental footprint often associated with external services.

Structured – Feedback must be structured against the existing rubric and presented in a form that students can digest and critically review within the facilitated live session.

To meet these aims the following data processing steps were conducted for each lab report submitted by a student who opted to receive AI feedback:

Text from the lab report split into sections by an automated search for expected headings (possible as students used a provided template),

LLM used to iterate over the rubric, with each prompt:

Requesting feedback for one rubric criteria

Including only the relevant section of the report

Structuring responses to produce a) a *pass/fail* for the criteria, b) *reasoning* for this and c) supporting *evidence* from the report where relevant

One or two criteria which were originally assigned a pass chosen at random and the LLM prompted to provide evidence for the contrary. This was included, transparently to students, as encouraged inaccuracies (discussed further in Section 3.4),

Feedback against entire rubric formatted into a Word document and emailed to student during live session

The above process was implemented on a University of Bristol owned M3 Ultra Mac Studio and processing the full 33-criteria rubric for one lab report took ~60s. Example snippets of formatted feedback are provided in Fig. 2.

During development of this process the most popular publicly available LLMs at the time were qualitatively tested for feedback quality. The most effective LLM was found to be Microsoft's Phi4 [14]; which most consistently matched human assessment of the reports and adhered to output structure requirements (e.g., reasoning being concise and evidence being either blank or a quote from the report). It should be noted that at 14 billion parameters Phi4 is a relatively small LLM, especially when compared to commercial models such as OpenAI's GPT4, which is commonly reported as having over a trillion parameters.

Most LLMs tested were found to consistently match human judgement of reports for most rubric criteria. This is largely due to the narrow scope of most of the criteria, e.g.: “*the abstract describes the reports aim*” and “*the introduction presents motivation/background*”. Exceptions to this agreement were found for rubric criteria where relevant context/human knowledge is difficult to embed into the prompt, such

as “there is no misidentification of sources of error”. It is also challenging to moderate how lenient an LLM should be for criteria such as “references are formatted correctly” where humans tend to overlook minor issues such as misplaced punctuation.

Introduction Criteria: there is at least one reference (to an external source) to support the motivation or describe background information Minor/Major: No Reasoning: The quote references an external source, Junaid (2020), which provides background information on the importance of Young's modulus in engineering. Evidence: "According to Junaid (2020), Young's modulus is important in engineering because it allows engineers to select the most suitable material through characteristics such as bending stiffness during structural analysis."
Discussion Criteria: there is no misidentification of sources of error (e.g., due to a human conducting the experiment incorrectly) Minor/Major: Potential for a Minor error Reasoning: The mention of 'operation errors' suggests that human actions in conducting the experiment might contribute to inaccuracies or misidentification of error sources. Evidence: "The errors during operation include ratio errors, operation errors, and signal distortion."
Conclusion Criteria: the main result is described Minor/Major: No Reasoning: This quote directly presents the main result of the experiment by comparing the experimental value to the theoretical value, highlighting the outcome and error. Evidence: "The average experimental Young's modulus is 142 GPa, and the theoretical value is 200 GPa."

Figure 2. Three examples of AI-generated feedback provided to students as part of documents covering the 33 criteria in the rubric

3.3 Live Feedback Review Session

Placing review of the AI feedback in a live session and framing it against (different but also fallible) peer feedback was felt to be an important part of this intervention’s success. Immediately after students reviewed peers’ reports a short framing talk on responsible use of AI and its ethical and environmental issues was delivered. Students’ AI-generated feedback was then emailed to them, and they were given ~30 minutes to critically review it in groups of ~3, with members of staff in the room actively encouraging and engaging in discussion of how best to interpret it. As mentioned above, every student’s feedback included one or two intentional inaccuracies. These were included to encourage critical review of the feedback over passive acceptance. With the knowledge that both intentional and unintentional inaccuracies were likely to be present, the review task for students was to assign each feedback point with one of the following responses:

- a) Agree
- b) Disagree as the reasoning and evidence do not follow from the contents of their report (e.g., the LLM’s evidence is “hallucinated”)
- c) Believe the LLM’s reasoning and evidence to follow from their report but still disagree with the decision (e.g., because the evidence is not sufficient to demonstrate pass/fail on the criteria)

4 STUDENT SURVEY RESPONSES

Evaluation of intervention impact focused on student perceptions of usefulness and self-reported engagement with the feedback. A post-intervention survey was distributed to the full cohort (830 invited) and received 32 responses. Table 1 describes the questions asked and responses given.

Table 1. Post-intervention survey questions and responses (n = 32 respondents)

Question	Responses
Did you consider the assessment of your work by the AI tool to be useful?	Very useful - 4% Quite useful - 67% Not very useful - 22% Not useful at all - 7%
Did you make any changes to your report based on the AI feedback?	Lots of changes - 0% Some changes - 89% No changes at all - 11%
Has this AI feedback made you more/less likely to use AI to produce feedback for yourself in the future?	More likely to use AI for feedback - 33% No change - 48% Less likely to use AI for feedback - 19%
Since getting this AI feedback, do you think you will independently verify AI outputs...	More often - 22% As often as before - 71% Less often - 7%
Given your experience of both peer review and AI feedback, which of these enhanced your understanding and learning the most?	AI feedback - 7% The combination of AI and peer review - 52% Peer review - 41%
How many more opportunities for AI feedback would you like to see in this degree?	Lots more opportunities - 26% Some more opportunities - 56% Less opportunities - 15% AI should be avoided as a feedback tool - 3%
What were the key reasons / considerations for not opting for AI feedback? - Asked only if student reported not opting in to AI feedback. No other questions asked to these students.	<i>Free text, 4 respondents:</i> - Wanted staff feedback only (x 2) - Didn't expect to be useful (x1) - Strongly opposed to AI from ethical standpoint (x1)
What did you think about using AI for obtaining feedback on your report?	<i>Free text, 25 respondents, manual thematic analysis:</i> - Concerns about inaccuracies / hallucinations (x 14) - Helpful for spotting issues quickly (x 11) - Preference for staff feedback (x 3) - Helpful as a supplementary tool (x 3)
Please describe your experience of reviewing the AI output and evaluating hallucinations	<i>Free text, 23 respondents, manual thematic analysis:</i> - Inaccuracies / hallucinations were common (x10) - Experience general useful / positive (x7) - Confused by contradictions between criteria (x6) - Easy to spot inaccuracies / hallucinations (x4) - AI appeared to be scanning for key phrases (x3) - Interesting as an academic exercise (x1)

Despite the low response rate, the survey provides an indication that the intervention provided students with a useful supplementary source of feedback. A majority of respondents (71%) reported that the AI feedback was useful, and nearly all respondents (89%) reported making at least some changes to their reports based on the feedback. It is interesting to note that a majority of respondents (52%) reported the combination of AI and peer review feedback enhanced their learning more than either alone, and 82% of respondents wanted to see more opportunities for AI feedback in their degree.

The free text responses were manually coded for sentiment and theme. These contained requests for feedback from staff members but also comments on the usefulness of AI feedback for spotting issues quickly. There were negative responses towards the (intentionally included) hallucinations but also some that found them easy to spot and one response describing it as a 'useful academic exercise'. Pass rate on the subsequent summative report was 70% for those receiving AI feedback versus 57% for those who did not, though this difference remains confounded by known correlations between engagement with formative activities and overall attainment.

5 CONCLUSIONS

This paper demonstrates how Gen-AI can augment feedback opportunities for a large undergraduate cohort. In this pilot implementation, LLM-generated, rubric-aligned feedback was reviewed by students that opted-in to receive it, in a facilitated live session. The feedback was produced in under 48 hours (processing taking ~60 s per report on local hardware), was judged useful by most survey respondents (71%) and prompted revisions to work (89%).

Qualitative analysis of the AI feedback found good agreement with human judgement, with some limitations where rubric criteria required background/context to understand fully. An open dialogue in the live feedback review session created an opportunity for these limitations to be visible to students. To encourage scrutiny over passive acceptance of Gen-AI outputs one or two intentional inaccuracies were included in each student's feedback. This had mixed reception in the cohort but alongside framing of AI feedback against (also fallible) staff and peer review this process was positioned to build critical thinking and AI literacy.

Looking ahead, the ECMDA teaching team plan to further embed AI literacy and critical thinking in the unit by (i) exploring Vision–Language Models as a route to covering rubric criteria considering figures, tables, and document layout and (ii) running a workshop in which students are given live access to a locally run LLM to assist in critique of their report drafts.

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FILLING THE (EDUCATIONAL) GAP: DESIGNING FOR AND WITH THE FUTURE

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ABSTRACT

The Norwegian University of Science and Technology (NTNU) Department of Design continually explores innovative educational methods to support student creativity in higher education and position the university as an incubator of innovation. One track in this endeavour is to engage students in shaping their own learning environments, opening discussions on modernising design pedagogy and fostering a culture of empowerment and innovation. As part of this ambition, we tested a novel approach in the course Design in Wood. While our department is in an overall process of reconstruction and reconceptualisation, we saw an opportunity to involve students in literally shaping their own – and future design students' – physical environment. Working in interdisciplinary groups, students identified and analysed leftover spaces in the Design building and transformed them into useful places, based on current and future needs, aiming to enhance the use of circulation areas. This was not merely a theoretical design assignment but also involved that each group made a full-scale realisation of their design.

We interviewed the design students who took this course to explore the value of involving students in co-designing their joint environment and how such co-design exercises may contribute to modernising design pedagogy and foster a culture of empowerment and innovation. This work treats leftover and circulation spaces as sites for learning, identity, and empowerment, inviting students to co-design the very environments they inhabit. It combines full-scale making, spatial transformation, and student co-creation to modernise design education while adhering to diverse student needs, and ways of working. The approach may be useful for design educators, course coordinators, and university leaders who want to develop and establish strategies for turning campuses into inclusive incubators of empowerment and innovation. Potentially, external partners may benefit from the students' competences if paired with research funding. It may also benefit programmes beyond design that seek to engage diverse student groups in co-creating meaningful learning environments. Our findings indicate that the exercise strengthened students' sense of ownership, responsibility, and innovation. We argue that such assignments offer significant potential for turning universities into incubators of empowerment and innovation, offering a promising path for modernising design education.

Keywords: Co-design, learning environments, innovation in design education, furniture design/furnistruktures, full-scale making

1 INTRODUCTION

Design education increasingly needs to prepare students for complex, socio-technical and materially grounded problems. Yet we see a general drift in the design education toward more screen-based work and academic deliverables that can underplay craft, prototyping, and the tacit competences designers rely on in practice. In addition, there is increased pressure – and societal need – to educate students that are creative, solution oriented and innovative. This paper studies the experiences from a qualitative case study of a course in which students co-designed and built full-scale furniture and spatial structures – "furnistruktures" – for leftover circulation areas in their own design building.

1.1 Course context and intervention

The ongoing process of redesigning the Institute of Designs (ID) provided an opportunity to involve the students directly in this process. The intention in doing so was to support student ownership of the future learning environment, practical, non-digital making, tacit learning through working alongside skilled practitioners, and teamwork. The course Design in Wood _, given autumn 2025, asked students to "fill the gap" by identifying underused leftover areas in the design building and transforming them into useful

informal meeting places. This meant that, rather than designing an object for an exhibition or a hypothetical brief, groups had to respond to a real site, with existing constraints and users. The specific assignment was formulated like this:

“The Institute of Design is in the process of restructuring all areas.

Your job in DIW is to identify and analyse the useful (leftover) spaces in the ID building.

By adding furniture/structures, you should make good and useful places within the building, based on our current and future needs.

Fill in structures to enhance the use of all circulation areas; workplaces, social zones, individual spaces, etc.”

The students worked in small interdisciplinary teams of 3 students from design, architecture, and exchange students from abroad. They had access to expert craft support from a professional cabinetmaker (non-academic staff), enabling tacit transfer of know-how about wood, joints, tools and buildability. The course involved continuous work in shared spaces where passers-by could observe, ask questions, and provide feedback during the build. Hence, the assignment explicitly connected student learning to a tangible, shared outcome in the physical campus environment.

The idea of studying this course was born from something one of the researchers had heard when passing by one of the groups during their practical work in the design building.

“This is our legacy”

This simple statement was at the same time intriguing and awakened a wish to find out more about this learning experience and what may be learned from it.

2 CONCEPTUAL FRAMING

The project is grounded in three overlapping perspectives: students as partners, future-oriented design education, and the campus as a living learning environment. Together, these perspectives frame the design of furniture for leftover campus spaces not simply as an exercise in product development, but as a collaborative exploration of how universities can support future forms of learning, social interaction, inclusion, and sustainability.

2.1 Students as Partners in Design

The project builds on research on student–staff partnerships and co-creation in higher education. This perspective understands students as active contributors to the shaping of learning environments and educational practices. Recent research on co-creation highlights how students contribute forms of situated and experiential knowledge that complement the expertise of academic staff and institutional planners [1][2]. This perspective is particularly relevant in projects involving campus environments as students have direct experience of how campus spaces are used in everyday life; they know where people meet informally, where they wait between lectures, where they collaborate, rest, concentrate, or feel excluded. Therefore, designing furniture for leftover spaces becomes more than a design assignment; it becomes a way of investigating how campus life is experienced and how it might be improved. Research on student-staff co-creation also emphasises the importance of dialogue and transparency in collaborative educational processes [3][4]. Notably, partnership does not imply that all participants have identical roles or responsibilities. Rather, it involves recognising different forms of expertise and creating room for negotiation and shared decision-making. In a furniture-design project this means that questions concerning aesthetics, usability, sustainability, accessibility, feasibility, and maintenance become part of the educational process itself.

2.2 Designing for Future Campus Life

The project also draws on discussions about the future role of design education. Contemporary design pedagogy increasingly emphasises sustainability, systems thinking, and social responsibility alongside more traditional design concerns [5]. Design education is not only about developing objects, but also about understanding how design shapes everyday life and future ways of living together. Within this perspective, furniture can be understood as a spatial and social intervention rather than a functional object. Designing furniture for leftover spaces invites students to reflect on how campus life may change in response to new forms of learning, hybrid education, collaboration, well-being, and environmental awareness. Recent work on sustainability in design education argues that ecological responsibility should be integrated directly into design processes and educational practice [6]. This may involve working with reused materials, modular structures, repairability, adaptability, and low-impact

production methods. Leftover spaces may also be viewed as a sustainability resource: instead of focusing primarily on new construction, universities can explore how existing underused environments may be activated through relatively small interventions. It combines practical prototyping with exploratory and future-oriented thinking as the furniture proposals are not only intended to solve immediate needs, but open discussions about possible future forms of campus life.

2.3 The Campus as a Living Learning Environment

A third perspective concerns the understanding of the campus as a distributed and living learning environment. Research on learning spaces increasingly highlights the importance of informal and transitional environments alongside formal classrooms. Learning takes place not only during scheduled teaching activities, but also in corridors, entrance areas, staircases, cafés, waiting zones, and other in-between spaces.

Recent studies on co-designed learning environments suggest that learning spaces should be understood as adaptable environments shaped through interaction between users and surroundings [7]. Similarly, recent guidelines for active and informal learning spaces emphasise flexibility, movable furniture, and support for different forms of individual and collective activity [8][9].

This perspective is particularly relevant for projects focusing on leftover campus spaces. Such spaces are often overlooked because they fall outside formal categories of teaching and administration, yet they play an important role in students' everyday university experience. Research on in-between spaces shows how transitional and residual campus environments can support informal learning, social interaction, and belonging when carefully designed [10][11].

Furniture interventions can therefore be understood as small-scale acts of spatial activation. New "furnistruktures" may transform overlooked areas into meaningful parts of campus life. Research on campus design further suggests that spatial environments influence patterns of social interaction and community formation [12]. The project connects to broader discussions of leftover spaces as opportunities for adaptation, experimentation, and reuse [13]. In this sense, leftover campus spaces become places where alternative futures can be explored through interventions.

3 METHOD

We conducted a 45-minute group interview February 26th, 2026, with 5 students and 2 academic staff involved in the course. The interview explored experiences of the brief, teamwork, site-specific design, deadlines, learning by making, and we discussed possibilities for extending the concept to other courses and contexts. Analysis followed an inductive thematic approach. Speakers are referred to by role (student, course coordinator, staff) to maintain anonymity.

4 FINDINGS

4.1 Ownership, legacy and shaping the future learning environment

The students and staff experienced the interventions as a way of taking ownership of the building. By designing and building elements that remained in everyday use, the project changed the building from something fixed into something students could actively shape. This seemed to generate pride, both in the work itself and in the identity of the design program. A recurring theme in the group interview was a strengthened sense that students could legitimately intervene in the campus environment. The course coordinator described an emerging tradition of "using the building as if it is a bit ours", including the permission to "hack" and build in ways that would normally feel forbidden in institutional buildings:

"We use the building as if it is a bit ours... we can actually use it for more than just walking through and sitting here. We can develop it ourselves." (Course coordinator)

"We have started using the building in our own way. We can also hack it a little, build onto it in one way or another." (Course coordinator)

Students especially appreciated that their work could become visible, forming a lasting contribution rather than a short-lived display (Figure 1). Students worked differently when they knew the outcome would remain in the building and be used by others. The task felt more meaningful than a temporary exhibition piece or a conventional school assignment. Long-term impact seemed to increase commitment and raise the perceived stakes of the work. Their pride was obvious:

"It creates ownership... everyone gets to use it. In previous years projects were placed elsewhere, and I don't know where they are now, but this is here in the building for everyone's benefit." (Student)
"With this it becomes even more permanent. It becomes our legacy." (Student)



Figure 1. "Furnistructures" designed and built by students. Photos taken during building process with professional cabinetmaker and evaluation by academic staff. Photos: Dieter Van Dortmont

4.2 Tangible outcomes, real users and 'learning for the real world'

Because the outcome would remain in place, students invested more effort and were taking more responsibility for their design's impacts on others. This shifted motivation from "a project for us" toward "a project for the community," introducing authentic constraints. The build process also drew staff and other students into conversations, turning corridors into social learning arenas. Students emphasised the importance of designing for the actual place, rather than producing isolated objects. They started to notice when furniture or spatial elements felt misplaced – also in other environments – and appreciated making custom, integrated interventions that responded to the building's architecture and use patterns. This suggests a stronger sense of environmental and contextual design awareness.

"People put in more effort when it's going to stand here and be used by people. You're doing something for others and for the future." (Student)

"You generate a lot of discussion with people who pass by, and that creates engagement." (Course coordinator)

"We had dilemmas because many people came by with thoughts... we got feedback that if it sticks out too much it could be hard to pass." (Student)

4.3 Non-digital, full-scale making as a 'breathing space' in academia

The participants compared this course with more digital, theoretical, and academic forms of study. It was experienced as a valuable counterbalance to the non-physical characteristic of design education. Also, the practical use of tools, materials, and full-scale construction helped students understand design in a more embodied and concrete way. Several participants described this as healthy, human, motivating, and closer to how they wanted to work as designers, repeatedly contrasting the course with screen-based work. Full-scale building was described as refreshing, embodied and personally meaningful – offering a "breathing space" from academic routines. Importantly, students framed making not as anti-academic, but as a way of grounding theoretical knowledge in experience.

"It reminded me how I like to work... try, fail... not sit in front of a PC all day, but use hands and body. I missed that a lot in everyday school." (Student)

"It's valuable... you can say wood swells in summer, but it means nothing until you've handled it and seen it." (Student)

The course gave direct experience with a material rather than abstract knowledge, stressing that practical engagement helped them understand issues such as fit, assembly, and material behaviour in ways that theory alone could not. Wood was also seen as a good teaching material because of "its low threshold for starting, but high threshold for mastering well". Furthermore, it offered something scarce in academic education, access to tacit knowledge, and an escape from the digital world. As any tacit knowledge, this is hard to grasp. However, at the end of the interview, the course coordinator formulated something that made a strong impression on all interviewees:

"There's something deeply human in making." (Course coordinator)

4.4 Interdisciplinary teams, working together by doing and time pressure

Mixed groups of students created both challenges and benefits. Participants suggested that physically making something together requires a different kind of collaboration than theoretical teamwork. It fostered stronger interpersonal ties, practical negotiation, and a more immediate understanding of each other's perspectives. Teamwork in this course was described as very different; creating teambuilding through shared action, including negotiation under time pressure.

"We learned to do something together - not just discuss. When you solve something physical together it creates closeness, because it's complex." (Student)

"When you're standing and building right next to each other, it becomes another type of teambuilding." (Student)

"We were mixed - architecture students and design students... also exchange students, so we got language barriers and new perspectives." (Student)

The design process itself was not linear. Students described experimenting, receiving feedback from passers-by, adjusting ideas, and sometimes changing direction late in the process. Time pressure was present, especially in the final phase, which seemed to push decisions forward. The learning process was therefore closely tied to trying, failing, adjusting, and building (iterative).

4.5 Co-design beyond the group: feedback from users and inclusivity

Although the interventions invited comments from others, participants noted that this input often came later in the process, rather than in the early ideation phase. One student explicitly reflected that there could have been more involvement from the wider building community. So, while the project supported participation, it was only partly co-design beyond the student groups themselves. Participants described how the installations generated conversation, curiosity, and informal interaction among students and staff. The interventions did not only solve spatial problems; they also worked as social catalysts. Passers-by commented, asked questions, and became involved in discussions, influencing the design process. However, broader co-design involvement was limited in the earliest idea phase. The students suggested earlier and systematic user engagement could improve fit between intention and use. Nevertheless, the project's openness made it visible and inviting, contributing to a building identity that signals student presence, supporting informal ways of working.

"Maybe more involvement of the rest of the people who use the building - to get more opinions in the course." (Student)

"I notice the furniture isn't used the way we thought... but that's not a bad thing. It works, but we may have missed something in the use." (Student)

4.6 Need for interactivity, feedback and accountability

When discussing how the approach might scale to other courses, students were critical of passive digital delivery. They suggested that digital components should be short, interactive, and tied to action, and that frequent feedback is necessary to sustain engagement.

"In the cases where everything has been digital... it's just a lecture. It's completely useless to watch lectures while you walk; it doesn't stick. But interactive modules - where you click through and answer - can work." (Student)

"We need some feedback that makes it move forward." (Student)

Contrasting this course with conventional lectures, they argued that passive lecture formats are difficult to engage with, while interactive formats, staged deadlines, and feedback supports participation. This broadens the relevance of the findings to design pedagogy more generally.

5 CONCLUSIONS

This study suggests that full-scale, site-specific making in an educational setting does more than teach material skills. It fosters ownership, strengthens disciplinary identity, activates social interaction, and makes design work feel meaningful because it has visible and lasting consequences. The case illustrates how a site-specific, full-scale co-design brief can 'fill an educational gap' between studio talk and professional action. Across themes, the intervention cultivated student ownership of the future by making their work materially consequential. Their designs altered daily movement patterns, supported informal meeting, and became part of the building's identity.

From a learning perspective, the project centred tacit knowledge. Students described how concepts like wood movement became meaningful through handling and observation. This resonates with tacit knowledge theory and reflection-in-action, where understanding emerges through iterative engagement with materials and constraints. It also aligns with research on maker-centred pedagogical infrastructures, where learning develops through ongoing relations between tools, spaces, materials, and collaborative activity. The project also functioned as a different social infrastructure for teamwork and inclusion. Mixed groups brought diversity of perspectives, and the open build site invited informal feedback. At the same time, students noted that user involvement arrived late, suggesting that incorporating structured early-phase co-design activities could strengthen inclusivity by allowing a wider range of users and needs shape the project from the start. Finally, deadlines mattered. Rather than treating time pressure as a necessary evil, participants described time-pressure (deadlines) as the mechanism that kept them making continuously and learning from it.

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TEACHING ENGINEERING DESIGN RESEARCH SKILLS; AN AUTHENTIC APPROACH

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ABSTRACT

This paper discusses the introduction of a new module and innovative pedagogical approach in teaching Engineering Design-related research topics to final year undergraduate students. Students were taught through research seminars where there was a focus on engagement and debate. The cohort were given independence to hone their research topics and read literature. The students were asked to submit abstracts and anonymous paper submissions for peer review by scientific committee before they had to submit a final paper and assessed through conference presentations. While student feedback was positive, the paper acknowledges the variety of undergraduate perspectives on University-based research, expectations on individual interests, themes and topics as well as the appetite to pursue a post-graduate research career. The paper also provides some unique insights into cohort diversity and how the unit might be tailored or improved to sustain such diversity in the Engineering Design research field for the future.

Keywords: Research, innovation, authentic, conference, writing

1 INTRODUCTION

The field of Engineering Design research can be very broad and diverse, sitting at the “crossing point of two spectra from science to production and from art to politics” [1]. When considering Pahl et al’s [2] simplified view of research communities, it does show how closely interlinked Design Research is with Engineering Science, Technology and Industrial Design. As of 2009, the scope of topics, specialist interest groups and methodology also proves to be varied, from Design Processes (experimental methods and modelling) to Human Behaviour in Design (observation and surveying). Fast forward 15 years, to a research era that now includes artificial intelligence (AI), data-driven design and sustainable design.

At University, undergraduate engineering and design students are surrounded by researchers and centres of excellence. The lecturer teaching 2nd year thermodynamics could be a world-leading professor in gas turbine research but is diligently trying to explain how to apply heat transfer principles to an engineering problem; akin to having a world rally car champion as a driving instructor. Equally, academics and practitioners in design bring authenticity and industrial experience respectively to problem-based learning (PBL) and studio-based project work.

Beyond tutorials and project supervision, the research-focussed aspect of an academic is part of a lecturer’s role that students rarely see, but nonetheless “being taught by academics who are active researchers is seen as stimulating and associated with teaching being seen as authoritative and the curriculum up to date” (as long as the research does not take them away from teaching). [3]. In circumstances where undergraduates partake in a research project, they may get a better glimpse into their supervisors’ disciplinary expertise. Students, particularly those in final year of an integrated masters, are treated almost like pseudo-PhD students. Their supervisors scrutinise their literature, methodology and analytical approach, and their final dissertations are assessed with a high degree of academic rigour. At this level of study, there is an expectation that students can scope projects and critically review academic literature. There are a range of approaches for facilitating this, from specialist modules to integrating resources and support in a final year design or engineering project (approaches include *active learning, PBL and cooperative learning*). This can prove to be challenging as ‘*research methods education is not an established field of research like, for example, math education, nursing education, science education, or statistics education*’ and anecdotally students fail to see the relevance of research to their course, are anxious or nervous about the difficulty of the course, or simply uninterested or unmotivated. This prompts further research in learning outcomes and assessment, to help

students understand the *process* of doing research [4]

A typical learning outcome would be to ‘search, appraise and synthesise literature’. For example, a literature review is a critical component of an engineering dissertation, as well as any conference or journal paper. A 2014 study by Maura Borrego et al [5] indicated that the number of systematic reviews from Scopus (between 1995-2012) for developing interdisciplinary subjects (in this case, engineering education) was relatively low. On a subject basis, engineering had approximately half the number of reviews compared to education, and a quarter compared to psychology. The study argued that not only would engineering students gain valuable experimental results but also draw from other disciplines when it comes to appraising the efficacy of design. Well established methods such as the PICO framework are discussed, as well as adaptation of PRISMA. Another well-cited study in 2018 [6] also provides a range of methodologies to conduct systematic literature reviews in a highly structured manner within the field of engineering research, but what strikes as typical of engineering design research is the broad range of quantitative and qualitative information in the field, as well as interdisciplinary within other associated fields, such as psychology. This often makes engineering design research more complex and somewhat distinct from traditional experiment-focussed literature.

Regarding structure, the life of a typical postgraduate research (PGR) or PhD student is not as neatly timetabled as a final year undergraduate. PGR students often work in research teams with others and have a strong relationship with their supervisor. Some PGR students may be expected to attend research seminars, or publish papers, present posters or attend workshops at conferences. Despite technically still being part of a post-graduate student community (or graduate school in the US), there is a balance of learning academic research skills, professional development and the discipline of scholarly thinking.

As such this paper explores the creation of a dedicated research-focussed module, which was offered as an elective to final year students on a design course, to provide a means of experimentation with different learning approaches and defined learning outcomes over a 2-year cycle. This unit was adapted from and compared with another research module which was mandatory for Mechanical Engineering students. The outcomes of the paper may prove useful in improving the following objectives to successfully integrate research methods teaching into final year engineering and design projects:

- Help students **understand the process** of academic research in an **authentic** manner
- Ensure **appropriate learning outcomes and assessments**
- Provide **relevance** to student’s course and discipline
- Support anxious and nervous students who find **active learning difficult**
- Maintain **interest and motivation**

2 THE WORLD OF RESEARCH; PUBLISH OR PERISH

It is important to note that students undertaking this optional unit would have done so in an elective manner and would already have some invested interest compared to students who would have to undertake a mandatory research project. The module also doubled down on Engineering Design research and associated specialist topics in this field to ensure disciplinary and course relevance. From the outset, students were asked to discuss their prior understanding of academic research and research specialisation within their own School of Engineering, which includes advanced research in aerospace composites as well as geotechnics, civil engineering structures, earthquake engineering and infrastructure (to the cohort’s surprise there is no dedicated research group for engineering design within the University. Part of the introduction was to impart a broad understanding, as well as introduce advanced research tools (including reference management, and institutional access to research literature). Students were also introduced to the differences between conference and journal papers, as well as their proceedings.

Following this, students were introduced to Engineering Design research, helping them understand the diversity of topics, as well as appropriate research methodology. This is where the diversity of engineering design research was acknowledged, and as students explored areas of interest, they gained a good understanding of appropriate methodology. They also gained an insight into engineering education research, research specialisation within the school as well as research which is conducted in collaboration with industry (for example, Autodesk) as part of the unit delivery. A PhD showcase was also conducted where current PGR students can discuss their research, as well as build some rapport with the cohort on why they chose a research career.

The scope of research, even in a single field, can be somewhat overwhelming for an undergraduate student on a time constrained module. To help ensure a manageable approach to literature reviews and methodology, a research ‘theme’ was introduced (much in the same way in conference proceedings). In

the first year of delivering of the module, students were asked to explore the impact of Artificial Intelligence in the Engineering Design field. For the cohort in the following year, the theme was a little more nuanced towards AI use in human-centred product-service design. By introducing a theme and disciplinary area, this ultimately provided a more systematic and manageable approach to relevant research topics and appropriate methodologies. For example, students interested in Design Organisation and Management were referred to literature studies, as indicated by the number of relevant papers in that specialist interest area.

With a relatively small cohort, students were treated like they were part of a research group and given a lot of freedom and autonomy. The module schedule and contact hours were skewed to allow as much time for self-study and writing as possible, with only a 2hr class scheduled in the week followed by a 1hr drop in (which students could use for 1:1 supervisory meetings or group discussions)

The chaos of academia dictates a 'publish or perish' attitude, and undergraduate students were not spared from joining the madness. To 'publish' a conference paper, students were asked to submit abstracts, followed by a full anonymised paper which undergoes a rigorous academic peer review. After edits, tweaks and re-writes, the students submitted a final paper which was followed by a conference presentation (which included a keynote speaker, poster sessions and sandwiches of a questionable quality). The comments provided in each submission provided ample formative feedback for students to develop and hone their research paper before undertaking the final revision (be it minor or major). Students also had to follow an established template and format and ensure paper numbers were assigned.

3 AUTHENTIC LEARNING OUTCOMES & ASSESSMENTS

With a dedicated research module, the learning outcomes and assessments could be directly tied to understanding the process of research and prepping undergraduate students for a potential career in academic or industrial research. Key learning outcomes included investigating state-of-the-art research developments, appraising resources and using appropriate tools for conducting research as well as discussing research findings in a peer-reviewed conference paper, written to a professional, academic standard, which made up the bulk of the module marks. A critical learning outcome associated with the conference presentation was to present findings and research impact in a clear, accessible and coherent manner, with the ability to answer questions and take comments. As such, the Q&A aspect of the presentation was weighted significantly higher than any assessment criteria related to presentation quality or delivery. As academic conferences include presentations, posters and workshops, students were given the option to either present an oral presentation or poster as part of their summative assessment. This approach provided an alternative to students who, for various reasons, may find oral presentations difficult, and was aligned to the University's Assessment and Feedback Strategy that strived to assess students learning in different ways, and offer alternatives for assessments that some students may find difficult. Instead of speaking in front of an audience, poster presentations were conducted in a more open, in-formal manner. The trick was to run the presentation assessments like a pseudo conference, such that it did not feel like an academic assessment at all. Students were encouraged to invite friends for moral support and feel more like an inclusive community of networking academics rather than students being marked (this was deemed significantly less triggering than a mock PhD viva/defence). The pseudo conference format offered ample breaks, the allure of a free (albeit disappointing and fashionably late) lunch and 'fun' workshop and networking activities. At the close of the 'conference' academics and the student cohort voted on who should receive the accolade of 'best paper', 'best presentation' and 'best poster'.

To ensure authenticity, students were asked to submit their conference paper in a rigid format (such that proceedings were consistent) and were scored using criteria directly mapped from those used by a scientific review board, which included thematic relevance, significance of theory and practice as well as innovation and originality. The student cohort were surprised to learn that a significant proportion of the marks (almost 50%) was attributed to the 'overall recommendation of the academic reviewer' and remarked that the fate of their paper being accepted for publication or rejected was determined by two (or three) independent academic viewpoints that they have no influence or control over.

4 SEMINARS VS LECTURES VS LECTORIALS

Another important consideration about life in academia is that PhD students do not go to lectures but may be expected to attend research seminars. A seminar is distinct from a lecture in that it is designed for a smaller audience (typically lectures could be 200 students, but seminars work well with smaller

cohorts of 30-40 students). As such, when compared directly, seminars are deemed better designed to stimulate interest, prepare entry level students in their learning and offer somewhat higher value to lectures; especially when it comes to professional knowledge or practice [7]. For specialised engineering topics, a seminar provides a degree of efficiency as it adequately supports pre-learning and consistency of engagement (students need to come to the seminar prepared) [8]. Moreover, a seminar provides a more intimate intellectual experience with academic staff and exposure to engineering thought, especially when an academic can use the session to talk about what they like [9].

The delivery approach for the research module was also inspired by lectorial formats used at NTU and other institutions, which provide a high level of intellectual engagement as seminars but can be adaptable to larger cohorts (100+) [10]. Students were asked to do some prior research and read a relevant paper or two prior to attending the session. As such, they were asked to be a participant in their learning rather than an observer and actively encouraged to ask questions during the session, especially if they did not understand something or needed clarification. Speakers were also given freedom to include questions or any forms of discussion during the session without being strictly timed, which allowed academics to expand on their points if required. As such, the 1hr lecture slot (in reality-45min once latecomers arrive and the room is used for another class) was deemed to be constraining and seminars lasted up to 2hrs. Rarely, was this timeslot used to full capacity but it did offer an opportunity for slower pace of delivery, 1:1 interactions, breaks and off-topic conversations, which would be otherwise difficult to achieve in a single lecture.

5 LEARNING TO READ PAPERS; & WRITE PAPERS (& DO ARITHMETIC)

University library services provide an abundance of services to undergraduate engineering students that they rarely seem to take advantage of. This includes direct access to research literature as well as standards, workshops for reference management software, patent searches, LaTeX and more. Many University libraries have pivoted to providing e-books for teaching, as opposed to having multiple print copies, for the large-scale demand of engineering students. Students on the design course are given a literature review exercise to conduct as part of their design methods model (critiquing papers in design thinking, rapid prototyping and inclusive design). This exercise proves to be a continual challenge for students, not only due to the loose essay-based format (which is widely different from technical and lab reporting students are used to), but also the amount of reading, resource management and synthesis of information it requires.

Many conference and journal papers are available in pdf format, which is ideal for downloading or printing in proceedings, but are not particularly engaging to read on a laptop or PC, let alone a smartphone (although some students do try). In the modules goal to give students more time to research, read and critique academic literature, a case-control study was conducted which allowed students to borrow a tablet device, on the basis that they would use the device primarily for reading literature and making notes. It was made clear to students that the use of a tablet did not provide an advantage to achieving learning outcomes (as all literature was available in multiple formats-and some students had their own personal devices). The study was to observe how students used the devices and gain some valuable insight into how they interact with unit content in this format. From a qualitative perspective, students remarked that the tablets allowed them to read papers on public transport, and away from their desk (they also acknowledged that they often read books for pleasure but have rarely handled a physical book or publication used for their studies). Comparative or quantitative studies on tablet use for reading in a higher education setting are somewhat limited, but literature around the use of these devices for improved reading and comprehension in school environments is extensive, since the introduction of these devices in 2010 [10]. Studies have indicated that access to tablet devices can assist struggling readers, such as those with Attention Deficit Hyperactivity Disorder (ADHD) [11]. Tablet technologies have been acknowledged as an effective means for improving reading rates, as well as providing accessibility to low-vision readers [12]. The current University Library Services provision is limited to short-term laptops and reading aids for students with disabilities, but other institutions, such as Imperial, can provide tablet devices on long term loan for any student on request. Further research is required in this area, given the studies were limited, but it opens a pedagogical research question that asks if students disinterest and poor engagement with academic literature could be linked to reading issues experienced in primary and secondary education, or English being a second language (after all, Engineering courses only ask for qualifications in Mathematics and Science as entry requirements). An engineering or design student with reading difficulties (visual impairment, or ADHD for example) would be able to navigate

course content, online resources and use appropriate, assistive tools in writing a research paper using a word processor and other software; but to read and synthesise information from a document, report or paper, may prove more difficult. This also demonstrates a viable threat from Artificial Intelligence, with tools becoming more advanced in the critique, summarisation and translation of text, bypassing the synthesis and critical thinking process. Tablet technology may help provide an inclusive and accessible means for students to access literature within a research-based module (and beyond), and coupled with adequate time and freedom to read, may help counter some of the difficulties diverse ranges of engineering students face in engaging with a research module (through no fault of their own). A significant amount of further research is required in this area (a separate study along with appropriate methodology) but seems like a relatively simple intervention to promote equity when accessing academic literature in a Higher Education context.

6 DISCUSSION/CONCLUSION

Over two academic cycles, the experimental research module has been withdrawn, and reflections and learning can potentially be integrated into other modules, programmes and academic practice. Comparing the outcomes of the design students research module, at time of writing, with that of Mechanical Engineering students, it can be noted that students that had chosen a research pathway tended to be more motivated and engaged. Mechanical Engineering students on their research unit were given a broad range of advanced topics (ranging from Biomechanics to Automotive Engineering) and were randomly allocated a topic for their assessment. While learning outcomes were closely matched, the assessments were different. The design module opted for an authentic conference paper submission followed by a presentation element, whereas the Mechanical Engineering module asked for a single piece of coursework in a technical report format. While the design module leaned on Engineering Design research and guided students in terms of topic and appropriate methodology, the Mechanical Engineering module offered dedicated topics with in-depth analytical approaches. The Mechanical Engineering students had a busy timetable, whereas the design students had significantly more self-study time, and less in-contact hours. While it is hard to quantitatively compare both modules and their approaches, the difference in scale is significant (with over 200+ students in the Mechanical Engineering module, and between 3-6 in the design module). In both programmes, these modules were coupled with a capstone group project activity.

In terms of meeting objectives, the following insights are as follows:

- Helping students **understand the process** of academic research in an **authentic** manner
Consider treating the undergraduates like PhD students, acting as supervisors and facilitators to their research topic. This should be a 1:1 relationship, or a small group. Their goal is to create publishable, meaningful research in their disciplinary field.
- Ensure **appropriate learning outcomes and assessments**
Focus on the skills required for appraisal of resources, synthesis of information, writing in an academic format for publication and providing sufficient means for formative feedback (abstract and peer review of paper), a presentation style assessment or viva is also recommended.
- Provide **relevance** to student's course and discipline
Play to the institutions research areas and centres of excellence, as well as individual academics and their research specialisation. Invite students into research areas or labs they are not normally permitted to enter and interact with PGR students to spark interest in a potential research career.
- Support anxious and nervous students who find **active learning difficult**
1:1 support and feedback are important for guidance, create an inclusive learning environment and give students the appropriate tools and time to succeed. Provide alternative means of assessment for students who find presentations or oral speaking difficult.
- Maintain **interest and motivation**
For small cohorts, consider a seminar format (allow academics freedom to talk about what they want) and for larger cohorts, a lectorial format may suffice. Allow freedom and time to ask questions and debate; avoid lectures.

Furthermore, it is important to ensure that students have the right tools for success, from access to library resources and reference management software, as well as IT equipment. The merits of using tablet devices to facilitate accessibility to reading will be further explored.

Further work will be conducted in how these insights could be integrated into final year research projects or other research-focussed modules. There is also a wide range of publications around the appetite,

retention and diversity of the post-graduate research community within engineering and design, which warrants further investigation. This includes studies around gender equality, ethnicity and mental health, which may offer valuable insights and comparisons between

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TEAMING UP TO PREPARE STUDENTS FOR PUBLIC-SECTOR SERVICE DESIGN

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ABSTRACT

Preparing students to design for diverse communities and complex welfare systems requires authentic collaboration between universities and local communities. This paper explores experiences from a university-city collaboration in which design students taking a service design course worked with municipal staff connected to four child- and youth-service districts. Drawing on surveys and reflections, we identify three interconnected forms of learning supported by the partnership: applied design competence, reciprocal learning across institutional contexts and the more tentative development of institutional literacy. We discuss how such partnerships can contribute to mutual value creation in design education and public-sector practice and propose pedagogical adjustments to make learning more explicit.

Keywords: Institutional literacy, situated learning, public-sector design education, university-city collaboration, service design, design education

1 INTRODUCTION

Although scholars such as Herbert Simon and Donald Schön framed public administration as a form of design decades ago, public-sector design only gained widespread traction much later, with the mainstreaming of design thinking in the 2000s and its uptake across governmental systems and services [1]. Today, public-sector design encompasses diverse practices, including service, policy, participatory, strategic and systems design, which enrich the field while complicating a cohesive understanding of design's evolving role [1]. As Pirinen et al. [2] note, design often enters the public sector with different values and logics, causing friction in practice. For design education, this presents a central challenge: preparing design students to engage with the complexity and institutional realities of welfare systems. Doing so increasingly requires authentic collaboration between universities and municipal partners. Yet there is limited insight into how real-case municipal collaboration contributes to learning across stakeholder groups, and uncertainty remains about what constitutes meaningful “making” in service design education and how deliverables connect to societal challenges [3]. Drawing on empirical material from a service design course conducted in collaboration with a municipality, this paper examines the forms of learning such partnership supports. The study is situated in Trondheim, Norway, and addresses educators, students and public-sector collaborators engaged in university-city partnerships.

We contribute to the field by foregrounding *institutional literacy* as a distinct learning outcome for public-sector design education, alongside applied design competence and reciprocal learning. By this we mean the capacity to read how welfare systems are organised, where decisions are made, and how design proposals connect to ongoing municipal processes. Our empirical material highlights a perception gap, in which students experience institutional uncertainty while partners recognise emerging competence. We argue this gap is part of how such literacy is built, and one public-sector design education should pay closer attention to.

2 BACKGROUND AND EDUCATIONAL CONTEXT

2.1 Conditions shaping public-sector design and learning

Service design, particularly in public-sector contexts, places demands on education that differ from those in commercial product contexts. Public organisations are characterised by complexity, bureaucratic constraints and persistent implementation challenges, requiring designers to work with different forms

of materiality. Rather than physical materials, designers engage with conversations, collaborations, institutional cultures and organisational histories [4]. Studies show that relational and organisational materials shape tensions and frictions in practice [5]. This requires access to real contexts and situated insights, as well as the ability to recognise underlying values, adopt an open mindset and engage in relational learning across professional and cultural boundaries. Co-design has therefore become central in public-sector contexts, providing access to lived experience and expert knowledge, building shared understanding among diverse actors, and delineating a process in which intangible insights are translated into actionable proposals.

Public-sector design is also shaped by how design roles are interpreted within organisations. Designers may be positioned as facilitators rather than practitioners engaged in concrete (re)design [6], reflecting differing expectations about what design should accomplish. Design education must therefore move beyond method training and support students in developing relational and organisational literacy, together with the skills needed to understand how design is and can be positioned in municipal contexts.

2.2 University-city collaboration in design education

University–city collaborations represent an important arena for developing the kinds of design capabilities that public-sector and municipality contexts require. While public-sector design operates with materials such as conversations, collaborations, institutional cultures, responsibilities and organisational histories [4], municipalities increasingly emphasise that collaboration must create both public purpose and public value. This means that partnerships between universities and municipalities must move beyond the formulation of goals, missions and visions, and instead cultivate the capacities, methods, learning processes and institutional shifts that make value creation possible in everyday practice. Recent public reports highlight precisely these systemic and strategic needs, pointing to the forms of competence and capability-building that are necessary for long-term societal change, including cross-sectoral coordination, citizen-oriented approaches, and iterative, learning-based practices as articulated in the national societal mission for inclusion [7] and in a local ten-year innovation programme [8]. Such reports operate on a strategic level; in our collaboration we translate these ambitions into concrete collaborative settings where students, municipal staff and community partners jointly explore how new knowledge, collaborative practices and everyday work methods can be developed within real municipal contexts. At the same time, such collaborations might strengthen municipalities' own epistemic capacities, their ability to create, share and act upon knowledge in dynamic and uncertain environments. As Kattel and Mazzucato [9] argue, innovation policy in Europe is shifting from a normative focus on direction-setting to an epistemic focus on how public organisations learn, interpret problems and mobilise diverse forms of expertise. Situated collaboration with students supports precisely this epistemic turn by fostering organisational reflexivity, shared sense-making and collective learning. Thus, university–city collaboration functions not only as an educational intervention, but also as a mutual platform for developing future-oriented skills and capabilities, relevant both for emerging designers and for public sector professionals engaged in societal transformation. Such collaborations also align closely with 21st century skills [10], including complex problem solving, critical and systems thinking, interdisciplinary collaboration and communication. Designing in municipal contexts requires students to navigate ambiguity, reconcile diverse professional logics and engage in reflexive, relational work, competencies that extend beyond method training and mirror contemporary skill frameworks.

2.3 Educational context and collaboration setup

The collaboration was conducted within a third-year introductory service design course in a five-year engineering master's programme in Industrial Design at the Norwegian University of Science and Technology (NTNU), in partnership with Trondheim Municipality. The 15-week course (7.5 ECTS) involved 28 students working in six groups and combined foundational perspectives on service design, sustainability and public-sector contexts with practical training in user research, co-creation, sense-making and prototyping. Throughout the project, students were expected to apply The Everyday Journey as a guiding framework [11], a step-by-step structure for developing environments and services that support active, social and meaningful everyday lives through insight work, co-creation and prototyping. The course aimed to prepare students to engage with complex societal challenges through situated, practice-based design work.

The overall task invited students to explore how local services might support meaningful everyday lives in four child- and youth-service districts in Trondheim marked by socio-economic challenges, limited

meeting places and a weakened sense of belonging. The municipality positioned children, young people and families as key actors and pointed to untapped potential in existing buildings, public institutions, voluntary resources and intergenerational relations as foundations for inclusion and participation. After an initial phase of theoretical framing and reflection, the course progressed into a practice-based collaboration with the municipality. A one-day Design Jam [12] served as the collaborative kick-off, bringing together students, municipal staff and voluntary-sector representatives to frame local challenges and establish shared project directions (Figure 1).



Figure 1. Design Jam (Photos: Amanda Jørgine Olsen Haug)

Throughout the following weeks, municipal practitioners contributed contextual and professional insights, facilitated access to local stakeholders and offered feedback on emerging service concepts. The course was run for the second consecutive year within this university-city collaboration format.

The six resulting service proposals illustrate the range of concepts developed across the four districts:

1. A resident-driven neighbourhood café, reopening a familiar local venue as a low-threshold, hybrid meeting place that combines affordable food, volunteer involvement, intergenerational encounters and multiple languages to strengthen local identity and ownership.
2. An open youth area in a future relocated library, designed as a flexible, modular space staffed by two young employees alongside an adult supervisor, providing a safe and inclusive meeting place for adolescents on the user group's own terms.
3. A school-based intergenerational after-school programme for fifth-grade pupils. Developed with a local volunteer centre, easing the transition from organised after-school care by connecting children with volunteer seniors in familiar school premises.
4. A transformation of a town hall into a multi-use community hub, building on existing facilities by relocating current activities to the upper floor and opening the ground floor for shared community functions such as library, music room, creative workshop, café and stage.
5. A cross-sector conversational service building on an existing social sustainability initiative, connecting the municipality, a local volunteer centre, schools and cafés through a locally designed cup that signals openness to conversation, supported by an annual school design competition and regular community café events.
6. A participation-oriented service activating local everyday nature, lowering the threshold for residents to engage in shaping their own neighbourhood through information, meeting places and simple tools that connect existing community resources and green areas.

3 METHODS AND DATA

The empirical material draws on three complementary data sources collected at different stages of the collaboration. First, a short post-Design Jam evaluation was conducted on-site immediately after the workshop. Of approximately 50 participants, 31 completed two reflection cards [13] addressing their experience of the session and its perceived value. Collected at the end of the workshop, this material provides a situated snapshot of impressions formed through direct engagement in the co-creation

activities. In addition, two structured online surveys were distributed at the end of the semester: one to students (11 of 28 respondents) and one to municipal and community partners (12 respondents). The surveys combined Likert-scale items and open-ended questions addressing learning outcomes, collaboration quality, contextual translation and areas for improvement. Given the limited response rates, the survey findings are treated as indicative rather than representative, while the Design Jam reflection cards offer a broader empirical base.

4 FINDINGS: FORMS OF LEARNING

The university-city collaboration appeared to support the development of *applied design competence* in public-sector contexts. Students reported high perceived learning (median 4 of 5), with 9 of 11 saying the collaboration helped them develop collaborative skills to some or a large degree. A similar share, 8 of 11, reported being able to translate the municipal context into design choices, and partner respondents largely confirmed this, with 8 of 12 assessing that students translated contextual insights into relevant service concepts to a large extent. All 12 partner respondents answered that students incorporated feedback and applied co-creation methods to a large or very large extent, and 10 of 12 experienced that students made their design competence clearly visible. Students appreciated working with “*real problems*” and “*real partners*,” finding it motivating. They also highlighted having “*many things to consider for implementation*,” the opportunity to collaborate with “*actors who are not students*,” and access to relevant user groups. Together, these responses point towards the value of authentic, situated learning within real municipal contexts.

Reciprocal learning across university-city boundaries emerged particularly through the Design Jam, which was rated as highly valuable by 9 of 11 students and 8 of 12 partner respondents. Students described it simply as “*fun*,” while partner respondents pointed to “*a useful outside-in view*,” highlighting the role of student-driven exploration in reframing familiar issues. Based on the post-Design Jam reflection cards (n=31), respondents from both groups characterised it as a meaningful and energising collaborative arena that enabled new perspectives and productive dialogue. Several noted that the process “*challenged established assumptions*,” and, as formulated by one respondent, made it possible to “*broaden our understanding of the issue together*,” signalling the reciprocal nature of the learning. Participants also described a strong sense of being able to contribute through sharing contextual knowledge, offering local insights or supporting the students’ developing concepts. At the same time, some participants suggested that clearer framing at the outset could have strengthened the experience, noting that “*it would have been helpful to understand roles and expectations earlier in the process*.” These insights help illuminate which aspects of the Design Jam format foster engagement, clarity and mutual learning, and where refinements could further enhance the collaboration.

Institutional literacy, appeared to be more tentative and unevenly distributed: 10 of 11 students reported only a small or partial grasp of municipal roles and decision pathways, with comments such as “*I have very little idea of how the municipality works*” and “*it would have been helpful to receive an introduction to municipal roles and decision pathways, so that one can more easily design a solution that can actually be implemented with existing resources*.” Partner respondents, however, viewed the students’ systemic understanding more positively, with 8 of 12 rating this to a large extent. This divergence between student and partner ratings reflects a perception gap.

Other issues related to clarity and expectations would also have shaped the conditions for learning: 8 of 11 students reported that the brief and expectations were clear only to a small or some extent, with comments such as “*it was unclear what was expected from both the lecturer and the municipality*” and that there were “*no clear criteria for either the solution or the collaboration*.” Some students also mentioned uneven communication and delays, noting that “*it is important to receive responses quickly ... the semester is not very long*.” Partner respondents noted the absence of a clear pathway for carrying concepts forward after final delivery.

5 DISCUSSIONS

Our findings indicate that the partnership supported several interconnected forms of learning: applied design competence, reciprocal learning across institutional contexts, and the more tentative development of institutional literacy specifically. They also point to the importance of clearer framing of roles, expectations and follow-through within the collaboration.

The municipal partnership did not only provide the students with a “*real case*.” From the start, briefs were tied to real districts, real staff and real concerns in the city, and those realities stayed present

throughout the design work. Students experienced how designing for society involves not only coming up with good ideas but also shaping proposals that can fit within everyday life and municipal organisational conditions. Much of their work unfolded through what Blomkvist et al. [4] describe as materials of service design, matters such as meetings, messages, and small moments of alignment – listening to employees who know the area, asking questions, checking assumptions, and slowly agreeing on what the real challenge was. The design work became a shared journey rather than a solo “concept sprint,” which may explain why students emphasised learning related to collaboration and feedback.

For example, one group worked with a brief about how a future relocated library could function as a neighbourhood meeting place for a diverse population. In practice, the students came to work more closely with a school rector who helped facilitate access to pupils and shape what was feasible. The design process reflected ongoing negotiation between the young people’s expressed wishes, what available partners could offer and what could be carried “*without a heavy burden on daily operations.*” This kind of relational work, reading institutional cultures, making sense of which conversations were available, working with what partners could realistically commit to, is what working with immaterial materials looks like in concrete terms and also how institutional literacy is built in practice.

The themes the students worked with also made the work feel more serious. Belonging, participation, meeting places, intergenerational contact, and access to everyday nature in culturally diverse neighbourhoods are not simple topics. They touch people’s daily lives and questions of fairness. The Everyday Journey framework helped the students look at everyday barriers and resources, but the collaboration made it harder to hide behind general statements. Students could not rely on generic personas or easy categories; they had to relate their ideas to concrete local realities and to staff carrying long-term responsibility for children and families.

At the same time, many students described only partly understanding municipal roles and decision routes, while partner respondents often considered the students to have developed a good overview. We think this perception gap is telling and understand it as part of how institutional literacy is built: encountering a real system can increase awareness of what remains unclear. What students experience as uncertainty may, from an external perspective, reflect an ongoing learning process. Part of what makes public-sector contexts demanding for newcomers is perhaps that institutional knowledge is rarely made visible to those still learning to see it. This suggests institutional literacy needs deliberate support. Our findings point to specific aspects that could be made more explicit: briefs, communication, roles and pathways for carrying concepts forward. In response, we propose an institutional literacy briefing early in the course: a short, structured introduction making visible who can do what and why within a municipality. Moreover, a post-presentation handover protocol could help ensure a realistic take-up after the course ends.

From the municipality’s perspective, the partnership provided fresh perspectives and visualised concepts that challenged established assumptions. Partner respondents were not only “clients” giving a brief; they helped shape the projects by sharing local knowledge, suggesting relevant contacts and giving feedback along the way. This also required time, coordination and availability alongside ordinary responsibilities. Beyond the design processes and proposals, the collaboration also offered the municipality a space for reflection on its own practices. Taken together, university-city collaboration can be seen both as an educational format and a means of creating value for municipal partners. The potential of such collaboration, however, depends on careful framing, realistic expectations and attention to how student work connects to ongoing organisational processes.

6 FUTURE WORK

Going forward, we aim to continue the collaboration with municipal stakeholders and further develop the format, activities and structural conditions that support meaningful partnership, the development of institutional literacy and longer-term outcomes for municipal practices and service development.

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BEYOND VISUAL TOOLS: AN INCLUSIVE EDUCATIONAL EXPERIENCE IN CO-DESIGNING YACHT INTERIORS WITH AND FOR USERS WITH VISUAL IMPAIRMENTS

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ABSTRACT

Interior design education relies predominantly on visual representation. Tools such as concept sketching, technical drawings, photorealistic renderings and digital animations continue to shape how students conceive, develop and communicate space. However, these tools presuppose a visually oriented user, an assumption that becomes critically limiting when the intended client or co-designer lives with a visual impairment.

This paper presents an industrial master's thesis project of an interior design student who, while initially investigating how to design yacht interiors for people with visual impairments, quickly encountered a more fundamental challenge. Beyond the spatial and sensory solutions required to make a yacht fully accessible to a blind or low-vision owner, the project revealed a significant methodological challenge: the necessity to imagine new ways and tools to communicate design intentions and to enable true co-design with non-visual users. As the perceptual system guiding the project shifted, the experience made visible what happens in both the design studio and the design process when visual dominance is suspended. In response, the project progressively adopted multisensory, tactile, and narrative-based representation strategies, including material exploration and verbal mediation.

The paper reflects on this educational experience and discusses its implications from two complementary perspectives: that of the student, navigating a profound reconfiguration of design habits, and that of the educator, observing how these changes affect teaching and assessment in design education. The outcome shows that moving beyond visual dominance fosters multisensory design literacy, with implications for inclusive design education beyond the nautical context.

Keywords: Interior design, design education, multisensory design, visually impairments, yacht design

1 INTRODUCTION

Interior design education is traditionally grounded in visually driven tools of representation. Sketching, 2D drawing, digital modelling, photorealistic rendering and, more recently, AI-generated imagery structure how spatial concepts are conceived, developed and assessed within the studio. Even as technological paradigms shift, visual output continues to function as the primary indicator of design competence and quality [1] [2]. In yacht interior design education – where architectural, engineering and aesthetic constraints converge – this reliance on image-based workflows is particularly pronounced, as students are trained to communicate complex spatial proposals primarily through drawings and visual simulations [3] and these artefacts often become the implicit measure of success.

This visual dominance is rarely questioned, largely because it is embedded in the epistemology of studio culture itself. Although design theory has long argued that space and objects are experienced multisensorially rather than exclusively visually [4] [5], pedagogical practices and assessment criteria continue to privilege what can be seen, displayed and critiqued. The tension between embodied spatial experience and visually mediated design tends to remain latent.

The issue becomes explicit when considering users with visual impairments. Visual impairment is not simply the absence of sight; it entails alternative modes of perceiving, orienting and constructing spatial understanding through touch, hearing, proprioception and smell. In such contexts, interior design must function as a multisensory system capable of communicating through tactile cues, acoustic differentiation, material contrast and spatial legibility. Research on educational environments for blind

and visually impaired users highlights the importance of textured flooring, acoustic modulation, clear circulation hierarchies and controlled lighting as fundamental elements for spatial comprehension [6]. Accessibility must be understood in relation to experiential navigation, cognitive mapping and the time required to reach and interpret information [7]. The analogy with design education is instructive: representational adequacy for sighted designers does not automatically translate into perceptual accessibility for blind participants. What appears resolved in visual terms may remain inaccessible in experiential ones.

The master's thesis discussed in this paper emerged from this disruption. Initially conceived as a project on designing yacht interiors for a visually impaired owner, it soon revealed a broader pedagogical challenge. Beyond addressing accessibility within a regulated maritime context, it exposed the limits of conventional visual tools in enabling communication and genuine co-design when vision is not the primary channel.

If design development relies on renderings and visual validation, how can a blind or partially sighted user participate as an active co-designer? Research in graphical design education shows that tactile aids and rapid prototyping can translate visual concepts into tangible artefacts [8], suggesting that representation need not be confined to sight. The issue therefore extends from inclusive yacht interiors to inclusive design processes. This paper frames the experience as an opportunity to observe what happens in design education when the perceptual system guiding both design thinking and design teaching fundamentally changes.

2 EDUCATIONAL CONTEXT AND METHODOLOGY

The project was developed within a master's programme in Interior and Spatial Design at the Politecnico di Milano and was structured as a research-through-design thesis embedded in an industrial internship. The thesis was developed over the course of one academic year, during which the student conducted the research while undertaking an internship at the shipyard Azimut | Benetti, addressing a topic of direct relevance to the firm. The project was therefore situated within a dual framework, combining academic supervision and industrial mentorship, with guidance provided by both a university professor and a company tutor. This dual context shaped the project's direction and constraints. The industrial setting required technical credibility in relation to yacht production, materials and regulations, while the academic environment encouraged critical reflection on design methods and co-design practices.

The research approach can be described as a research-through-design [9] educational case study [10]. The process involved the design student, the academic and industrial supervisors, a broader group of blind and visually impaired participants engaged through questionnaires, and one blind co-designer who was continuously involved in the in-person co-design phase. This involvement was structural rather than consultative.

Methodologically, the project combined qualitative research tools with iterative co-design. An initial phase included questionnaires distributed to around 30 blind and visually impaired participants working at an experiential exhibition in Milan where visually impaired guides accompany visitors through non-visual environments. Their contribution, although mediated through online questionnaires, provided essential insights into orientation, material perception, emotional comfort and everyday navigation practices. These findings informed early concept development and emphasised the importance of tactile and auditory cues. A subsequent phase consisted of in-person co-design with a blind participant who remained directly involved throughout the project. Through hands-on exploration of material samples, surface finishes and textural contrasts, the sessions investigated how materials could communicate information, evoke emotions and support spatial understanding through touch alone. In line with participatory approaches developed with blind users, where ideas must be communicated through accessible forms rather than visual artefacts alone [11], the process prioritised verbal explanation, shared interpretation and continuous feedback. As emphasised in recent research on co-design with visually impaired participants, materials themselves act as mediators in the process, sometimes facilitating and at other times constraining shared understanding [12]. Particular attention was given to how differences in texture, temperature, softness, rhythm and directionality could communicate spatial boundaries, circulation hierarchies or functional distinctions. These sessions often revealed mismatches between the designer's visual intentions and the co-designer's tactile interpretation of the same elements, prompting revisions in both material selection and spatial articulation. Feedback from questionnaires, co-design sessions and reflective observations was analysed through thematic clustering. Recurring themes such as welcoming atmospheres, directional clarity, tactile legibility and emotional comfort progressively

emerged from participants’ comments and reactions. These themes later informed the development of the project’s guiding strategies and became the conceptual basis of the final design proposal. While no full-scale prototype was produced, the iterative material testing informed the conceptual validation of the proposal.

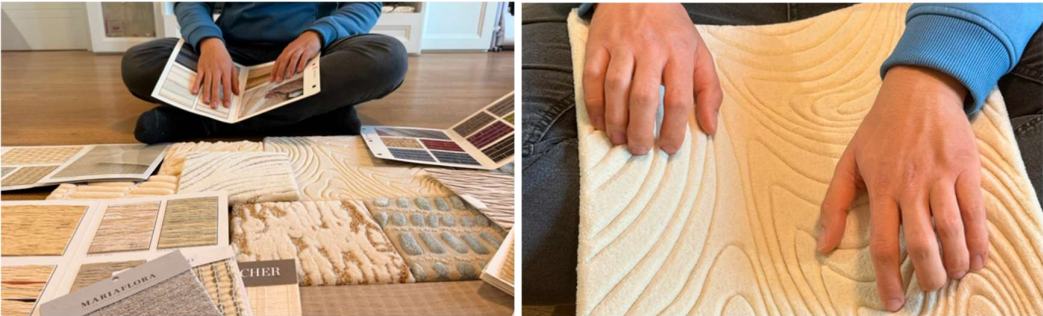


Figure 1. Material sample explorations during a co-design activity

Importantly, the methodology was not fully predefined at the outset. Instead, it evolved in response to concrete challenges encountered during the early project phases. The need to explain drawings that were not visually accessible, to test materials beyond aesthetic criteria, and to reframe design decisions in sensory rather than visual terms gradually reshaped the process. Adaptation, experimentation and critical reflection were therefore not supplementary activities but core components of the educational experience.

3 INTERIOR YACHT DESIGN EXPERIENCE

The design experience was developed within the professional context of Azimut | Benetti, one of the leading international groups in the luxury yacht sector. The company operates in a highly competitive market where innovation, craftsmanship and brand identity play a central role. Despite this advanced positioning, accessibility, particularly in relation to sensory disabilities, remains only marginally explored within the nautical industry. Within this framework, the thesis introduced a deliberately atypical design brief: the hypothetical arrival of a blind owner for whom no consolidated design protocol yet existed. The Magellano 30M model yacht was used as the reference platform for the development of the project, allowing the student to work within realistic spatial, structural and production constraints. The aim was not to redesign the vessel from scratch, but to reinterpret its interior architecture through a multisensory and inclusive lens.

3.1 Project strategies

The project was structured around two interpretative keys: *welcoming* and *direction*. These two dimensions frame the spatial experience of a blind owner on board, establishing the conditions through which the yacht can be perceived as both reassuring and navigable. *Welcoming* refers to the creation of environments that feel protective, legible and emotionally balanced. *Direction* concerns the capacity of space to guide movement, support orientation and enable the construction of a coherent mental map. To translate these principles into spatial action, the project operates through three dimensions: *forms*, *surfaces* and *perceptions*. Together with the two interpretative keys, these constitute the guiding strategies matrix: a tool to coordinate spatial, material and atmospheric interventions into a unified sensory language.

Table 1. Guiding strategies matrix

	Welcoming	Direction
Forms	Curved line	Guiding elements
Surfaces	Tactile decoration	Material discontinuities
Perceptions	Olfactory identity of spaces	Scent as guidance

Form refers to the three-dimensional structure of the interior and the way spatial volumes organise movement. Through solids and voids, continuity and curvature, form shapes both bodily experience and spatial character. Curved lines play a key role in creating welcoming conditions: they allow continuous

tactile exploration, avoid abrupt edges and convey protection and continuity. At the same time, form supports direction through guiding elements integrated into circulation paths. Handrails and volumetric alignments are conceived as spatial references that structure orientation, and in some cases curved forms themselves subtly guide movement, showing how welcoming and direction overlap.

Surface represents the immediate point of contact between body and space. For a blind user, tactile perception is central to understanding and memorising the environment. Decorative elements are therefore translated into tactile richness rather than visual display. Textures and material variation communicate comfort and quality through touch. Material discontinuities mark thresholds and functional changes, providing spatial information that supports navigation through embodied perception.

Perception includes the intangible atmospheric components that complete the experience of space. In particular, each area is defined by a distinct olfactory identity calibrated to its function. Scent contributes to welcoming by creating recognisable and emotionally differentiated atmospheres. Variations in fragrance intensity also support direction, allowing the user to sense proximity to or distance from specific areas, making smell an effective non-visual guidance tool.

3.2 Project outcome

The results of these strategies were consolidated in the redesign of specific areas on board, including the main deck saloon, the owner's cabin, the lobby and staircase, and the external dining area. The final proposal suggests how a universal design language could generate spaces accessible to both sighted and non-sighted individuals without diminishing aesthetic coherence. Rather than producing a specialised environment exclusively for a blind user, the project articulated a multisensory interior architecture capable of enriching the experience for all occupants.

A central element of the project is the handrail, conceived as a continuous spatial guide rather than a secondary safety feature. It accompanies circulation routes and connects functional areas, providing a stable tactile reference along both horizontal and vertical paths. In transitional zones, particularly around the staircase, it becomes a primary orienting device, ensuring perceptible and secure movement without reliance on visual cues. Here, material differentiation is used to delineate thresholds and signal functional changes. Furthermore, variations in flooring and surface textures mark transitions between circulation and living areas, allowing the user to construct a tactile mental map of the yacht.



Figure 2. Project Outcome: main saloon, a detail of handrail, upper deck

In the main saloon, curved lines in spatial elements and furnishings reinforce both *welcoming* and *directional* intentions. The absence of sharp geometries reduces perceptual tension and encourages fluid movement. Curvature softens the spatial experience while subtly guiding the body along natural trajectories. Olfactory identities complete the perceptual framework. Each primary area is associated with a calibrated scent corresponding to its function and atmosphere. Variations in fragrance intensity support spatial recognition and memorability, allowing smell to operate as an invisible orientation tool. In the upper deck, material contrasts distinguish circulation from seating zones, while the handrail continues to structure movement along the perimeter. The olfactory identity is lighter and more dynamic, reinforcing the social character of the space while maintaining recognisability. Finally, in the owner's cabin, tactile richness and softer materials emphasise comfort and stability. Texture differentiates key functional areas, supporting independent movement. A calm and subdued olfactory identity reinforces the cabin's private and restorative role.

4 REFLECTIONS

4.1 from student perspective

From the student's perspective, the project significantly transformed the understanding of design practice. As an interior designer in training, the student was accustomed to working primarily through visual tools: drawings, floor plans, renderings and spatial compositions. Working with a blind user disrupted this habitual framework and required a reconsideration of how space can be communicated, perceived and designed beyond the visual dimension.

The absence of visual access on the part of the co-designer exposed the extent to which conventional design processes rely on visual validation. The student recognised that spatial decisions are typically developed, evaluated and legitimised through drawings and images. In this project, however, such tools could not function as the primary medium of exchange. Space had to be translated into words, materials and sensory references. Unfortunately, due to time and budget constraints, there was no possibility to produce tactile mock-ups, relief plans and three-dimensional models to render volumes and hierarchies more accurately. In their absence, the process relied mainly on dialogue and material experimentation. Visual concepts were translated into multisensory narratives, and material samples – surfaces, textures, directionality and temperature – became tools for design communication. The core strategies emerged precisely through this tactile interaction and shared discussion.

Throughout the process, the student acted as a mediator between two dimensions: the multisensory perspective of the blind user and the visual, technical language required in dialogue with the academic supervisor and the company. Tactile impressions and experiential insights had to be reformulated into drawings and diagrams compatible with traditional design representation.

The student also recognises the limitations of the work. The strategies were developed through dialogue and theoretical reflection but were not tested through physical prototypes or real spatial simulations. Without implementation, their effectiveness cannot be fully verified. At the same time, this constraint revealed an important insight: meaningful design strategies can emerge from listening, dialogue and material perception. The project shifted the approach from designing for the user to designing with the user, broadening the conception of space as intrinsically multisensory and questioning the exclusive centrality of vision in the design process.

4.2 From educator perspective

From the educator's perspective, this project represented the first occasion in which visual impairment was addressed within a co-design framework in the context of interior yacht design education. While issues of accessibility are frequently discussed in the framework of mobility impairments, this was the first time that sensory disability became the central driver of the design process for a yacht co-design experience. In the initial phases of the research, several difficulties became evident. The student, as expected, relied heavily on visual representation tools: plans, sections, renderings and compositional studies. However, these instruments quickly revealed their limits when confronted with a non-visual co-designer. From an educational standpoint, it became clear that the challenge was not only technical but epistemological. The design studio traditionally operates through visual critique and visual validation. Assessments, discussions and feedback are largely mediated by drawings and images. When these tools lose their centrality, both student and educator must renegotiate the criteria through which design quality is recognised and evaluated. As an educator, this process demanded a reframing of supervision itself: feedback had to address multisensory consistency and experiential clarity.

Another observed difficulty concerned the absence of consolidated references or methodologies within both the nautical design sector and the interior design education for addressing visual impairment co-design experiences. Unlike more standardised accessibility contexts, such as public architecture, yacht interiors lack established protocols for sensory inclusion. This required both educator and student to navigate a largely unexplored design territory, balancing innovation with feasibility. In this context, educator felt the need to suspend the initial judgement on certain design decisions, as the project could not follow the conventional yacht design process. In many instances, the blind co-designer became the primary reference for assessing the validity of spatial and material choices, effectively redefining what constituted a "successful" design outcome.

Overall, the experience demonstrated that inclusive co-design does not simply produce alternative spatial solutions; it reshapes the educational process itself. It challenges representational hierarchies and invites a broader understanding of design literacy.

5 EMERGING INSIGHTS FOR INTERIOR DESIGN EDUCATION

The experience documented in this study reveals insights that extend beyond yacht interiors to broader questions in interior design education. Engaging with users outside the dominant sensory mode exposes how conventional processes rely on visual validation: spatial decisions are typically developed and assessed through images, while in this case space had to be conveyed through verbal descriptions, material samples and sensory references. This aligns with critiques in design education literature, which identify visual-centric bias as a barrier to inclusion and innovation, calling for greater engagement with multisensory knowledge in teaching and practice [13]. The pedagogical tension between conventional visual methods and inclusive co-design shows that inclusion is not only about accessibility outcomes, but about reshaping the criteria of the design process itself. Inclusive design education requires reflexivity in supervision, assessment and representation, encouraging educators and students to recognise and respond to bias in their methods, while challenging both academia and industry to rethink not only what is designed, but how it is conceived, communicated and critiqued.

Ultimately, this study does not only concern inclusive yacht interiors but raises a broader pedagogical question. From an educator's perspective, it prompts a necessary reflection: are we truly prepared to include visually impaired individuals within design studios? This project is a preliminary and situated exploration, yet it reveals structural tensions and suggests that inclusion requires more than technical adaptation. If vision is no longer the unquestioned centre of the studio, multisensory literacy, dialogic practice and methodological flexibility must become core pedagogical components. The main open questions remain: are we ready to move beyond treating difference and disability as project topics, allowing them instead to reshape the foundations of design pedagogy? Do we possess the tools, methods and assessment frameworks to teach design beyond visual primacy?

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REGENERATIVE RESPONSIBILITY IN ACTION: CO-CREATION OF KNOWLEDGE IN TIMBER COMMUNITIES OF QUERÉTARO

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ABSTRACT

This paper presents an exploratory qualitative case study framing the first stage of a pedagogical and design-based experience developed with timber communities in the Sierra Gorda Biosphere Reserve in Querétaro, Mexico. The project is grounded in the conceptual framework of Regenerative Responsibility (RR), presented in this study as a pedagogical framework developed by the authors, and explores how this framework can be implemented through a relational and participatory methodology focused on building mutual understanding between students and communities.

The process explored the early phases of a five-step methodology: Sensitise, Connect, Imagine, Co-create, and Strengthen. For this stage, the emphasis was placed on Sensitising participants through immersive field experiences and on Connecting + Imagining together with community members, exploring new relational and regenerative futures around the local use of wood as a raw material.

Data collection included reflective student journals, facilitator field observations, participatory mapping activities, dialogue sessions with community members, photographic documentation, and collective reflection exercises. An inductive thematic analysis was conducted to identify recurring themes related to students' understanding of materiality, responsibility, and relational design practice.

By activating a space of knowledge exchange, the project allowed for the recognition of traditional practices and ethical relationships with the forest. Students engaged in collective reflection and situated learning, understanding the socio-environmental complexities of the territory while envisioning possible futures that connect people, nature, and technology.

This approach reinforces design as an eco-social practice, and opens possibilities for innovation rooted in ethical awareness, cultural connection, and circular economic thinking. It also invites a shift in the designer's role, from creator to connector, highlighting the importance of reciprocity, listening, and learning with others. Rather than validating a fixed methodology, the study documents how implementation functioned as an adaptive and reflective pedagogical process that refined the RR framework through situated practice. The study contributes a transferable pedagogical model for embedding regenerative ethics into engineering and product design education through relational and situated implementation.

Keywords: Regenerative responsibility, regenerative design, participatory design, educational innovation

1 INTRODUCTION AND CONCEPTUAL CONTEXT

Design education is at a turning point. While sustainability has become a central discourse within design schools, many approaches remain focused on reducing harm rather than restoring systems. The urgency of socio-environmental crises requires a shift in how designers are formed and how they relate to the territories in which they intervene [1].

This paper presents an exploratory qualitative case study developed with timber communities in the Sierra Gorda Biosphere Reserve in Querétaro, Mexico. The project is grounded in the conceptual framework of Regenerative Responsibility (RR), developed as a strategy for design education, and explores how this framework can be implemented through a relational and participatory methodology. Rather than approaching the community with predefined solutions, the experience sought to build mutual understanding between students and local actors. The emphasis was placed on listening, mapping relationships with the forest, and collectively imagining regenerative futures around the local use of

wood. This paper contributes to the current discussion on regenerative education and design through five interrelated dimensions:

1. To articulate Regenerative Responsibility as a coherent pedagogical framework that integrates ethics, systemic thinking, and participatory practice.
2. Operationalise this framework through a structured five-moment methodology that is transferable and adaptable to other socio-ecological contexts.
3. Provide empirical insight derived from reflective journals, field observations, and participatory activities into how immersive, relational implementation can reshape students' understanding of materiality, professional responsibility, and design agency.
4. Bridge regenerative theory and situated pedagogical practice, the study advances current discussions on how design education can meaningfully respond to socio-environmental crises.
5. Scaffold the praxis of the project through the conceptual framework.

1.1 Regenerative Responsibility

Regenerative Responsibility emerges from the recognition that sustainability, while necessary, is insufficient. Sustainability often operates within a logic of mitigation: reducing impact, minimising waste, improving efficiency. Regeneration seeks to restore the adaptive capacity of socio-ecological systems through a systemic, relational, and place-based approach, rather than merely focusing on reducing harm [2]; Contemporary researchers emphasise reciprocity, living systems thinking, and long-term socio-ecological transitions [3] [4]. RR integrates regenerative design, professional responsibility, and design pedagogy into a unified framework. It positions designers not only as creators of objects, but as agents embedded within living systems whose decisions carry ethical and systemic consequences.

In educational contexts, RR is not presented as an isolated topic. It is conceived as a transversal stance that informs how projects are framed, how methodologies are chosen, and how relationships are built. It calls for designers in formation to recognise interdependence between ecological, social, cultural, and economic systems. The implementation described in this paper represents an attempt to translate this conceptual framework into situated practice.

1.2 Relational Design

Relational Design frames design as a process of cohabitation rather than intervention. Instead of positioning the designer as an external expert who introduces solutions, this approach understands design as a shared inquiry shaped by dialogue and mutual learning [5] rather than measuring predefined outcomes, the study examined shifts in perception, relational awareness, and systemic thinking that emerged through situated interaction, understanding learning as a reflective and relational process [6].

In the context of timber communities in Querétaro, Relational Design meant prioritising relationships over outputs. The workshop was not structured around rapid prototyping or product development in its initial stage. Instead, emphasis was placed on collective mapping, open conversations, and recognition of local knowledge. This perspective allowed students to understand that wood is not merely a raw material. It is part of a living network involving ecological cycles, economic practices, family histories, and territorial identity. Relational Design becomes the operational dimension of Regenerative Responsibility. It translates ethical intention into concrete modes of interaction. Relational Design becomes the operational dimension through which RR is implemented in practice.

1.3 Implementation as Investigation

Implementation is often understood as the execution phase of a previously defined plan. In this project, implementation was approached as a reflective form of investigation in action. The workshop functioned as a living laboratory where assumptions were tested through interaction. Theoretical principles of RR were not imposed; they were examined, adjusted, and sometimes questioned in response to what emerged in the field. This perspective challenges linear design models. Rather than designing first and applying later, the process unfolded iteratively. Implementation became an adaptive and dialogical practice where learning occurred for both students and facilitators [7]. In this sense, implementation is not validation but transformation.

2 THEORETICAL FRAMEWORKS

The theoretical framework integrates three complementary perspectives: ethics of responsibility, systemic and transition design, and participatory design. Together, they support the articulation of Regenerative Responsibility as a pedagogical and methodological approach.

2.1 Ethics of Responsibility

Design decisions are not neutral. They shape material realities, social relations, and ecological conditions. Professional responsibility therefore extends beyond functionality or aesthetic value [8].

Within RR, ethics is framed not only as avoiding harm but as actively contributing to collective well-being. This includes recognising asymmetries of power, respecting local knowledge systems, and fostering reciprocity in collaborative processes. Working with timber communities required acknowledging historical tensions related to resource extraction and economic vulnerability. Ethical responsibility meant avoiding extractive research practices and ensuring that participation was meaningful rather than symbolic. Responsibility becomes situated. It is exercised in the quality of relationships, in the transparency of intentions, and in the willingness to remain accountable beyond the duration of the workshop.

2.2 Systemic and Transition Design

Systemic and transition design perspectives inform the understanding that challenges related to timber use cannot be isolated from broader socio-ecological dynamics. Wood in the Sierra Gorda is embedded in ecological regulation, market structures, cultural heritage, and policy frameworks. Any design intervention that ignores these interconnections risks oversimplification. Systemic thinking encourages attention to feedback loops and long-term consequences [9]. Transition design, in turn, invites incremental pathways toward regenerative futures rather than abrupt disruptions. In the workshop, proposals were not treated as finished products but as nodes within larger transition processes [4]. Students were encouraged to consider how design ideas might contribute to ecological balance, economic resilience, and cultural continuity over time.

2.3 Participatory Design

Participatory Design provides the methodological grounding for the collaborative dimension of the project. Participation in this experience moved beyond consultation. Community members engaged in collective mapping exercises, storytelling sessions, and shared reflections about their relationship with the forest [10]. These activities revealed that the forest was perceived not as a resource but as a living presence. This reframing significantly impacted students' understanding of material use. Participation functioned as mutual learning. Students suspended assumptions, while community members explored future-oriented possibilities that integrate tradition and innovation. Design became a shared exploration of what regeneration could mean in a specific place, this perspective aligns with pluriversal design approaches that recognise the coexistence of multiple ways of knowing and inhabiting territory [11].

3 METHODOLOGIES: THE FIVE-MOMENT MODEL

This exploratory qualitative study examined situated learning and active participation through an immersive workshop conducted in Sierra Gorda, Querétaro, Mexico. The initiative involved 12 undergraduate design students, 4 facilitators, and community members during a multi-day immersive workshop. The analysis focused on identifying how engagement with the territory and community narratives influenced students' understanding of wood, relational practice, and professional responsibility within regenerative design contexts.

The methodology applied is structured around five moments and developed as part of the broader RR research process and refined through field implementation.

- **Sensitise.** Through territorial walks and open dialogues, students were invited to observe and listen without the pressure of immediate production. This stage aligned ethical perspectives and helped participants recognise the complexity of socio-ecological systems.
- **Connect.** Collective mapping allowed community members to represent daily interactions with the forest. Connection was understood as foundational for regeneration. Without relational depth, design risks remaining superficial.
- **Imagine.** These scenarios were grounded in previous dialogues rather than abstract speculation.

Imagination functioned as a bridge between present realities and desirable transitions.

- Co-Create. Emphasis was placed on experimentation rather than finalised outputs. Co-creation revealed complementarities between academic knowledge and local expertise.
- Strengthen. Reflection sessions and shared documentation ensured that the experience would not remain isolated. Strengthening implies consolidating relationships and supporting long-term collaboration.

Rather than measuring predefined outcomes, the study examined shifts in perception, relational awareness, and systemic thinking that emerged through situated interaction, understanding learning as a reflective and relational process.

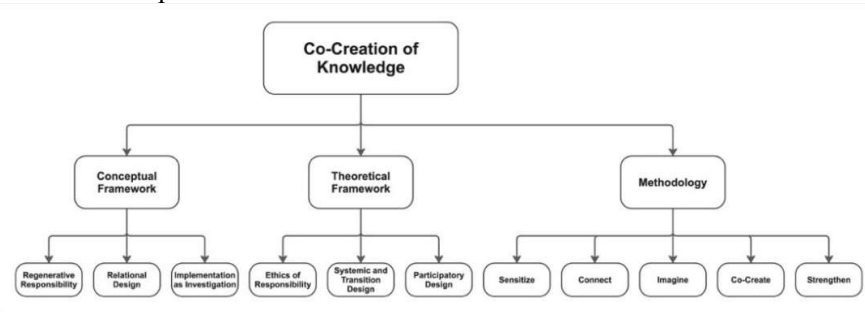


Figure 1. Regenerative Responsibility in Action

4 CASE STUDY: IMPLEMENTATION IN EL MADROÑO, SIERRA GORDA

The implementation took place in El Madroño, located within the Sierra Gorda Biosphere Reserve in Querétaro. The region is characterised by ecological richness and a strong cultural relationship with timber as both livelihood and identity.

This first stage of the project emphasised immersion and relational engagement over production outcomes. The case study is structured according to the methodological model of Regenerative Responsibility, specifically focusing on the first two moments: Sensitise and Connect. As illustrated in the five-moment framework, these initial phases aim to cultivate ethical awareness, recognition of people and their stories, and a deeper understanding of territory before moving toward collective imagination or co-creation.

By grounding the workshop in Sensitise and Connect, the implementation prioritised attentiveness, dialogue, and relational depth. Rather than advancing immediately toward design proposals, participants engaged in reflection about regenerative thinking, personal experience, and shared responsibility, while also recognising community narratives and territorial dynamics. This foundation was essential for framing any subsequent regenerative action within the lived realities of the community.

4.1 Context

The case study took place in El Madroño, a community located within the Sierra Gorda Biosphere Reserve in Querétaro. The region is characterised by ecological diversity and a strong historical relationship between its inhabitants and forest resources. Timber is not only an economic asset but also part of local identity, memory, and daily life. The workshop was developed within a collaborative academic framework involving design students and community members. Students entered the territory with a conceptual grounding in Regenerative Responsibility, yet most had limited direct experience with rural socio-ecological systems. The context presented both opportunity and responsibility. On one hand, the forest represents a material resource for design exploration. On the other, it embodies a living system that sustains livelihoods and cultural continuity. The objective was therefore not to “apply” design solutions, but to understand how design might operate within existing regenerative logics already present in the community. The case unfolded as an initial stage of a longer-term process, focusing primarily on relationship-building and shared understanding rather than on finalised product outcomes.

4.2 Field Immersions

Field immersion functioned as the methodological core of this first stage. Rather than beginning with structured design briefs, the process started with direct exposure to the territory.

Students participated in guided walks through the forest and surrounding areas. These walks were not technical inspections but opportunities to observe ecological cycles, discuss timber practices, and

understand how extraction and regeneration are balanced locally. Community members explained selection criteria for wood, seasonal rhythms, and informal rules that regulate responsible use. This immersion slowed down the conventional pace of academic workshops. Students were encouraged to suspend the impulse to propose solutions and instead focus on attentive observation and listening. The physical presence in the territory allowed participants to experience the forest beyond abstraction. Environmental conditions, spatial relationships, and the embodied knowledge of local actors became part of the learning process. Field immersion therefore operated as an ethical calibration. It aligned students' perception with the complexity of the system and prepared the ground for meaningful dialogue.

4.3 Community Narratives

Community narratives emerged through open conversations, collective mapping, and shared reflection sessions. Participants were invited to speak about their relationship with the forest: what it represents, how it has changed, and what concerns or hopes they associate with its future. These narratives revealed that the forest is not perceived merely as a resource. It is described as a living presence, something that gives and requires care. Stories referenced family histories, intergenerational transmission of knowledge, and experiences of environmental change.



Figure 2. Participatory activities fostering community narratives of place

For students, these narratives reframed the role of material in design. Wood ceased to be a neutral raw material and became embedded in a network of ecological, emotional, and cultural meanings.

The sharing of narratives also shifted power dynamics. Knowledge did not flow unidirectionally from university to community. Instead, the community's experiential knowledge became central to shaping the direction of imagination and subsequent design exploration. Through these conversations, the groundwork was laid for collective imagining of regenerative futures, informed by lived experience rather than external projection.

5 RESULTS AND REFLECTIONS

The first stage of implementation generated results that are primarily relational and pedagogical rather than material. While no finalised products were developed during this phase, significant shifts occurred in perception, positioning, and methodological clarity.

One of the most evident outcomes was the transformation in how students understood timber. Initially approached as a design material with functional potential, wood gradually became recognised as part of a living socio-ecological system embedded in cultural practices, economic realities, and intergenerational knowledge. Through field immersion and engagement with community narratives, students began to question extractive logics that often remain implicit in design education. The material was no longer neutral; it was relational.

The experience also reconfigured the perceived role of the designer. Students entered the workshop expecting to generate solutions. However, the emphasis on listening, mapping, and dialogue required them to reposition themselves as facilitators and learners. This shift was not immediate. Moments of uncertainty emerged, particularly when the absence of rapid deliverables created discomfort. Yet this tension proved productive. It exposed how strongly solution-oriented habits are embedded in academic training and highlighted the pedagogical value of slowing down the design process.

From a methodological perspective, the five-moment model demonstrated coherence in practice. The Sensitise and Connect phases effectively grounded ethical awareness and fostered meaningful dialogue. At the same time, implementation revealed areas requiring refinement, particularly in managing

transitions between collective imagination and early co-creation. The workshop confirmed that regenerative methodologies must remain adaptive rather than prescriptive.

Structural limitations also became visible. Academic calendars constrain continuity, and institutional assessment systems often prioritise tangible outputs over relational processes. These tensions underscore a broader challenge: regeneration in design education cannot be confined to isolated workshops. It requires institutional alignment and long-term commitment.

Students demonstrated an expanded understanding of timber as embedded within ecological cycles, economic dependencies, and cultural histories. Reflective journals revealed a shift from material-centred reasoning toward system-oriented thinking, recognising feedback loops and long-term implications of design decisions. Overall, the implementation functioned as investigation. Rather than validating a fixed framework, the implementation functioned as an adaptive investigation that refined and deepened the RR framework through situated practice.

6 CONCLUSIONS AND FUTURE WORK

Future work will focus on deepening the Co-create and Strengthen phases through sustained collaboration with the community. This includes developing pilot initiatives that integrate traditional timber practices with contemporary design tools while maintaining ecological balance and cultural integrity. Further research will also explore mechanisms for evaluating long-term pedagogical impact and for embedding Regenerative Responsibility more systematically within curricular structures.

Regenerative Responsibility should not be understood as a fixed methodology but as an evolving pedagogical stance. Its relevance lies in its capacity to reorient design education from isolated problem-solving toward collective capacity-building within living systems.

The project incorporated informed consent procedures aligned to institutional approval processes to ensure that participants clearly understood the scope, objectives, and potential dissemination of the work. This was not treated as a procedural requirement, but as an ethical commitment aligned with Regenerative Responsibility: participation must be voluntary, transparent, and based on mutual trust.

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INTEGRATING DESIGN THINKING TO FOSTER PATENTABLE INNOVATION IN DESIGN EDUCATION

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ABSTRACT

Design education is increasingly challenged to align creative outputs with real-world innovation and intellectual property (IP) generation. This study presents a pedagogical framework that integrates the Design Thinking methodology into the design process to support the development of patentable products within an undergraduate design curriculum and addressing the growing demand for applied innovation within higher education. The model was applied over different academic programmes, i.e. Industrial design and Interior Design, with a senior-level practice-based courses, structured around the five stages of Design Thinking: Empathise, Define, Ideate, Prototype, and Test. Students were guided not only through user-centred research and iterative prototyping but also through a tailored framework for IP screening, novelty assessment, and patent drafting. The approach aligns with national innovation strategies and reflects a global shift in design education moving beyond traditional instruction toward producing solutions that are not only creative but also protectable and commercially viable. Assessment rubrics were redefined to include indicators for technical originality, feasibility, and IP potential. The outcomes included several high-quality design concepts, of which the majority were filed as patent applications. This integration demonstrated that undergraduate academic environments could serve as innovation incubators, transforming design outcomes into protectable and potentially commercialise products. It also fostered an entrepreneurial mindset among students, encouraging them to think beyond academic deliverables toward transformative innovation.

Keywords: Intellectual property (IP), design thinking (DT), design pedagogy, industrial design education, interior design education, design-studio practice, design patents, design innovation

1 INTRODUCTION

Design Education has been evolving through major industrial and technological transformations. During the industrial revolution, Design education marked a pivotal shift to prioritise mass production, mechanisation and systematic manufacturing processes [1]. This transition promoted design educational institutes to meet industrial demands by aligning their curricula with such needs while emphasising interdisciplinary knowledge, problem-solving skills and teamwork, in which to support industrial growth [2]. In light of this, Design Thinking (DT) has become one of the lead players in the pedagogical transformation of the approach, which reflects significantly upon design education [3]. Unlike the traditional approaches for design education, Design Thinking focuses on real-world problems, active and collaborative learning where the user is the focus of the process, which promotes innovative solutions and challenge teacher-centred models [4].

This research presents the transformation of design concepts from practice-based courses into patentable innovations within design programmes. This was achieved through integrating a structured innovation-to-patent framework into design curricula that guides the process to produce innovative patentable work. Following this framework, both students and faculty members are encouraged to develop design solutions that are sustainable and high in commercial value, which in turn expands beyond the academic deliverables.

2 DESIGN THINKING AND PATENTABLE INNOVATION IN DESIGN EDUCATION

Design thinking frameworks have been implemented to design education, offering structured approaches that foster innovation, problem-solving, and user-centred innovation. These frameworks

generally highlight iterative processes, user-focused empathy, and collaborative ideation, closely aligning with educational objectives that foster critical thinking and practical skills. [5]. Stanford's approach, for instance, is one of the widely used frameworks in design education, it outlines five stages: Empathise, Define, Ideate, Prototype, and Test. This model promotes a human-centred approach by prioritising user needs and supports iterative learning through prototyping and feedback, fostering resilience and adaptability [6].

Another widely adopted framework is the Double Diamond model, developed by the UK Design Council, which structures the process into four phases: Discover, Define, Develop, and Deliver. It highlights divergent and convergent thinking cycles, enabling students to explore broad problem spaces before refining feasible solutions [7]. Its clarity and simplicity make it effective for teaching complex design processes in an accessible manner. In addition, hybrid design thinking frameworks have emerged to address discipline-specific or learning outcomes needs. These include approaches that integrate storytelling and systems thinking to support holistic problem-solving, as well as participatory models that prioritise co-creation and stakeholder involvement to foster empathy and collaboration.

The integration of these frameworks in design education reflects a shift from traditional, linear design methods to a more flexible, user-centred approaches. Frameworks such as Design thinking helps students to test assumptions and learn from their mistakes in a low-risk environment through iterative prototyping and feedback loops. These frameworks provide structured yet flexible methods that foster innovation, empathy, and critical problem-solving across educational levels and disciplines. Evidence further indicates that effective integration of DT enhances innovation and supports the development of patent-aware, user-centred designs when implemented with an appropriate capacity, contextual adaptation, structured IP education, and robust assessment. Eventually, the difference in outcomes reflects contextual diversity, which highlights the importance of carefully designed methodologies when fostering patentable innovation.

Design Thinking process encourages the identification of deep needs and problems, translating these insights into tangible, valuable designs that can lead to innovative and potentially patentable outcomes. Primarily, Design Thinking enhances creativity and innovation by structuring a cognitive practice aimed at uncovering profound user needs and converting them towards innovative solutions, by placing the user and their experiences at the core of the design process, innovations generated are more likely to meet real-world demands, increasing the chance of developing unique and effective products that can qualify for patents [8].

Additionally, Design Thinking fosters a culture of continuous problem identification and collaborative design, which is essential in sustaining innovation within higher education organisations. The iterative nature of DT characterised by stages such as understanding, observation, ideation, prototyping, and testing; helps teams refine ideas actively, thus improving the novelty and functionality of designs that enhance their patentability. This process allows students to develop original product designs and document their process systematically, which is critical for patent applications.

Design Thinking relatedly supports innovation through its role in active learning and motivation toward sustainable design. For example, in engineering education, embracing DT traits like integrative feedback and collaboration has been shown to motivate students to tackle sustainability challenges creatively, promoting innovative design solutions with potential for real-world applications and intellectual property creation [9]. This educational foundation prepares students for innovation that can be protected through patents.

To conclude, it is only fair to confirm that Design Thinking can confidently drive innovation by promoting a structured, human-centric approach that nurtures creativity and iterative improvement. It enables teams and individuals to develop original, user-centred solutions that address real needs, incorporates mechanisms to protect intellectual property early, and exploits supporting technologies that enhance creative processes. This comprehensive approach increases the likelihood that design outcomes will not only be innovative but also patentable, thereby advancing traditional, linear design processes and proposing competitive advantages. However, despite this potential, the systematic integration of DT in design education to intentionally support the production of patentable solutions remains limited.

3 METHODOLOGIES

3.1 Research Design

This study adopts a practice-based educational intervention approach to examine the integration of Design Thinking (DT) with structured intellectual property (IP) processes within senior-level design studio courses that may lead to potentially patentable outcomes. The study is exploratory in nature, focusing on assessing the feasibility and educational potential of integrating IP-focused practices into design pedagogy rather than to establish causal relationships. The intervention was implemented within real course settings, allowing observation of both the process and outputs of student work. It was conceptually structured around four interconnected stages, i.e. IP literacy, Design Thinking Process, Intellectual Property integration, and finally leading to the project outcomes as illustrated in Figure 1.



Figure 1. Design-process for IP-focused outcomes

3.2 Context and Participants

The study was conducted within undergraduate Industrial Design and Interior Design programmes at the College of Design, through two separate practice-based courses: an Industrial Design Elective course and a senior Interior Design Studio course. Both courses were delivered over a single 15-week academic semester and included a major project-based assignment that integrated design development with intellectual property (IP) considerations, encouraging students to move beyond creative ideation toward potentially patentable innovation. Although both cohorts followed the same overarching framework, which combined design thinking with IP screening and protection processes, they worked on discipline-specific project briefs aligned with their programmes.

Participants comprised a total of 48 undergraduate senior students (final year), organised into teams of two to four students per project. The only participation criterion was being enrolled in the course. While all students had baseline experience with design briefs and prior exposure to selected DT phases, their familiarity with DT and IP varied across cohorts, as Industrial Design students had prior exposure to patent literacy and the application process, whereas Interior Design students encountered structured IP screening for the first time within this project.

3.3 Intervention and Screening Process

The intervention was implemented across two practice-based courses independently, both courses adopted a Design Thinking (DT) instructional approach. DT stages, i.e. empathy, problem definition, ideation, prototyping, and testing, structured the project process as an underlying pedagogical framework. Intellectual Property (IP) and patent application were formally introduced in both courses by the College's Innovation Unit Representative, establishing key aspects of patentability criteria, prior art considerations, and submission procedures.

In parallel, projects underwent structured screening for patent potential at key stages of development. This included reviewing project viability, preparing required documentation, completing application forms, and coordinating formal submission procedures. All processes were overseen by the Innovation Unit, ensuring consistency in evaluation, compliance with institutional and legal requirements, and alignment between academic outputs and patent application standards.

3.3.1. Duration and Project Timeline

The intervention spanned approximately 15 to 20 course-hours over a period of 5 to 6 weeks, covering the full project cycle from ideation to submission of the patent application files through the university Patent and Technology Transfer Office (PTTO).

Following a timeline aligned with DT stages, the project began with Phase 1 (3 hours), which focused on IP literacy, followed by Phase 2 (3–6 hours), involving ideation and concept development alongside an introduction to patent application processes and prior art exploration. Phase 3 (3 hours) included low-fidelity prototyping and iterative testing, while Phase 4 (3–5 hours) focused on the final design development and presentation, including faculty review of patent application drafts. The process concluded with Phase 5 (3 hours), which involved the compilation of project documentation and the submission of preliminary patent applications for eligible projects to the university PTTO, including the required forms and supporting materials such as all drafts, presentations, technical drawings, and rendered images.

3.3.2. Supporting Tools and Resources

1. IP literacy workshops and expert feedback:

Workshops delivered by the faculty liaison with the PTTO introduced patentability criteria, prior art search strategies, and basic patent drafting. Additional support was provided by internal IP consultants and external mentors from the Industrial Design Department, offering feedback on novelty and industrial applicability to Interior Design teams.

2. Patent databases:

Prior art searches were conducted using free and institutional patent databases such as WIPO-Patent-scope, Google-Patents, and USPTO, with guidance on search procedures and disclosure form completion provided by course coordinators.

3.3.3. Patent Screening Process

During the design development and refinement stage, both formative and summative assessments were integrated to support student learning and strengthen the patent potential of the proposed concepts. Evaluation was conducted through continuous discussions, iterative reviews, and formal assessment activities. Formal evaluations were guided by structured rubrics assessed key criteria, including design concept and impact, innovation, feasibility, and overall development quality.

Following the initial screening, projects underwent an additional review by the College Innovation Unit to ensure the completeness of documentation, drawings, and required forms. Subsequently, submissions were forwarded to the PTTO for final evaluation of the application, including compliance checks and assessment of submission quality, afterwards, projects were either accepted for further processing or received preliminary approval i.e. “green light.”

This multi-stage screening process (Figure 2) functioned both as an evaluation filter and a learning mechanism. It guided students in refining their concepts toward more viable, well-documented, and potentially patentable outcomes.

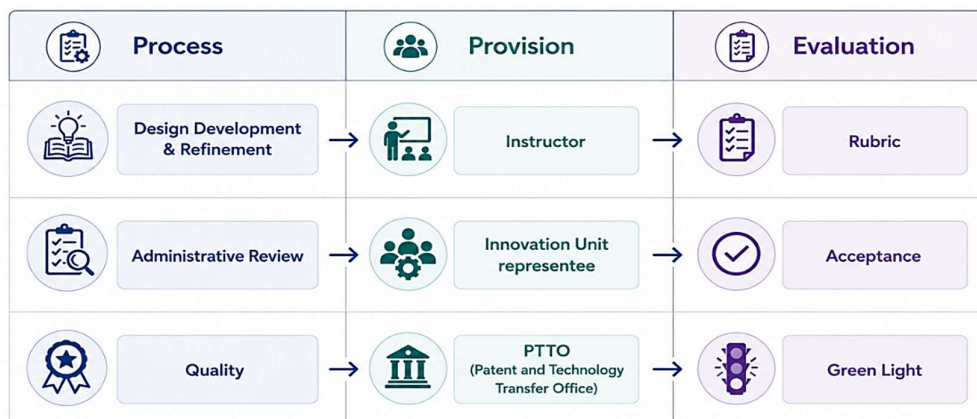


Figure 2. Reviews and evaluations

4 PROJECT OUTCOMES

A total of 16 projects were submitted to the PTTO for patent consideration (8 by Industrial Design, and 8 by Interior Design), thus far (4 months after courses' completion), five projects have received preliminary approval, i.e. "green light" by the PTTO office and moved forward to the preparation for the next stage, i.e. "filing stage" in addition to two projects that actually progressed to the formal patent filing (Figure 3).

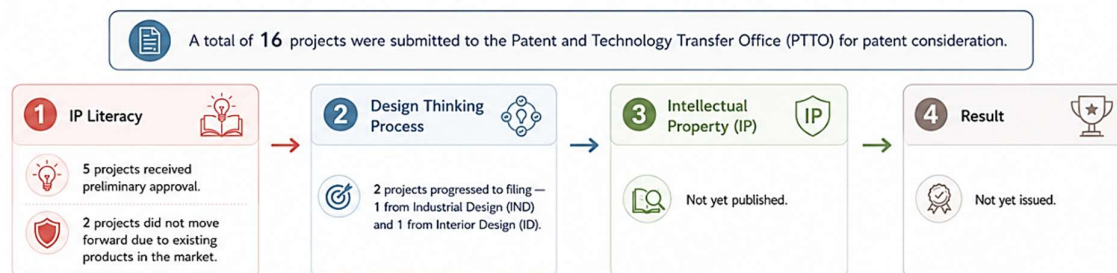


Figure 3. Projects' outcomes

5 DISCUSSIONS OF OUTCOMES

The integration of DT within the two practice-based courses yielded measurable academic and innovation-oriented outcomes. Students demonstrated enhanced capability in performing user-centred problem definitions, generating concepts grounded in empathy findings, and developing designs supported by professional feedback.

Compared to prior cohorts (before the structured DT integration), project documentation reflected greater clarity in problem framing, stronger justification of design decisions, and more systematic iteration processes. A key outcome of the intervention was the increased awareness and consideration of intellectual property (IP) dimensions during the design development phase. By introducing patentability criteria, students shifted from producing conceptually strong but academically confined projects toward solutions positioned within real-world innovation ecosystems.

Several projects were screened for patent potential, and a subset progressed to formal application procedures. This demonstrates a tangible shift from design as an academic deliverable to design as a protectable innovation asset.

The structured exposure to the patent application process further contributed to students' understanding of innovation beyond ideation. Engagement with prior art searches, documentation requirements, and formal submission procedures strengthened analytical rigor and critical comparison skills. Students were required to defend the uniqueness of their concepts relative to existing solutions, which deepened their strategic thinking and reduced superficial novelty claims. This alignment between DT and patent evaluation criteria appears to have reinforced the practical dimension of innovation competence.

From a pedagogical perspective, embedding IP processes within practice-based courses reduced the traditional separation between creative exploration and commercialisation pathways. Rather than treating patenting as a post-graduation activity, the intervention positioned it as an integrated component of design development. The consistency of implementation minimised procedural variability and ensured alignment between educational objectives and innovation outcomes.

However, the findings also reveal challenges. Not all high-quality design projects demonstrated patentable potential, underscoring that creativity alone does not guarantee protectable innovation. Additionally, the patent screening process required substantial faculty involvement, raising concerns about scalability in larger cohorts. This could be addressed by standardising IP literacy before project initiation, for example through recorded lectures, and by partially automating the screening of non-confidential IP related sections using tailored AI tools. These tools could also support longitudinal tracking and help monitor the long-term commercial potential of the projects.

Despite these constraints, the outcomes suggest that structured integration of DT with explicit patent education can meaningfully enhance students' innovation literacy and increase the likelihood of generating patent-oriented design outputs.

6 CONCLUSIONS

The proposed pedagogical framework contributes to design education by linking creativity, feasibility, and protectability within a single instructional model. It positions academic practice-based courses as early-stage innovation incubators and demonstrates the value of integrating IP literacy into design curricula.

The framework also shows potential for adaptation across other practice-based disciplines seeking to enhance innovation-oriented outcomes.

Future efforts should focus on scaling the model through institutional support mechanisms, interdisciplinary collaboration with legal and technology transfer units, and longitudinal tracking of commercialisation outcomes. Further multi-institutional research is recommended to validate and refine the framework across diverse educational contexts.

DECLARATION

During the preparation of this manuscript, ChatGPT was used solely for proofreading and improving sentence clarity and readability. The authors reviewed and approved all edits and remain responsible for the manuscript's content.

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THE DIVERSITY OF LEARNERS' VOICES AS A DRIVER FOR DESIGNING A LEARNING SYSTEM 4.0 THROUGH A TRIZ-BASED METHOD

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ABSTRACT

The rapid evolution of Industry 4.0 has increased the gap between academic programmes and labour-market expectations. Although Education 4.0 promotes learner-centred and digitally supported learning, many existing systems still lack personalisation, accessibility, pedagogical support, and connection with real industrial contexts. Designing an effective Learning System 4.0 therefore requires combining technological advances with a clear understanding of learners' expectations. This study focuses on learners' voices as an initial step within the ConNect method, a TRIZ-based design method for developing a Learning System 4.0. A structured questionnaire was administered to engineering students at the beginning of their programme to collect data on their profiles, pedagogical preferences, expectations, and perceived learning difficulties. An open-ended question also explored what students expect from a learning system to support their transition into employment. The study adopts a mixed-method approach. Descriptive statistics are used to identify overall trends and differences across student profiles, while thematic coding of open responses highlights recurring themes. The expected outcomes aim to identify learners' priorities and define pedagogical requirements to support the future design of a Learning System 4.0.

Keywords: Industry 4.0, Education 4.0, Learning System 4.0, learners' voice, TRIZ-based design method, mixed-method approach

1 INTRODUCTION

The transition from school to higher education and then to industry has become increasingly complex, as students' learning pathways are not always aligned with their expectations, working methods, prior experiences, and skills [1]. This misalignment is reinforced by the rapid evolution of industrial skill requirements, driven by emerging technologies such as AI and new decision-making processes [2]. As global education systems evolve toward more digital, interconnected, and data-driven models often referred to as education and Learning System 4.0 there is a growing need to understand how these transformations are perceived and experienced by the students themselves [3]. Despite the rapid diffusion of advanced technologies such as learning analytics, immersive environments, and adaptive platforms, the voices of learners remain insufficiently integrated into the design of these systems [4]. This need is empirically supported by Strating, Vanlommel, and Vermeulen (2025), who show that students' perceived opportunities to express their voice in curricular decisions are positively associated with the satisfaction of their basic psychological needs and their autonomous learning motivation. Their findings indicate that when students' expectations and experiences are not adequately captured, a misalignment arises between educational design and learners' needs, thereby reducing the effectiveness of educational systems [5]. The literature on student voice indeed shows a strong concentration of research at the secondary education level, to the detriment of higher education. A systematic review published in 2024 highlights that the majority of empirical studies focus on high schools, while research dedicated to higher education remains limited and is often theoretical [6]. Current literature highlights that overlooking user needs in education design can reinforce existing inequities and create new forms of exclusion, especially for learners who lack social capital or cultural representation within higher education [4]. In this context, capturing, interpreting, and acting upon the voice of learners becomes

essential to ensure that Learning System 4.0 does not merely digitise existing practices but instead fosters inclusive, meaningful, and empowering learning experiences [7]. Understanding learners' motivations, expectations, challenges, and perceptions is therefore a foundational step toward the creation of systems that support diverse pathways and promote equitable progression from education to employment [8]. In this study, learners' voices are considered as the first data collection step in a broader design process based on the ConNect method, a TRIZ-based design approach. They are used not only as descriptive feedback, but also as design inputs to identify needs and parameters for developing a Learning System 4.0. This paper presents a structured survey on students' profiles, learning preferences, expectations, and difficulties, followed by the methodology, results, discussion, and future work.

2 METHODOLOGIES

This study adopts a mixed-methods approach based on an online survey conducted among bachelor's and master's engineering students. Administered via LimeSurvey, the survey explored students' profiles, learning difficulties, and expectations regarding the design of a Learning System 4.0 focused on skills development and employability. A total of 334 complete responses were retained. Participation was voluntary and anonymous, and the data were collected for scientific research purposes.

3 DESCRIPTIVE ANALYSIS OF THE RESULTS

This section presents the descriptive results based on the 334 complete responses. It first describes the student population, then analyses students' responses and expectations regarding the development of a new Learning System 4.0.

3.1 Description of student population

The sample mainly consists of students beginning a new higher education programme, mostly first-year bachelor's students (70.3%) and first-year master's students (24.8%). The represented fields include Electrical Engineering and Industrial Computing, Multimedia and Internet Professions, Quality, Industrial Logistics and Organisation, Industrial Engineering and Maintenance, QHSE, and Industrial Engineering. These fields were selected due to our direct involvement, which limits the generalisability of the findings. Respondents had diverse academic backgrounds, mainly general (51.2%) and technological (37.1%) high school diplomas. Most students reported some professional experience (87.7%), ranging from short internships to apprenticeships. Their programme choice was mainly driven by personal interest (62.2%), followed by Parcoursup¹ (29.6%) and social influences such as family or peers (24.25%).

3.2 Learner's Expectations: Format

This section examines students' expectations regarding learning formats and their preferences across different pedagogical aspects.

- **Preferred learning format:**

Survey question: "What learning format do you prefer?"

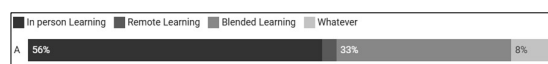


Figure 1. Students' preferences for learning

Figure 1 shows a strong preference for in person learning (56 %), while one third of students favour a blended learning (33 %). Fully remote learning is rarely preferred (3 %).

- **Preferred learning balance: Company vs University and Practice vs Theory**

Survey question 1: "What distribution between time spent in the company and time spent in university would best suit your way of learning?"

Survey question 2: "During the university programme, what balance between practical activities and theoretical courses would best suit your way of learning?"

¹ Parcoursup is a national admissions platform restricted to French nationals.

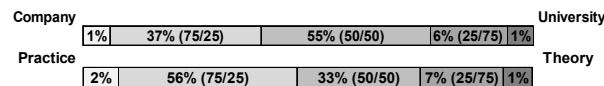


Figure 2. Preferred learning balance: Company vs University and Practice vs Theory

Figure 2 presents students' preferences along the company vs university and practice vs theory axes, analysed by study level and field. For company vs university, master's students mainly prefer 75 % company / 25 % university (48.1 %), while bachelor's students favour 50 % company / 50 % university (57.6 %). By field, QHSE students mostly prefer 75 % company / 25 % university (54.4 %), whereas QLIO students favour 50 % company / 50 % university (62.9 %). For practice vs theory, bachelor's students prefer 75 % practice / 25 % theory (61.1 %), while master's students favour 50 % practice / 50 % theory (44.6 %). By field, GEII students strongly prefer 75 % practice / 25 % theory (79.2 %), whereas GIM students mostly prefer 50 % practice / 50 % theory (77.5 %).

- **Learning conditions**

Survey question: "When learning something new, how important are the following conditions for you?"

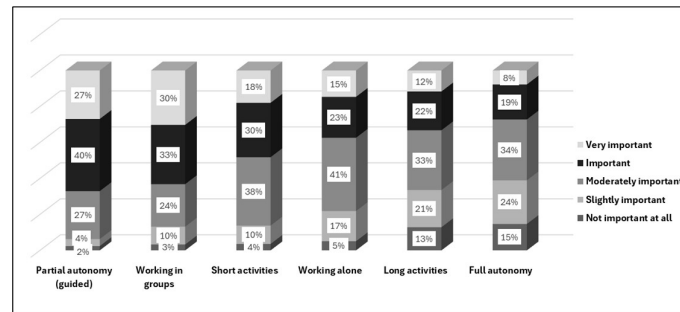


Figure 3. Importance of learning conditions

Figure 3 presents students' preferences regarding learning conditions according to their level of study. The results show a clear preference for partial autonomy among both bachelor's students (66.8%) and master's students (66.6%), while total autonomy is less frequently chosen. Similarly, students tend to prefer group work over individual work, with 66.4% of bachelor's students and 55.9% of master's students selecting this option. Regarding activity duration, most students do not express a clear preference between short and long-term activities, although short activities are slightly more favoured.

- **Importance of different learning elements**

Survey question: "If you could adapt your university programme, which elements would you consider important to modify?"

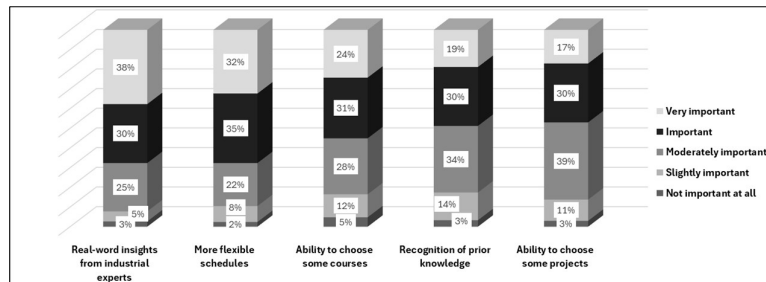


Figure 4. Importance of different learning elements

Figure 4 shows that students value learning elements linked to professional realities, especially industrial expert insights, flexible schedules, and course choice. Master's students show stronger preferences for autonomy and project selection, while bachelor's students appear to need more structure and guidance. Overall, engineering students seek more flexible, personalised, and professionally oriented learning experiences.

- **Importance of learning resources**

Survey question: "When you start a new university programme, what would you like to have as a priority to learn effectively?"

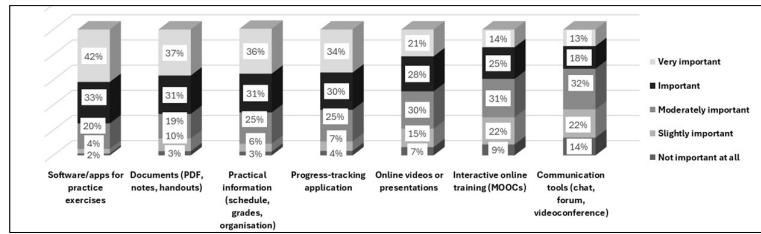


Figure 5. Importance of learning resources

Figure 5 shows that bachelor's and master's students mainly prioritise resources supporting active learning and task organisation, such as software, applications, notes, PDFs, and schedules. However, master's students value online videos and presentations more than bachelor's students. Interactive online learning and communication tools receive lower levels of importance in both groups.

3.3 Learner's Expectations: Content

This subsection focuses on students' expectations regarding university content to identify the elements they consider most important for their learning needs.

- **Difficulties encountered during learning**

Survey question: "What difficulties do you encounter during your learning process?"

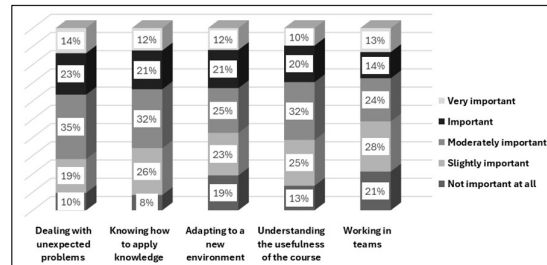


Figure 6. Difficulties during learning

Figure 6 shows that students mainly struggle with adapting to new situations and solving unexpected problems. These difficulties suggest that learning barriers are more related to applying knowledge in varied contexts than to understanding theory. They also indicate a need to better connect learning with professional realities and to develop initiative and adaptability.

- **Expectations about learning content**

Survey question: "How important are the following elements for your future employability?"

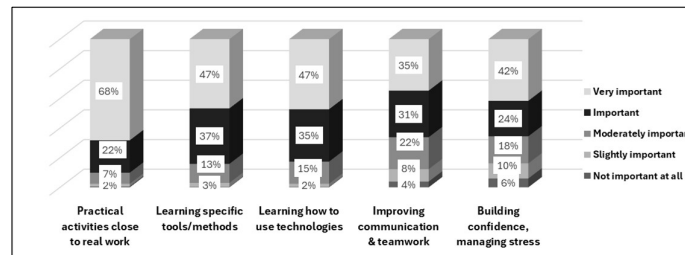


Figure 7. Expectations about learning content

Figure 7 shows that students mainly prioritise practice-based learning, especially practical activities connected to real work, followed by the acquisition of tools, methods, and technological skills. Although soft skills such as communication, creativity, and stress management are valued, they remain secondary. Overall, engineering students strongly associate learning and employability with technical and practical skills, which may reveal a gap with professional expectations where soft skills are increasingly important.

- **Expected roles of teachers**

Survey question: “In your opinion, what roles should teachers play to help you succeed in your learning at university, and how important is each of these roles to you?”

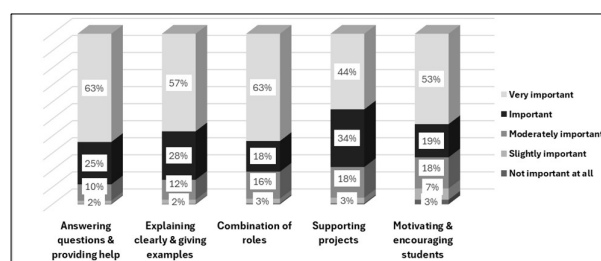


Figure 8. Expectations regarding teacher roles

Figure 8 shows that students mainly expect teachers to provide expertise, clear explanations, and concrete examples. This reflects a need for guidance and support, while revealing a gap with Education 4.0 principles that emphasise learner autonomy and the teacher’s role as facilitator.

• Open-ended question

In the final survey question, students stated what a learning programme should provide to support their transition into employment. A thematic analysis of 274 responses identified six recurring themes, presented in Figure 9.

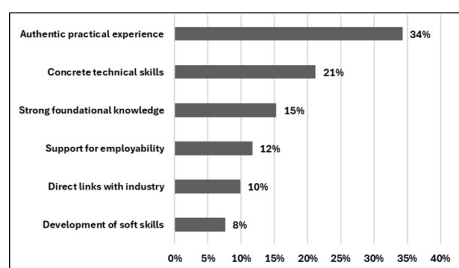


Figure 9. Distribution of students' expectations for employability

Figure 9 shows that students mainly associate employability with practical experience and technical skills, while foundational knowledge is seen as complementary. They also value stronger links with industry, whereas soft skills are less prioritised.

4 BEHAVIOURAL ANALYSES

The behavioural analysis highlights strong student expectations for practical, profession-oriented learning. Students prefer real-world situations, company exposure, and hands-on activities integrated into university programmes. They also expect greater adaptability, flexibility, and accessibility through flexible schedules, course organisation, project choice, digital tools, and clear learning information. These expectations reflect difficulties in applying knowledge, solving unexpected problems, teamwork, and adapting to new environments. Master’s students show stronger needs for autonomy, project choice, and flexible pathways, while bachelor’s students prefer more guidance, structure, and pedagogical support. Students strongly value employability, technical skills, professional tools, and real work practices, while soft skills receive less attention. They also expect teachers to provide clear explanations, continuous guidance, and direct support, which differs from the Education 4.0 vision of teachers as facilitators and coaches. Therefore, students need to be progressively supported toward autonomy through an expert-coach role combining expertise, guidance, and co-construction of knowledge. Overall, the results align with Education 4.0 by identifying conditions for its implementation. The proposed Learning System 4.0 should emphasise hands-on, project-based, and problem-solving activities linked to industry, while promoting collaborative learning, flexible modular pathways, adaptive digital tools, feedback, self-assessment, progress monitoring, confidence, and autonomy.

5 DISCUSSIONS

The results highlight five consistent expectations that shape students’ learning behaviours: flexibility, accessibility, adaptability, employability, motivation and engagement. Students prioritise practice learning, flexible and personalised learning paths, easy access to resources and information, and strong links with professional contexts. These expectations are closely aligned with the core principles of Education 4.0 as defined by Peter Fisk [3], which promote flexible learning across time and place,

personalised and adaptive pathways tailored to individual capabilities, freedom of learning methods and tools, project-based and experiential learning connected to real-world contexts, stronger emphasis on data interpretation and critical thinking, continuous competency-based assessment instead of traditional exams, greater student involvement in shaping curricula, and a shift in the teacher's role toward mentoring and guidance in increasingly autonomous learning environments. The first contribution of this study lies in its empirical grounding within higher education. Several recent studies confirm that higher education students favour active learning approaches based on the concrete application of knowledge and exposure to situations close to the professional world [9].

6 CONCLUSION AND PERSPECTIVES

To design a Learning System 4.0 aligned with students' expectations, this study uses a Voice of the Customer (VoC) approach, derived from Lean management and continuous improvement, to capture stakeholder needs through surveys. Engineering students are considered the primary customers, as they are the direct beneficiaries of the learning system. Students particularly value practice-based learning, flexible and personalised pathways, easy access to resources, and stronger links between academic learning and professional contexts. However, the study is limited to engineering education and cannot yet be generalised to other disciplines. Moreover, while the survey provides a broad quantitative overview, it does not explain the underlying reasons behind students' choices. Future research should therefore include qualitative methods, such as interviews or focus groups, and explore disciplinary differences within engineering education. This survey represents a sub-phase of the VoC process within ConNect, a TRIZ-based design method for Learning System 4.0. Future work will integrate the perspectives of teachers and companies and use these results to define action and evaluation parameters, analyse their relationships, identify contradictions, and generate innovative solution concepts.

ACKNOWLEDGEMENTS

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SET UP TO FAIL: REFLECTIVE PRACTICE AND CULTURAL ADAPTATION IN TEACHING DESIGN AT A TRANSNATIONAL INSTITUTION IN CHINA

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ABSTRACT

Teaching design within UK–China partnered higher education institutions is increasingly common. In these TNE contexts, students encounter Western iterative, failure-driven design processes alongside educational expectations shaped by filial piety (xiao) and Confucian principles. Where public embarrassment or loss of face is significant, openly sharing creative experimentation can become difficult, requiring failure-led studio practice to be carefully scaffolded.

Drawing on the author’s experience, this paper examines how Dweck’s Growth Mindset and Kolb’s Experiential Learning Cycle can be adapted for design teaching in China through an AI-assisted creative module. Students transformed sketches into AI-rendered outputs and used AI-generated “failures” as prompts for critique, reflection, and refinement. This created psychological distance between students and their work, making failure acceptable - and at times humorous, while re-framing iteration as a core component of creative development. The structured cycle of iteration and self-evaluation supported open discussion of mistakes and strategies for improvement.

The AI-mediated reflection model preserved face while fostering creative risk-taking, offering insights for educators navigating cultural expectations in transnational learning environments.

Keywords: Growth mindset, AI in design education, cross-cultural pedagogy, filial piety

1 INTRODUCTION

China hosts an expanding number of transnational education (TNE) programmes [1], increasing the need to examine how Western pedagogies and ideas such as Design Thinking (DT) are enacted in Confucian environments. In UK–China partnered institutions, students engage with DT while shaped by xiao (孝), where success honours family and failure risks loss of face. Visible failure, public critique, and disagreement can create ethical discomfort; risk-avoidance may reflect responsibility to teachers, peers, and family rather than limited creativity. This study tests AI-assisted design to adapt DT so iterative failure becomes acceptable while preserving face.

RQ1: How do AI outputs create psychological distance for reflective iteration?

RQ2: What critical thinking behaviour changes emerge across DT cycles?

1.1 Confucianism, face, and rote learning

Confucian Heritage Culture (CHC) education prioritises moral, intellectual, and ritual instruction, organised around a “tripod” of xiao, ren, and li that reinforces hierarchy and social harmony [2]. Academic effort is framed as familial duty, and saving face (miànzi) discourages public mistakes. Rote memorisation (repetition for mastery within teacher-led instruction) can clash with exploratory, failure-driven studio learning in TNE design education, and must be addressed for both approaches to coexist.

1.2 Design Thinking as pedagogical orthodoxy

In contemporary Western education, Design Thinking (DT) is a key pillar of design education [3,4] and is often positioned as a neutral, transferable framework [5]. DT is frequently presented as a failure-driven learning model that encourages iterative experimentation, user-centred thinking, and reflective mindset [6]. These frameworks frame failure as productive and open critique as beneficial, promoting

individual autonomy, visible experimentation, and critical debate. This concerns imported pedagogical assumptions; Western design students may conceal imperfect work and struggle to learn from failure. In Chinese TNE systems, DT must therefore be re-interpreted through Confucian learning environments. The apparent neutrality of failure in DT rests on assumptions about how learners relate to error, critique, and identity. Growth-oriented pedagogies frame failure as informational rather than evaluative, supporting development through strategy and revision rather than fixed ability [7], yet this is context-sensitive: when critique carries relational or moral consequence, responses to failure may reflect threat rather than capability. DT also draws on experiential learning traditions, cycling experience through reflection, conceptualisation, and renewed experimentation [8], which presumes learners can publicly engage with provisional work without identity threat. As Winnicott argues, creativity flourishes within a ‘transitional space’ where ideas can be explored provisionally without immediate risk to the self [9]. Where this separation is not culturally assumed, the productive framing of failure cannot be transplanted and must be deliberately scaffolded.

1.3 AI as an ethical disturbance in transnational design education

Within design education, AI is most commonly framed through instrumental narratives that emphasise efficiency, creativity enhancement, or productivity [10]. However, teaching and learning using AI needs to be taught in a responsible way with integration that foregrounds critical engagement rather than technological solutionism [11]. Critically, it risks shifting responsibility away from students’ evaluative judgement and towards algorithmic output. In educational contexts shaped by hierarchical or authority-oriented learning cultures, AI outputs can be perceived as inherently correct or superior. [12].

Exhortations to value effort or failure without changing learning conditions risk producing a “false growth mindset” [7]. This paper argues that AI should not be understood merely as an innovation or productivity tool within design education, but as an ethical disturbance that destabilises established relationships between authority, authorship, and evaluation. The ethical challenge is not whether AI is used, but how responsibility and judgement are retained by the learner. Positioning AI as a design assistant [13] rather than a solution generator exposes these tensions directly, forcing students to confront questions of evaluation, refusal, and justification rather than passive acceptance of outputs.

Learning depends on context [14]; environments shape willingness to face challenge and failure. This paper examines AI as a co-agent in a TNE design classroom, surfacing authority/failure tensions to cultivate self-evaluation.

2 METHODOLOGIES

The research took place within a TNE partnership between two HE institutions: a university in Lancashire, UK, and a partner institution in Hebei, China. The AI-Scaffolded Reflective Critique was implemented with one cohort of 29 second year (Level 5) design students at the Hebei institution.

2.1 The AI-Scaffolded Reflective Critique

The intervention followed Kolb’s Experiential Learning Cycle [8] to ensure iteration was reflective rather than repetitive and was embedded in existing modules as three stages of using AI within critical DT: (1) Introductory, (2) Design assistant, and (3) Analytical tool.

Across stages, students moved from sketching and AI visualisation (concrete experience) to collective critique of AI outputs (reflective observation), then articulated success criteria and output limitations (abstract conceptualisation) to guide subsequent iterations (active experimentation). This cycle framed failure as a learning stage and supported evaluative judgement. Students chose their own GenAI text-to-image and LLM tools; this reduced early language barriers compared with enforcing a fixed UK-standard toolset.

2.2 Data Sources and Reflective Materials

Data comprised student visual outputs (sketches and AI iterations), studio fieldnotes, and anonymous questionnaires (n=15). Visual outputs traced iterative development and refinement across cycles. Fieldnotes were analysed qualitatively for shifts in critique behaviour (e.g., reluctance to upload, humour, refusal, comparison, justification) and links to iteration. The questionnaire used a 5-point Likert scale to capture evaluative judgement, comfort sharing imperfect work, and confidence in human-driven design judgement; responses were voluntary and not assessed.

2.3 Reflexivity and Researcher Positioning

The lead author is a Western product design educator teaching on the course at the Chinese institution. Reflexivity was maintained through fieldnotes that separated description from interpretation, and by treating silence and delayed critique as culturally situated responses to evaluative threat rather than disengagement.

3 RESULTS - AI-SCAFFOLDED REFLECTIVE CRITIQUE

Prior to this workshop students' verbal perception of AI was as a correct, helpful, and authoritative tool.

3.1 Stage 1: Initial Student Expectations of AI

During the stage 1 exercise students were tasked with creating AI designs based on simple items found around them. Outcomes as displayed in figure 1 were purely to explore what can be created to provide output in the creative process. Students were then tasked to evaluate unavailable items to use as influences for creating initial design ideas. Below is an example where a student created an initial design using a picture of a cat, an unusual choice for inspiration, however providing change of perception in the creative design process.



Figure 1. Student cat photo (left) generated design concepts using image-to-image AI tool

Students uploaded their AI generated images to explore what they had created and could quickly generate content regardless of if the work is deemed successful or not. With the sole purpose of identifying what could be created from their initial pictures, this stage was designed as a way for students to explore AI in its most basic form, exploration.

3.1.1. Early Encounters with AI Failure

Early encounters produced generic, poor outputs that challenged assumptions of AI reliability and created discomfort. Students began judging what was “good” or “bad,” but initially avoided sharing work, as public evaluation risked conflict with xiao (孝). Within the scaffold of “failure to succeed,” these outputs—sometimes humorous—helped students treat results as neither inherently “good” nor “bad,” enabling personal judgement and use within the design process.

3.1.2. Externalising Failure Through AI

Attributing failure to AI preserved face and made critique psychologically safer. Silence or delayed critique reflected norms around authority and the relational significance of public error, rather than lack of critical capacity. By externalising error into artefacts not wholly owned by students, AI created a transitional space for play and critique without identity threat [9]. Structured through Kolb's cycle [8], students moved from sketching/AI visualisation to collective critique, criteria for improvement, and re-experimentation; without this, critique often defaulted to teacher correction. AI redistributed evaluative risk and scaffolded reflective participation rather than shortcutting ideation.

3.2 Stage 2 Shifts in Critical Behaviour - The Design Assistant

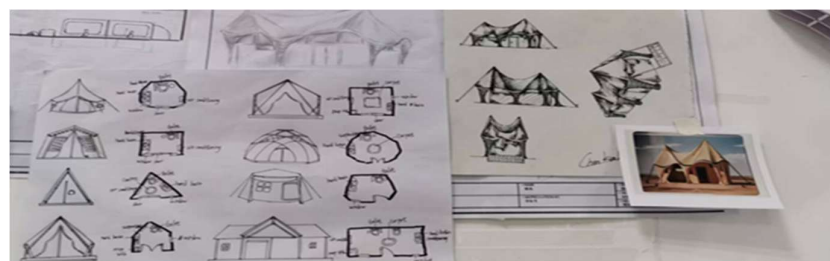


Figure 2. Student sketches and GenAI image-to-image rendered tent product concepts

As students built their understanding of structured ethical AI, behaviours shifted: they began rejecting, comparing, and justifying decisions rather than accepting outputs. AI outputs were not taken on face value but used for critical reflection, and as a design assistant it supported students’ ability to self-criticise design work as can be seen in the student sketches and AI generated render in figure 2. In Stage 2, students designed camping equipment for complex scenarios to create space for rapid self-critique. As current students are surrounded by fast paced content while design processes can be lengthy and lead to disinterest, AI enabled creativity to develop quickly. Students had less time to become overly attached to designs and instead used outputs to communicate ideas.

3.3 Stage three: Iteration as Evaluation Analysis with academic applications



Figure 3. Student work using AI as an analytical tool to recognise cross-cultural patterns

Within the academic application of iteration as evaluation, students used learned skills to create academic posters, as shown in figure 3 comparing a western art movement and Chinese historical art items, then combine both into an artistic design or product. They had to showcase not only the result but the iterations used to develop the final image. This encouraged reflection on AI outputs through their own acquired knowledge, rather than accepting outputs as factual, recognising their knowledge as key to judging whether outputs were correct or incorrect. Iterations slowed, becoming reflective rather than performative, creating depth of understanding that could be applied to further creative learning.

3.4 Student interpretation survey

Table 1 shows the results (1 = strongly disagree, 5 = strongly agree) of the short post- course questionnaire in teaching the use of ethical AI within the context of design thinking.

Table 1. Post-Course Results Table

Student Feedback Questions		Response/score (%)				
		1	2	3	4	5
1	The activity of using AI in the design process helped me improve how I evaluate design outcomes?	0	0	13.3	40	46.7
2	I felt comfortable sharing work that was imperfect during discussions?	0	0	26.7	73.3	0
3	The activity helped me build confidence in my design judgement rather than assuming AI generated images was ‘correct’?	0	0	0	66.7	33.3

Table 1 shows the intervention strengthened students’ evaluative judgement and independent decision-making with AI. Comfort sharing imperfect work was comparatively weaker, suggesting face (miànzi) still shaped participation. Respondents agreed the programme supported independent design judgement.

4 DISCUSSION - RESTRAINT AND JUDGEMENT IN DESIGN THINKING

The results indicated that the activity first altered students’ epistemic position toward AI (reduced assumption of correctness), then strengthened evaluative judgement, and only subsequently influenced willingness to publicly expose incomplete work. Highlighting that cognitive change preceded social confidence. This pattern suggests the intervention primarily functioned by externalising error, allowing students to critique artefacts before critiquing themselves, rather than directly increasing confidence.

4.1 Rethinking Failure as Ethical Practice

Within the framework of TNE systems ‘failure’ is reframed as moral and relational, not merely procedural. Higher Education systems need to be able to evaluate and understand that students need to approach failure in an alternative way, breaking these standards, students come to universities to not only ‘do’ but to understand ‘why’. Within TNE systems, educators need to understand cultural expectations around questioning and support students’ Design Thinking development through culturally responsive scaffolding. We need to ask ourselves as educators to not only build upon these principles but make students to feel comfortable to thrive, moving away from the ‘standard’ method of design thinking of speed and production but lead first into ethical judgement and structure restraint to provide a scaffold for TNE students to thrive before the scaffold is removed.

4.2 Design Thinking Beyond “Fail Fast”

Student feedback challenges the assumption within Design Thinking that learning emerges through immediate ownership of failure [6,15]. While students expressed confidence in evaluating and rejecting AI outputs, they were less comfortable presenting imperfect personal work, indicating that reflection preceded public ownership. The AI assistant functioned as a transitional site of failure. When outputs were perceived as unsuccessful, students attributed error to the system rather than themselves (“the AI got it wrong”), creating evaluative distance. In Winnicott’s terms, the artefact operated within an intermediate space between self and other [9], enabling critique without immediate threat to identity.

In TNE contexts where public error carries relational consequence, immediate authorship may inhibit participation. AI-mediated iteration did not remove failure but relocated it, staging critique before self-exposure and allowing reflective judgement to form prior to ownership. Pedagogy in transnational classrooms may therefore need to scaffold ownership rather than demand it at the outset.

4.3 Cultural Implications for Transnational Design Education in Confucian Heritage Culture educational environments

Universal pedagogical models in design education are often treated as transferable across contexts; however, in transnational environments they may function as incomplete rather than incorrect frameworks. Western studio pedagogy assumes participation through open critique, individual positioning, and visible iterative failure even though students may present this process selectively within assessed work. In cohorts shaped by Confucian Heritage Culture (CHC), values such as respect for hierarchy, preservation of harmony, and avoidance of public error can significantly shape classroom behaviour. What may appear as disengagement can instead reflect culturally embedded approaches to knowledge and self-presentation.

Western models frequently assume that confidence precedes critique. In CHC contexts, confidence may instead develop through relational trust and gradual demonstration of competence. When immediate public ownership of failure is required, participation may be constrained. Embedding staged “failing successfully” processes through AI as a co-agent relocates error from the individual to the artefact before students are asked to own imperfect work. This enables evaluation without immediate loss of face, supporting reflective engagement while remaining culturally responsive. Over time, such scaffolding can foster designers capable of critical judgement within culturally coherent modes of participation.

4.4 Toward a Post-Method Design Thinking

Design Thinking is reframed as reflective capability rather than toolkit.

- Design thinking will need to be refined to be in line with existing teaching frameworks while working with delicacy in delivery TNE systems coexisting in CHC educational environments.
- Reflexivity in the design process is the focus and foundation of this process, to ensure students are not just completing because they are being told but because they understand the importance
- Define that they are the designer, and there is a learning point within failure
- Failure does not equal fail.

Beyond this UK–China TNE context, these principles can transfer to learning environments where open critique is expected but socially, culturally, or institutionally challenging.

5 CONCLUSIONS

Drawing on Growth Mindset and Kolb’s Experiential Learning Cycle, this paper shows how AI-mediated failure can create psychological safety for critique, preserve face, and support the development

of judgement in culturally complex learning environments. Rather than proposing a universal solution, it offers a culturally responsive approach to integrating AI into design education that prioritises ethical reflection over efficiency or output.

In HE TNE systems, culturally responsive engagement with Confucian Heritage Culture (CHC) is needed when adapting imported Design Thinking pedagogy. Cultural awareness of how CHC shapes classroom engagement is crucial for supporting students' participation and critique. Developing foundational ethical AI in TNE systems can strengthen students' academic and real-world skillsets and help bridge gaps between educator and student within Confucian rote-learning traditions in the context of Design Thinking. If educators do not adapt approaches defined for Western systems, we risk limiting students' confidence in critical thinking and Design Thinking methods within product design and wider practice.

This study is limited by sample size (a single cohort) and potential bias in student feedback, which may be shaped by Confucian teachings around xiao. As a culturally situated qualitative study, the findings are context-specific rather than statistically generalisable. Future work should replicate across cohorts to identify consistent trends in students' responses to AI tools and examine impacts on comparative assessment as students' progress, while accounting for cohort differences in ability and skillset.

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TEAM DYNAMICS & AI MEDIATION: THE CENTRALITY OF DECISION-MAKING IN DESIGN ENGINEERING HIGHER EDUCATION

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ABSTRACT

Multidisciplinary collaboration is central to engineering and product design education, where project-based learning requires students to integrate diverse expertise and perspectives. However, early-stage team decision-making is often informal and weakly structured, leading to fragmented knowledge sharing, limited traceability, and uneven participation. From an EDI perspective, such fragmentation can disproportionately affect whose knowledge is surfaced and recognised. This study investigates how an AI boundary tool can support decision-making without undermining student agency. Grounded in a KS–DM Boundary Model derived from initial empirical work, an AI Figma plugin was developed to scaffold discussion rather than generate solutions. Findings indicate improved decision traceability, temporal structuring, and internal alignment, while adoption depended on summary quality and contextual accuracy. The study demonstrates that constrained, process-level AI can support inclusive collaborative learning in DE-HE while preserving student authorship and creative responsibility.

Keywords: Design engineering, decision making, boundary objects, AI, teamworking

1 INTRODUCTION

Multidisciplinary teamworking is increasingly central to professional practice and higher education, particularly in design engineering (DE) where project-based learning (PBL) dominates [1]. In such settings, early-stage decision-making (DM) often have long-term consequences in shaping project direction, scope, and prioritisation [2]. However, student teams typically lack structured leadership and procedural guidance, and decision processes tend to remain implicit and embedded within ongoing discussion. Consequently, DM depends heavily on how effectively team members share, interpret, and integrate knowledge—a dynamic process referred to as knowledge sharing (KS) [3]. When KS is fragmented or uneven, teams experience looping discussions, loss of focus, unequal participation, and weak decision traceability. Collectively, these issues reduce decision efficiency and hinder the development of shared understanding during a critical phase of collaboration. Existing models of DM and KS provide valuable theoretical foundations, but many originate from domains such as healthcare or business, where roles, authority, and decision criteria are relatively stable [4]. In contrast, student PBL teams operate in dynamic, exploratory environments where decision points emerge fluidly and knowledge is exchanged in real time through conversation and evolving artefacts. Initial empirical work in design engineering (DE) education has shown that conventional models often fail to capture how knowledge is externalised, internalised, and integrated during live team discussions. This gap highlights the need for context-sensitive approaches that reflect early-stage student collaboration challenges and support actionable interventions. The concept of boundary objects (BOs)—artifacts used to share, exchange, integrate and create new knowledge [5]—offer one route to supporting KS in multidisciplinary collaboration. In design engineering higher education (DE-HE) contexts, BOs may function as platforms, facilitators, or mediators, and take multiple forms, including physical artefacts (e.g., prototypes, Post-it notes), visual or verbal tools (e.g., whiteboards, digital canvases), and conceptual models (e.g., frameworks, process maps). While these artefacts support externalisation, they are often static, inconsistently maintained, or poorly integrated into fast-moving discussion. Consequently, decision rationale may remain tacit, be lost during topic shifts, or be unevenly accessible across team members. Integrating Artificial Intelligence (AI) into higher education presents both significant opportunities and ethical challenges. To date, AI adoption in higher education has largely

focused on system-level optimisation, such as automated feedback or tutoring tools [6]. However, by positioning AI as a powerful problem-solving agent, such approaches risk expanding its functional scope to the extent that students may become reliant on AI-generated solutions, raising concerns regarding agency, skill development, and over-dependence. In contrast, comparatively little attention has been paid to AI's role in supporting students' real-time collaborative learning processes. Existing AI meeting tools typically generate transcripts or summaries but are rarely embedded within design workflows or structured to scaffold decision-making. To address this gap, the study developed a workflow-integrated AI boundary tool implemented as a Figma plugin. Figma was selected as it is already widely used by DE students as a shared workspace [7]. Embedding the intervention within this platform minimised disruption and onboarding friction. The plugin augments rather than replaces existing boundary artefacts and is grounded in the KS-DM Boundary Model (see Figure 1), synthesised from prior empirical observation of multidisciplinary DE student teams. The model conceptualises DM as a recursive, knowledge-driven process involving externalisation, internalisation, and integration. Observations revealed that the KS and DM process was not consistently completed, with some stages missing or underdeveloped. Recurring barriers were also identified across KS and DM. The plugin was designed to address these identified barriers. Its role was intentionally limited to supporting the process itself—structuring discussion, making reasoning visible, and highlighting overlooked contributions—without generating solutions or replacing team decision-making. By embedding this controlled form of AI support within authentic PBL activities, the study evaluates how targeted process intervention can influence collaborative decision-making in design education. Accordingly, this study addresses the following research questions: (RQ1) How do KS and DM process barriers manifest in live, time-limited multidisciplinary student team discussions, and to what extent can the AI-integrated Figma plugin mitigate them? (RQ2) To what extent does a workflow-integrated, deliberately constrained intervention improve short-term DM efficiency, shared understanding, participation inclusivity, and perceived team performance? (RQ3) What workflow frictions, breakdowns, and adoption challenges emerge when embedding the intervention within the existing workspace? (RQ4) How can issues of student agency and academic integrity be addressed when deploying such AI support in design engineering education?

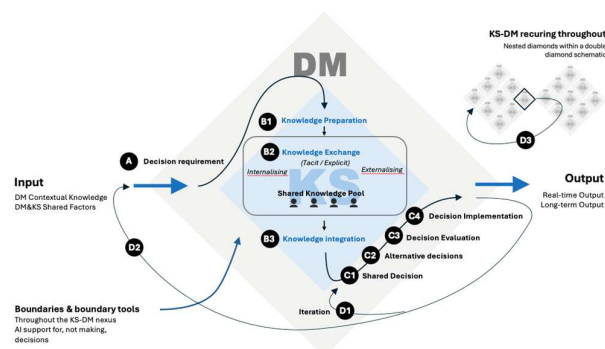


Figure 1. KS-DM (Knowledge Sharing – Decision Making) Boundary Model

2 METHODOLOGIES

This study adopts an intervention-oriented mixed-methods approach, building on initial empirical research that developed the KS-DM Boundary Model and identified key process barriers. The model was derived from a four-week naturalistic observation study of DE student team meetings, in which recurring KS and DM process barriers were identified through thematic coding. The present study focuses on operationalising these findings through the development and evaluation of a functional prototype. The methodology comprises three stages: (1) prototype development, (2) workshop-based deployment, and (3) qualitative evaluation of decision-making processes.

2.1 Prototyping Methodology and System Development

The Figma plugin was developed as a high-fidelity, fully deployable prototype designed for stable use in live collaborative workshops. It can be easily installed and operated within the Figma ecosystem, with emphasis placed on robustness, cross-session reliability, and minimal runtime disruption. Methodologically, the system adopts a modular architecture separating recording, processing, storage, and visual rendering. Due to Figma's limitations on persistent audio access and background processing,

recording and AI analysis are handled externally via a browser interface hosted on Vercel. Serverless API routes manage transcription and analysis, Supabase provides structured storage and session traceability, and the plugin functions as the visual interface layer within the workspace. Speech recognition and speaker segmentation are handled through AssemblyAI, preserving conversational structure and ensuring that multi-participant dialogue can be reconstructed accurately. Speech recognition and speaker segmentation are performed using AssemblyAI to preserve conversational structure. A two-stage processing pipeline supports both incremental, near real-time updates during sessions and a consolidated full-session synthesis after the meeting. Analytical requests are governed by a configurable prompt-generation library, which dynamically adapts prompts based on contextual parameters while maintaining consistent output structure. AI responses are constrained to predefined formats to ensure reliable rendering. Overall, the system prioritises operational stability, modular separation of functions, and seamless integration into existing collaborative workflows.

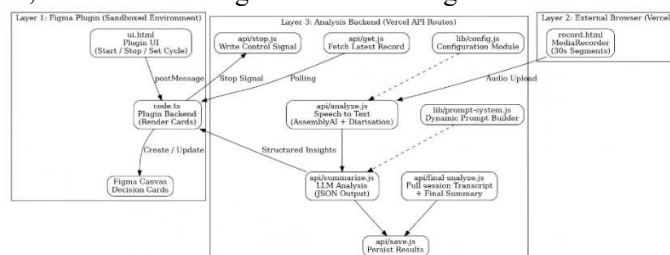


Figure 2. Plugin Product Architecture

2.2 Workshop based deployment

Following iterative prototype refinement and pilot use in tutor–student meetings, the intervention was evaluated through four structured workshops with pre-existing multidisciplinary student teams. Sixteen participants took part (four teams of four). An A/B design was adopted: two teams (Condition A) completed the task without the plugin, while two teams (Condition B) used the plugin. Each one-hour workshop involved an early-stage conceptual design task based on a breadmaker brief. Teams were required to (1) define a primary user, (2) identify three key pain points, and (3) propose a final concept, with decision points structured at 10-minute intervals to ensure observable DM stages within the session. The brief was intentionally designed to be accessible yet unfamiliar to participants. The brief was intentionally designed to be accessible yet unfamiliar to participants, reducing prior knowledge bias and enabling comparable starting conditions. The format allowed controlled comparison across defined decision stages, while focusing on short-term process effects rather than long-term behavioural change.

2.3 Qualitative evaluation of the decision-making processes

All workshops were recorded and transcribed alongside facilitator observation notes for analysis independent of the plugin interface. Manual semantic coding was conducted to record KS barriers, DM stage transitions, and behavioural patterns. Coding captured occurrences of KS barriers, DM–KS loop cycles, time intervals between decision stages, and interaction changes following AI-generated decision cards. Coding categories were predefined based on the KS–DM boundary model to maintain analytical consistency. Post-workshop surveys were collected individually using five-point Likert scales across dimensions including perceived decision efficiency, clarity of reasoning traceability, understanding of selection logic, and individual contribution for the three key decisions, with team-level means used for cross-condition comparison. In the plugin condition, AI-generated summaries served as an additional artefact for analysing decision traceability and interaction dynamics. The evaluation therefore focuses on immediate process-level impacts within the workshop setting.

3 RESULTS

Results are reported in relation to the studies research questions RQ1-3. Issues of student agency and academic integrity (RQ4) are explored in the discussion section.

3.1 The Final Prototype

The plugin operates through four structured steps. First, users configure the meeting by selecting the meeting type, module, roles, team details, and goals, and may upload project PDFs or previous

summaries to ensure continuity and link the session to the appropriate analytical prompt. Second, they set the summary interval, determining how frequently Decision Cards are generated based on meeting length and team preference. Third, during the session, the plugin processes discussion in the background and generates structured Decision Cards on a dedicated Figma canvas, separating explicit knowledge (stated decisions and reasoning) from tacit knowledge (implicit assumptions). Fourth, at the end of the meeting, it produces a Final Meeting Summary that consolidates decisions, synthesised knowledge, and progress indicators, supporting goal alignment, gap identification, and decision traceability across stages.

3.2 Manifestation of KS–DM Process Barriers and AI Mitigation

Table 1 summarises the comparative manifestation of KS–DM barriers across conditions. In the non-plugin condition, several barriers were evident. Key decisions were rarely documented during discussion, resulting in weak traceability and incomplete consolidation of reasoning. Topic switching frequently disrupted decision stages, and tacit insights, although expressed, were not systematically integrated into shared understanding. In the plugin condition, these barriers were mitigated through three primary mechanisms. First, the tool functioned as a shared knowledge pool, capturing discussion content and maintaining visible records of decisions within the workspace. Second, periodic decision cards introduced structured checkpoints that reduced topic drift and reinforced stage progression. Third, the explicit–tacit structure clarified reasoning and supported more consistent knowledge externalisation. Rather than replacing DM, the AI-supported boundary tool stabilised discussion cycles by consolidating and visualising collective insights, thereby improving continuity and reducing fragmentation.

Table 1. Indicative Occurrence of KS–DM Barriers Across Conditions

KS-DM Barriers	Non-Plugin participants	Plugin participants
Forgetting Key Discussion Points	Key decisions were rarely documented during discussion; summarisation often incomplete, leading to overlooked points.	Periodic decision cards record key decisions and supporting rationale, enabling teams to revisit and verify prior reasoning.
Loss of focus due to frequent topic switching	Frequent topic drift within stages; discussion often re-centred only after facilitator prompts.	Topic drift occasionally observed, but periodic card generation re-anchors discussion to prior decisions.
Blurred distinction between explicit & tacit knowledge	Tacit insights articulated but not systematically integrated into shared reasoning.	Explicit–tacit distinctions surfaced within structured summaries, improving knowledge visibility.
Collaboration Tools & Styles Misalignment	Minor coordination inconsistencies within shared workspace.	Minor misalignment observed; shared summaries enhanced alignment across members.

3.3 Impact on Short-term DM Efficiency, Shared Understanding, and Participation

Building on the KS–DM barrier analysis in Section 3.2, impacts were examined across DM efficiency, shared understanding, and participation. Overall survey rating differences were moderate, but clearer effects emerged in temporal regulation and decision traceability. **DM efficiency** was reflected in perceived time allocation and confidence in implementation. In the plugin condition, participants reported clearer stage boundaries and reduced need to revisit unresolved points. Transcript analysis showed fewer DM–KS loops and reduced topic drift following periodic decision cards. During final presentations, plugin teams demonstrated stronger recall of selection logic, indicating improved traceability and greater confidence in the feasibility of their decisions. The intervention did not accelerate discussion speed but supported more deliberate progression across stages. **Shared understanding** was assessed through variance in team members’ ratings and consistency in decision explanations. In the plugin condition, smaller gaps were observed across alignment-related survey items, indicating stronger internal agreement. During presentations, plugin teams provided more consistent justifications for decisions, suggesting more stable consolidation of reasoning. **Participation** was evaluated through speaking distribution (transcript analysis) and self-reported contribution. Structured review moments around decision cards led to more balanced articulation during key checkpoints. Participants also reported greater awareness of their own and others’ contributions. These effects appeared to arise partly from an indirect mechanism: the presence of the AI system introduced a reflective monitoring dynamic. Knowing that discussions would be captured and reflected back in real

time increased attentiveness to articulation, encouraging clearer expression and more deliberate engagement. The returned summaries also functioned as confirmation mechanisms, reinforcing alignment and strengthening confidence in decisions. Together, these effects indirectly supported perceived efficiency and collaborative participation.

3.4 Frictions and Adoption Challenges with AI Boundary Tool integration

While short-term integration was technically smooth, several frictions and adoption challenges emerged. A key short-term friction concerned the contextual accuracy and perceived value of the Decision Cards. Adoption was highly dependent on the quality of the summaries: when cards were perceived as precise and contextually aligned, engagement remained strong; however, when later cards contained repetitive or overly general content, participants reported reduced trust and diminished willingness to use the tool. This suggests that perceived accuracy and relevance are critical determinants of sustained use. Participants also requested stronger traceability features, such as quotations or timestamps linking to the explicit, tacit statements. These concerns highlight a limitation of current AI processing: output clarity and reliability depend heavily on prompt design and contextual framing. Although the prompt-generation system adapts to meeting inputs, users indicated that more precise prompting, more advanced model and stronger contextual linking would improve consistency across sessions. Long-term adoption challenges were also evident. Unlike AI tools that provide direct solutions or immediate performance gains, this intervention focuses on structuring discussion rather than generating ideas. During the final concept stage, one team asked, “AI, please brainstorm for me,” revealing a tension between the tool’s process-support role and expectations of AI as a solution generator. This highlights the need to clearly define the boundaries of AI assistance in design education. Overall, adoption depends on summary quality, contextual accuracy, and clear expectation setting. Sustained engagement requires improved precision, stronger traceability, and clearer boundaries for AI’s role in collaborative creativity.

4 DISCUSSIONS

The KS–DM boundary model (Figure 1) provides a framework for examining student agency and academic integrity in AI-supported DE education. By clarifying the role of DM within the design process, the model helps define operational boundaries for responsible AI integration in DE pedagogy. The following discussion interprets the findings in relation to RQ4:

- A. In DE-HE, **decision requirements** are often shaped by project briefs and tutor guidance. Determining what decisions need to be made is itself a learning outcome and should not be delegated to AI. While participants requested stronger scaffolding, the plugin did not decide for the team. Users defined meeting details in the configuration step, and the AI adapted its prompts accordingly. This demonstrates that students set the direction, while the AI responds to their defined needs to enhance clarity and generate more relevant outcomes without replacing student judgement.
- B. In a team context KS stages include; **B1. Preparation** – Teams are not always effective at independently gathering relevant knowledge. AI can make this process more efficient by suggesting multiple sources, but students must define what to search and critically select evidence themselves. They should not rely solely on AI-generated answers, especially when primary data—such as user surveys or real user insights—is required. AI may recommend sources, but responsibility for framing questions and validating evidence must remain with students. **B2. Exchange** – When knowledge primarily resides with an individual, it has limited value to the team. Students are often not adept at exchanging knowledge effectively, making boundary tools such as sketches or shared boards vital. Frictionless input and output from multiple tools cannot currently be achieved with AI platforms which tend to focus on one communication medium. As this stage frequently involves brainstorming, AI intervention must be carefully constrained. Direct solution generation risks narrowing the solution space and limiting creative exploration. Instead, AI should support visibility, organisation, and reflection without replacing the team’s ideation process. **B3. Integration**, or a shared mental model, of critical knowledge is difficult to achieve and to verify. AI as a boundary tool can play a significant role in streamlining collation and reporting on knowledge integration in real-time. A recurring usability requirement from the workshop was traceability: participants requested that explicit/tacit statements be supported by short quotations or timestamps from the conversation, as the lack of provenance reduced interpretability and trust.

- C. **C1. Shared Decision:** AI can document shared decisions and support evaluation, but it should not make decisions for the team. **C2. Alternative Decisions:** While AI may assist divergent exploration, students remain responsible for generating and critically assessing alternatives. **C3. Decision Evaluation:** AI and other team outputs must be subject to explicit critical review rather than implicit acceptance, as is often the case in existing DE-HE practice. Developing students' capacity for critical evaluation is therefore essential. AI-generated outputs should also be transparent in their reasoning, with students understanding how and on what basis results are produced. Making the underlying logic visible helps prevent blind trust, over-reliance, and uncritical acceptance of AI suggestions. **C4. Decision Implementation:** With previous steps shared and verified through AI, DM implementation is supported with a robust evidence trial.
- D. Highlighting **iteration** as a key characteristic of DE, shown on the model as looping process, reflects the reality that iteration happens throughout DM sub-process (D1), the overall KS-DM process (D2), and within the overall DE process (D3).

5 CONCLUSIONS

AI integration in design engineering higher education need not solely centre on solution generation or efficiency gains. Instead, evidence from our evaluation suggests that carefully constrained, workflow-integrated AI can stabilise collaborative decision-making processes by improving reasoning visibility, temporal regulation, and decision traceability. These effects were most evident in reduced fragmentation across KS-DM cycles and stronger internal alignment during final articulation of decisions. From a design education perspective, the key contribution lies in reframing AI as a boundary tool that mediates team dynamics rather than replacing cognitive effort. By making tacit and explicit reasoning visible, the intervention supports more inclusive participation in multidisciplinary teams, particularly where diverse expertise may otherwise remain under-recognised. Importantly, the development of a fully functional, deployable Figma plugin provides a practical foundation for ongoing experimentation in authentic educational settings. It enables testing across multiple year groups, team configurations, and tutor-student contexts, offering a scalable platform for future research. Findings reinforce that AI should scaffold collaborative cognition while preserving student authorship, judgement, and critical evaluation practices. However, the study is limited by its small sample size (N=16), short-term workshop format, and reliance on perceptual measures. Longitudinal impacts on learning development, academic integrity behaviours, and sustained adoption cannot be inferred. Future research should examine extended deployment across multiple cohorts and contexts, refine traceability mechanisms, and develop robust pedagogical metrics for evaluating AI's influence on collaborative learning rather than productivity alone. Responsible AI integration in design education must therefore prioritise mediation of team processes over delegation of decision authority, ensuring that diversity of thought is surfaced, examined, and critically negotiated within evolving collaborative environments.

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A FRAMEWORK FOR FORMATIVE FEEDBACK, ENCOURAGING ENGAGEMENT AND AUTONOMY OF NEURODIVERGENT STUDENTS

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ABSTRACT

Engineering education requires students to engage with formative feedback that regularly critiques their work. Some neurodivergent students can find this particularly challenging due to Rejection Sensitivity Dysphoria (RSD), an emotionally or physically painful response that can seriously impact their engagement with, and capacity to respond to, perceived criticism. This paper proposes an accessible framework for lecturers that focuses on RSD as a critical yet under-recognised factor shaping students' responses to formative feedback in higher education. Grounded in andragogical principles, the framework encourages tutors to reflect on how language, tone, structure, and intent may be interpreted by adult students whose prior experiences, identities, and emotional responses shape their engagement with feedback. By examining closely one aspect of the neurodivergent experience of perceived judgement, while supporting autonomy, dialogue, and self-directed improvement, the framework seeks to mitigate feedback practices that may unintentionally provoke avoidance or disengagement. Although developed in response to the experiences of neurodivergent engineering students, the framework has wider relevance, offering a structured approach to formative feedback that supports inclusive, reflective, and emotionally responsive practice across Higher Education.

Keywords: Andragogy, neurodivergence, neuro-identities, formative feedback, rejection sensitivity, engineering education

1 INTRODUCTION

It is estimated that the UK has 1.2 million autistic people and 2.2 million people with attention deficit hyperactivity disorder (ADHD) [1]. With a current UK population of 69.8 million, this suggests that around 5% of the population may be neurodivergent, and this is likely to be an underestimation given the growing number of adults seeking assessment and support [2]. There is also a clear need for improved national data, particularly for ADHD assessments, for which no national dataset is currently published [2].

Higher Education Statistics Agency data indicate that approximately 387,000 students were enrolled in UK higher education in 2024/25, of whom around 41,000 were studying Engineering and Technology programmes [3]. Using a conservative 5% estimate, more than 2,000 engineering and related STEM students each year may identify as neurodivergent.

However, increasing numbers of neurodivergent students are only part of the challenge. Research continues to highlight the difference in academics involved in research and those with an education focus [4], that there is a persistent resistance to teaching [5], and there is a perception of teaching as “second tier” academic work [6]. This difference raises concerns that high-quality teaching practice may not be prioritised by some academics and, therefore, the quality or style of formative feedback provided may not be informed by evidence-based teaching practices or pedagogical or andragogical understanding.

2 WHAT IS FORMATIVE FEEDBACK?

Shute [7] provides a detailed review of research on formative feedback, defining it as “information communicated to the learner that is intended to modify his or her thinking or behaviour for the purpose of improving learning.” Shute also highlights a critical qualifier “if delivered correctly” [7]. While the review recognises extensive evidence supporting the importance of feedback in learning, it also reports

that feedback can be ineffective or even harmful. Shute identifies two key features of formative feedback described by Kulhavy and Stock [8]: verification and elaboration. Verification involves confirming whether a learner's response is correct or incorrect. Elaboration provides further detail, such as discussing an error, offering a worked example, or giving what Shute [7] terms "gentle guidance."

2.1 Theoretical base

Narciss and Huth [9] demonstrated that systematically designed formative feedback can positively influence both achievement and motivation. They argue that adapting the content, function, and presentation of feedback, accounting for instructional goals and learner characteristics, can maximise its informative value. Narciss and Huth also propose that feedback frameworks should clearly distinguish between the function, content, form, and mode of presentation of the feedback. They note, consistent with Kulhavy and Stock [8], that these facets are often conflated in existing feedback systems.

2.2 Pre-university models

Pre-university pedagogy, including secondary schools, sixth forms, and further education (FE) colleges, can be characterised as increasingly evidence-based, with a strong emphasis on formative assessment and feedback. These principles align closely with the Assessment for Learning practices outlined in the Department for Education 'Assessment for Learning Strategy' [10].

In secondary education, formative assessment is positioned as a tool for identifying learning gaps, enabling teachers to adjust instruction and supporting students' progress toward summative assessment. Guidance from the Education Endowment Foundation (EEF) is available to teachers [11], who are also required to undertake regular CPD; this is not the case in HE where CPD uptake can be quite variable. National (UK) policy developments further support AfL implementation. The Department for Education *Curriculum and Assessment Review* [12] emphasises assessment, particularly formative assessment, as central to maintaining high standards, tackling inequity, and aligning education with current societal and technological demands across pre-16 and 16–19 pathways. Sixth forms, often part of established school structures, generally retain these principles, adapting them to prepare older learners for advanced examinations and transitions to higher education or employment.

In FE colleges, pedagogy is more diverse due to vocational, technical, and academic programme demands. Recent FE-specific research highlights the complexity of feedback processes, noting that formative assessment is often inconsistently applied and sometimes conflated with summative, accountability-driven practices [13]. Feedback must also account for diverse learner backgrounds, including socio-economic factors, and respond to students' prior experiences and dispositions toward learning. The FE sector is supported by practice guides such as the *2025 Powerful Pedagogy* report [14], which identifies metacognitive approaches, dialogic questioning, and adaptive feedback as key to improving progress and achievement, aligning with EEF-supported principles across the sector.

Overall, secondary, sixth form, and FE settings demonstrate increasing coordination in pedagogical approaches, with formative feedback positioned as a central element of instructional design. In contrast, higher education feedback commonly assumes learner resilience, emotional neutrality, and self-regulation, assumptions that may not hold true for all adult learners and are particularly problematic in the presence of RSD.

3 FEEDBACK IN ENGINEERING

3.1 Academic expectations

Engineering sits at the intersection of science, mathematics, and design, with design further complicated by its need for the understanding of sociological, psychological and physiological aspects of human factors [15]. Studying across these domains is demanding, and studying engineering often exposes gaps in a student's knowledge, understanding, skills, or practice.

Research by Holloway *et al.*, [16], and Baillie *et al.*, [17] highlights the challenge of threshold concepts as defined by Meyer and Land [18]. In engineering, these concepts can act as barriers, leaving students feeling stuck. Holloway *et al.*, also note that crossing a threshold may provoke an emotional response, an "aha" moment, while for others remaining stuck can trigger emotional discomfort [19].

Formative feedback is therefore critical in engineering education, supporting conceptual understanding, design reasoning, and the development of professional competencies, particularly in environments where complex problem-solving and iterative design are central. Emotional responses appear to influence how students experience this process.

Kinnunen's pilot study on students' emotional reactions to feedback reinforces this point. It was observed that "strong negative emotions" were experienced by engineering students and recalled by teachers from their own studies of engineering. The study recommended three strategies to reduce negative emotional reactions: clear learning outcomes, progressive formative feedback on smaller sub-tasks, and promoting student self-assessment [20]. These approaches could be associated with good andragogical practice [21].

While feedback can motivate students, it may also provoke anxiety or confusion when delivered poorly. Lui and Andrade [22] suggest that such responses can hinder learning and discourage risk-taking, which are essential elements of experimentation and engineering design.

Structured frameworks, such as the formative assessment strategies proposed by Wiliam and Leahy [23], have helped standardise and improve feedback practice. These strategies include clarifying learning intentions, designing tasks that elicit evidence of learning, providing forward-looking feedback, and encouraging self-assessment; mirroring those suggested by Kinnunen [20] and Knowles [21].

Overall, formative feedback is a powerful driver for learning in engineering education, but its impact depends on thoughtful, evidence-based implementation. When responsive to student needs, it strengthens understanding, supports skill development, and fosters reflective practice. When applied superficially or without sensitivity to the learner experience, it can fail to achieve its transformative potential and create emotional distance and disengagement.

3.2 Engineering student characteristics

Professor Beverly Gibbs [24], writing for the Engineering Professors Council, asks whether there are more neurodivergent students in engineering than in other subjects, and concludes that we don't know. She notes, however, that higher-education students are not a direct reflection of the general population, and neurodivergent students may represent up to 15% of the student body. This suggests that 12,000 to 15,000 neurodivergent students could be entering engineering courses in the UK each year. The Institution of Engineering and Technology (IET) similarly acknowledges that, while exact numbers are unknown, they possibly underestimate the true prevalence of neurodivergence in engineering [25].

Ortega and Choudry [26] prefer the term "neurological identities" rather than "disabilities," presenting examples of individuals who bypass diagnostic framing and are instead developing an identity, and even a culture, around their neurodivergence. Gibbs [24] also notes that some experience these differences as disabilities and some do not and, even if a student does not consider their neurodivergence a disability, the easiest way to get adjustments or support is often to pursue a process that treats them as if they have a disability.

Separating identity from the discussion still leaves the complex issue of RSD. Cundill [27] notes that while RSD is frequently associated with Autism and ADHD, citing Bedrossian [28], rejection sensitivity may shape the experiences of a much wider range of students in higher and adult educational settings.

4 FORMULATING A FRAMEWORK FOR FORMATIVE FEEDBACK (RSD)

Modestino et. Al., [29] describe RSD as intense emotional responses to perceived criticism. These emotional responses may be disproportionate to the feedback intent but can be decisive in shaping subsequent engagement. Whilst RSD is commonly discussed in relation to ADHD, this emotional dysregulation may be experienced by any student as a response to feedback, and therefore students where other life experiences and contexts may impact on their studies should be considered. For example, a student who has recently been bereaved may be less able to process feedback that is framed for the idealised, resilient student. Recent qualitative and quantitative research shows that feedback may be experienced as both emotionally and physically distressing, leading learners to mask difficulties or disengage from assessment altogether.

The proposed framework (Table 1) considers feedback as a cyclic process, for both students and academics. It is common practice in secondary schools and sixth forms to review marking on a regular basis, to inform best practice and continuing professional development (CPD), and to standardise grading across the faculty. Wiliam and Leahy [23] explored the development of teacher learning communities to provide peer review and accountability. The framework therefore includes Monitoring and Reviewing, with a recommendation to ensure monitoring is established and valued, with structured and consistent approaches that include consideration of knowledge and understanding of RSD.

Table 1. Feedback framework

	Seeing the Dimensions While each element of this framework reflects established good practice, their combination is intentionally oriented toward reducing perceived rejection, emotional threat, and withdrawal behaviours associated with Rejection Sensitivity Dysphoria
	Framing and Intent. Where feedback can be pre-framed as formative and forward-looking, rather than summative, this can signal the developmental intent of the feedback. Offering feedback that is too authoritative or final may amplify perceived judgement. Over-confident language (“clearly incorrect”, “fails to meet”) risks triggering RSD responses [7, 30].
	Language and Tone. Encourage tutors and lecturers to audit feedback language systematically for emotionally charged terms and prioritise task-focused, non-personalised wording. Care is needed to avoid sounding too impersonal or absolute as this may increase emotional distancing.
	Structure and Predictability. Closely aligning feedback to criteria, exemplars, and learning outcomes, in a patterned structure can reduce ambiguity and support engagement with all the dimensions considered. Predictable structures provide cognitive scaffolding and reduce emotional uncertainty.
	Emotional and Cognitive Load. Chunking feedback, prioritising key actions, and separating “must fix” from “optional enhancement” supports effective learning, particularly if delivered in a timely fashion. Excessive detail or exhaustive error identification can be cognitively and emotionally overwhelming for students [7, 20,].
	Agency and Dialogue. Learning questions and reflective prompts, or feed-forward options rather than conclusions can be more encouraging and invite a response, potentially opening dialogue. One-way feedback risks passive receipt rather than dialogue and students may feel reluctant to seek clarification [21].
	Monitoring and Reviewing. A practice of monitoring and reviewing feedback should be established, not only by the individual to inform their future practice, but within and across faculties to inform future assessment, and complete the cycle across all dimensions of feedback.

5 DISCUSSIONS ON IMPLEMENTATION

For some tutors and lecturers this framework perhaps already reflects their own good practice, with steps that seem common sense, such that they may even question the need for such a framework. This means that many students are already receiving high-quality, impactful formative feedback, from tutors and lecturers willing to reflect and fine tune their own approach. However, it is also likely that some academics will consider such a framework unnecessary, particularly where existing feedback practices are perceived as adequate or have become entrenched as part of their normal way of working, or where teaching is considered a secondary aspect of their role and not as important as research. This means that there would also be many students suffering from poorly structured, ineffective feedback, which in some cases may be emotionally and physically distressing.

6 CONCLUSIONS

Rejection sensitivity dysphoria is not unique to neurodiversity or those of differing neuro-identities, but it is debilitating when and wherever it is experienced. The practices around neurodivergence in post-compulsory education at higher education institutions lag behind those in schools, colleges, and further education institutions. A key limitation within the higher education sector for changing formative feedback practice is the understood freedom that academics have operated under for many years with

regards to their own ‘style’ of feedback. Without guidance or a framework, they often develop a style that may be personal, and that they may feel has been adequate or even successful, and therefore difficult to relinquish.

A formative feedback framework developed using an andragogical approach, carefully considering the language used and the emotional impact it can have, and providing a clearer understanding of the importance of addressing threshold concepts, offers the potential for a better, more consistent, and less emotionally challenging student experience, not only for those with specific neuro-identities but for all students of Engineering. This paper offers a theoretically grounded, RSD-informed framework and suggests there is scope for future scholarship in formative feedback that explicitly foregrounds emotional risk, learner agency, and the mediating role of language in undergraduate engineering education.

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OBSERVATIONS ON STUDENT DESIGN STRATEGIES IN THE CONTEXT OF A COLLABORATIVE TIMBER DESIGN WORKSHOP

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ABSTRACT

Group design projects are ubiquitous in design courses, and the pedagogical benefits of cooperative learning are well established. The workshop entitled '*Geometric deformation of wood*' hosted by Southeast University, Nanjing, provided an unusual setting to observe and reflect on specific aspects of collaborative learning and its influence on design strategies. Of particular interest was the hands-on format of the timber behaviour workshop, the level of education of the engineering and architectural technology students (all post-graduate) in addition to the cross-cultural mix of the individual groups, with students from Denmark, the Netherlands in addition to students from the host institution. The brief was open and the defined outcome was limited to a presentation and discussion. This paper reflects on the various design strategies adopted by the students, examined through the lens of the chosen design methods and the author's observations on the organisation of each group. The reflections are informed by conversations with and observations of the students, the content of their final presentations and photographs. The groups observed varied greatly in their use of convergent and divergent strategies and included a range of design methods including brainstorming, analogy, speculative testing of materials, precedents, form-finding, analysing and prototyping. It was observed that groups who coalesced around concepts early on developed clear outcomes and convergent strategies within the limited time frame, although the authors would suggest, not necessarily high levels of collaboration. The authors also suggest that aspects of the workshop which contributed to the richness of design outcomes included the range of design tools and methods known to the students, the high levels of woodworking skill and the immersive environment.

Keywords: Design strategies, open ended design, collaborative learning, cross-cultural design

1 INTRODUCTION

Open ended design problems present specific challenges for students. This is particularly the case for those who have had a highly structured education, based on the staged acquisition of knowledge, which is typical of, for example, engineering. Without clearly defined favourable outcomes, which in turn imply a linear and converging design process, design strategies need to be evolved. Collaborative learning, through groupwork, is often cited as a fruitful environment for students to construct such strategies [1]. The workshop entitled '*Geometric deformation of wood- a hands on workshop*' hosted by Southeast University in Nanjing, China, provided an excellent opportunity to observe and reflect on how students achieve this in a hands-on workshop environment with limited external guidance.

The workshop, which took place between 6th and 15th November 2025, was cross-cultural and included the participation of masters and PhD level engineering and architectural technology students from Denmark, the Netherlands, in addition to students from the host institution, working in culturally mixed, self-selected groups with limited input from the tutors of the various institutions. Students were required to develop design ideas informed by the structural behaviour of timber by drawing, making, testing and analysing with no specific assessment other than a presentation and discussion at the end. The workshop could be characterised as 'material driven design' with the goal of bridging the 'experiential quality of materials...to their technical properties' [2]. Given that the students were post graduate level, it was implicitly assumed that they had the skills and experience to develop their own design strategies with limited direction from the tutors. The students had access to a timber workshop as well as adjacent break

out meeting spaces, including a café which were used extensively. This paper reflects on the outcomes of the various learning strategies adopted by the 29 students in 6 groups, in response to the workshop framework, based on conversations with the students, student observation, student presentations and extensive photographs. The strategies observed ranged greatly in level of structure and included selecting a range of design methods including brainstorming with sketches, undertaking speculative tests of the various timber and bamboo source materials (by bending/steaming/saturating/scoring/cutting/loading/lacing etc), looking for precedents (already known and searched for), digital parametric models, form-finding, analysing and prototyping.

2 LITERATURE REVIEW

2.1 Cooperative learning

Cooperative learning is an established pedagogical approach with the potential to promote positive outcomes [3]. Of particular interest in the development of design ideas are the observed outcomes including students' ability to 'influence other's efforts to achieve goals,' 'provide groupmates with feedback,' 'challenge other's reasoning and conclusions' and 'take the perspectives of others more accurately' [3,4]. The group dynamic aligns closely with industrial design practice as it is identified that whilst ideas come from individuals, 'concept selection and enhancement is best performed in groups' [5,6]. Cooperative learning promotes tacit learning and accessible language, aspects appropriate for an inter-cultural workshop [7]. It also provides a suitable framework for design processes based on material investigations which promote hands-on activities including 'tinkering' [8]. Cooperative investigations have been identified as a suitable format for students to hone their leadership skills, particularly where the model is to promote 'authentic leadership, mentorship, collaboration and personal growth' [7].

2.2 Design strategies with convergent and divergent elements

Design strategies can generally be defined in terms of the balance between deliberate divergent and convergent design activities, in the development of a design [2,5,6]. This characterisation of the design process maps closely to neurological evidence suggesting that creative thinking is characterised by continual shifts between convergent and divergent thought processes [9]. Design strategies in engineering have evolved from strongly defined convergent processes, to incorporating design tools which foster divergent thinking [10]. The success of a range of tools and activities to encourage divergent thinking include brainstorming, 'tinkering' with materials, morphological analysis, using function trees, tools incorporating deliberate search for analogy, sketching and study of precedent have been demonstrated [11]. It is also recognised that groups with a strong range of skills and strong domain knowledge, which they can access with ease, can assist divergent design processes as does deliberate prompts to 'think out of the box' with reward for quality rather than quantity of ideas [12].

2.3 Design environment and intercultural setting

Practical aspects of the quality of the working environment including the space, equipment and facilities available can impact the design process [5]. Equally the more abstract aspects of the environment including the organisational culture within which the design is taking place can influence creativity and innovation [13]. The authors are not aware of any comprehensive models which map how receptive different world cultures are to cooperative learning. However, evidence suggests that most students across cultures are open to such learning techniques with the pedagogical basis of their schooling, a key influence. Furthermore, with increasing if sporadic information and cultural convergence the situation is evolving [14,15].

3 METHODOLOGIES

This paper examines the various design strategies adopted by the individual groups in response to the workshop framework. The specific design methods chosen by the groups, which form part of their design strategies, have been identified by the authors from conversations with the students, student observation, student presentations and extensive photographs taken by the authors and other participants in the workshop. To structure the discussion of the paper, design methods used are identified and categorised regarding their purpose as problem research or '*discover methods*', problem definition and direction '*define methods*' and design solution generation and assessment '*develop methods*' following the framework defined in 'The Delft Design Guide' although it is recognised that many design methods cross these boundaries. Also, some methods noted do not appear in the guide itself so are categorised

based on the judgement of the authors [2]. This guide is referred to for the range of design tools presented. It is noted that this publication has its origins in an industrial design school although the target audience includes the wider design community. The authors acknowledge that following further discussion with the students more design methods might emerge, and that the categorisations are subject to interpretation. Reflections by the authors on the mode of organisation of each group is based on observations of, and interaction with, each group and can be seen as subjective. The identification of the six groups as A-F is for the purpose of differentiation in this paper.

Discover Methods Problem search	Exploring form Exploring material Design drawings to discover Sourcing precedent
Define Methods Problem definition and direction	Categorise and test samples Design drawings to define Concept model
Develop methods Design solution generation and assessment	Brainstorming/writing/drawing Form finding Analogies and medium transfer Paper (form) mock ups Analysis Modelling (A+D).virtual prototyping Design by drawing to develop Testing models Verificaiton Recording

Figure 1. Design Methods Observed

4 OBSERVATIONS AND DISCUSSION

4.1 Design strategies and chosen design methods

Although there was clearly common knowledge of design processes, skill sets and tools, across the groups, it was interesting that the overall strategies of the groups were quite distinct. Group D settled early on with the objective of exploring a pre-existing designed form by substituting the original material for timber, following a clearly defined convergent process. Group E developed a set of behavioural rules or ‘syntax’ for combining thin timber elements with an array of strand tension elements, systematically examining the form and structural possibilities. Group F had a multiplicity of directions, including one particularly interesting exploration of origami and kirigami shapes using thin timber veneer elements, formed with curved and hinged edges. By contrast, Group A followed a clearly defined convergent structural form finding approach shaping a lattice using loads and steam to modify properties in real time.

The design methods chosen by the various groups provide a useful point of reference to examine their design strategies. Some methods were used by many groups and others were unique to a particular group. The authors found that the range was surprisingly rich (see Figures 1 and 2).

‘Discover methods’ which were used by several groups included exploring materials in the workshop and sourcing precedents (C, D and F), prompted perhaps by precedents being used heavily in the introductory lecture. Drawings to discover and exploration of form were identified only in the work of group F.

The range of ‘define methods’ used was more restricted. Groups A and C systematically categorised and tested the various timber and bamboo materials supplied and specific concepts defined by drawing and modelling were evident in groups A, B, E and F. There was little evidence of systematic problem definition as part of ‘define methods,’ to develop a framework to assess ideas, which is perhaps understandable given the open-ended nature of the workshop.

By contrast, there were a wide range of ‘develop methods’ observed across the teams in the latter stages of the workshop. These included brainstorming (in reality a direction selection approach), digital form finding, medium transfer, paper mock-ups, 3D CAD and layout drawing, analysis of both analogue and

digital models (virtual prototyping); developing design by drawing, particularly at a detail level; testing, verification and recording of model behaviour under load.

It was observed that groups tended to either undertake open ended domain research using '*discover methods*' (groups C, D and F) or rapidly progressed to a process of problem refinement using '*define methods*,' leading to a concept design, (groups A, B and E). This was followed in all cases by extensive use of a variety of '*develop methods*,' with the exception of group F.

There were both divergent and convergent outcomes at the end of the workshop, with convergent outcomes tending to correspond to groups which had used '*define methods*.' Groups A and B could be categorised in this way. Group D is an important exception to this observation, as a highly convergent process was established without any recognisable '*define methods*' being used. The group recognised a good idea and followed it. Some groups had identifiable divergent stages, prompted by deliberately choosing design methods which promoted divergence, most notable brainstorming. For example, group E returned to search for possible forms based on the syntax they had established early on. In groups C and F, which did not have a convergent process, it is difficult to identify deliberate attempts at divergence.

4.2 Design strategies and group organisation

As cooperative learning is seen as a forum for the development of authentic leadership, it was interesting to observe that group organisation played a role in the direction of various groups [7]. Some teams seemed to operate with less obvious design and organisational leadership. By contrast groups A and B appeared to have emergent leaders. These groups coalesced around a single idea and adopted highly structured convergent strategies. They developed specific outcomes within the limited time frame and had specific measurable outcomes. In both cases the emergent leader promoted a concept around which the design process was organised, so there was a close alignment between the emergent leader, the originator of the idea (assumed to be the same or at least an early champion), the choice of design methods and as a consequence the design strategy [6].

It is interesting to compare groups A and B to D with regard to group organisation. The members of group D also coalesced around a single idea early on which resulted in the choice of specific design tools being used as part of a highly convergent strategy. But in contrast to groups A and B, although group D had a clear originator of the idea, there was no clearly identifiable leader. Group D consciously presented themselves as collaborative, (including mentioning their group badminton session in their presentation), but perhaps, despite outward appearances didn't have a substantially different design process to groups A and B.

Group E provides an interesting contrast to D, as a group which also operated on a collaborative basis. Group E had a clearly defined design strategy based on a process rather than a specific physical outcome, which involved exploring a design space or syntax where bent timber pieces and tensioned strands were combined to form a family of structural variations. Common understanding within the group defined a design process with convergent and divergent stages where interaction between group members created possibilities. Importantly, the individuals of this group, although of various nationalities, came from the same institution. Perhaps this reflects that authentic collaboration, which has recognisable impact on design strategies needs to be nurtured over time and is difficult to foster in a short workshop.

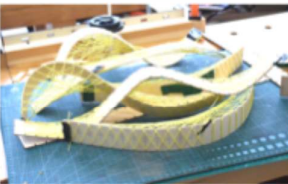
Group	No. Students	No. Nationalities	Main concept/approach	Methods Observed	Image of Project
A	6	2	Physical form finding of a timber gridshell by modifying properties under load.	Define Methods: categorising and testing samples, design by drawing to define. Develop Methods: brainstorming, digital form finding, analysis modelling, design by drawing to detail, testing model, verification, recording.	
B	5	1	Wave profile bracing formed by steaming timber.	Define Methods: drawing to define (concept), concept model. Develop Methods: drawing to detail, testing model, verification.	
C	4	2	Developing meshed forms from steamed and cut bamboo sections.	Discover Methods: exploring material, sourcing precedent. Define Methods: Categorise and test samples.	
D	4	2	Exploring a previously defined kirigami form in timber.	Discover methods: exploring material, sourcing precedents. Develop methods: brainstorming, medium transfer, mock ups, analysis modelling, testing model.	
E	3	3	Developing a 'syntax' for combining bent timber pieces with tensioned strands.	Define methods: concept model. Develop methods: brainstorming, physical form finding, analysis modelling, model testing.	
F	5	3	Folding and bending timber sections and veneers following origami patterns.	Discover methods: exploring form, exploring material, drawings to discover, precedent. Define methods: drawings to define. Develop methods: medium transfer, paper mock ups, drawings to detail, model testing.	

Figure 2. Group outputs

4.3 Reflections on the cultural and physical environment

With the exception of group B, the groups had students from at least two of the institutions or countries of origin. It was observed that the individuals generally worked professionally together. It was not possible to discern differences in how the designs were developed between the groups based on cultural backgrounds or discipline, when considering what types of design methods or strategies were used in each of the groups. It is noted that participation was voluntary, so students chose to take part in this open-ended workshop. The authors feel that this perhaps resulted in a degree of self-selection by the students at each institution, resulting in a cohort with a high degree of common purpose and eagerness to work together and overcome cultural differences. To explore this issue interviews with the individual students might have yielded more inciteful and revealing findings.

The students clearly took advantage of the range of spaces to find a suitable working environment. They were given access to a traditional classroom with rows of seating 10 minutes' walk from the workshop, in addition to a café close to the workshop and a small table just outside the workshop. The groups used

all the facilities, with the exception of the more remote traditionally laid out classroom. The workshop was very heavily used, as was the café.

All the groups did something unique. Perhaps this was due to the particularly rich knowledge of 'develop methods,' in making, analysing, and drawing which the various institutions and backgrounds brought together but there seemed to be something else at work. Bringing together students with excellent making skills, provided a common forum and language to communicate and mix ideas in the context of an open-ended explorative workshop which crossed global cultural boundaries. Equally the working environment, (the combination of a well-lit, organised and equipped timber workshop with congenial spill out spaces within a leafy campus university) set the scene for a culture of engagement, thoughtfulness and enjoyment of design. Perhaps a celebration.

5 CONCLUSIONS

The opportunity to observe significant numbers of post-graduate level students of engineering and architectural technology from Europe, studying in Europe, interacting with their peers in China, on site in China, in an open-ended workshop, based on materials, provided an unusual opportunity to study collaborative learning and its influence on design strategies. The importance of common skills and knowledge of design methods, particularly those involving making or 'tinkering' with material were observed to provide a language to supplement verbal communication and strengthen the design process. More fundamentally the authors would argue that bringing together a diverse group of students with a depth of design process knowledge and high degree of model building skill, in an enabling environment, ensured thought provoking and unpredictable design outcomes but perhaps also demonstrating that collaborative working benefits from more sustained periods of interaction and short term workshops favour convergent strategies.

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DESIGNING REFLECTION: LEARNING ABOUT SUSTAINABILITY IN SMALL CRAFT-BASED DESIGN FIRMS

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ABSTRACT

Small craft-based design firms must address sustainability as a condition for long-term viability, yet training often remains expert-led, prioritising factual knowledge over reflective and organisational learning. This gap is critical in small firms, where tacit knowledge, cross-functional dynamics, and hierarchies shape how sustainability is understood and applied. This study examines how a design-based training programme can foster inclusive organisational learning by activating higher-order and metacognitive processes across roles. Grounded in Anderson and Krathwohl's Taxonomy, it adopts an interventionist single-case study in a small Italian fashion firm. A three-day immersive, screen-free programme used narrative, visual artefacts, and collaborative reflection to support progression toward evaluative and strategic thinking. Qualitative data from observations, external notes, and questionnaires show participants developed analytical, evaluative, and shared strategic intentions. Visual reflection helped surface tacit knowledge and co-create meaning, positioning design-based pedagogy as a driver of collective learning and organisational sense-making and offering a transferable model for engineering and design education, where sustainability learning can move beyond knowledge transmission toward evaluative and metacognitive competences.

Keywords: Design-based capacity building, sustainability competences, industry-academia collaboration, experiential learning, metacognitive reflection

1 INTRODUCTION

Small craft-based design firms are increasingly confronted with sustainability transition as a structural condition of their long-term viability. In these contexts where tacit knowledge and situated expertise are central, transmissive models of training and capacity building risk widening the gap in sustainability learning and everyday practices. If sustainability requires shifts in shared assumptions and interpretative frames, training must foster collective reflection and evaluative agency across roles. Assessment, in this sense, can be reframed as a learner-led reflective practice that surfaces tacit knowledge and supports organisational sense-making. Building on Anderson and Krathwohl's Taxonomy for Learning, Teaching, and Assessing, this study examines how training programmes can activate higher-order and metacognitive processes within a small Italian fashion firm. Through an interventionist single-case study, it explores whether immersive, screen-free, visually mediated reflection can enable cross-functional participants to analyse past actions, evaluate strategic alternatives, and articulate shared sustainability intentions. By designing reflection as a collective practice, the paper contributes to inclusive organisational learning in small craft enterprises.

2 BACKGROUND THEORY

2.1 Inclusive organisational learning for sustainability in small design firms

Design firms face rising environmental, regulatory, economic, and socio-cultural pressures; sustainability is now a structural condition for long-term viability. Yet adoption is often hindered by cognitive and organisational dissonance, creating gaps between commitments and practice [1]. This transition requires shifts in values, assumptions, and interpretative frames that guide decisions and everyday practices; it implies a paradigmatic change to build a sustainability culture in which members

balance economic efficiency, social equity, and environmental responsibility [2]. Sustainability thus lies in shared meanings, not isolated initiatives.

Developing this culture depends on intentional learning processes [3] that go beyond technical knowledge and promote collective critical reflection at the organisational level [4].

Indeed, organisational transformation entails shifts in shared understanding, collective assumptions, and patterns of thinking, which has been described as the “invisible glue” of institutions [5]. Thus, organisational change depends on organisational learning: the acquisition of competence in response to internal or external stimuli, producing lasting changes in collective behaviour and improved effectiveness [6]. This perspective emphasises that learning may involve not only incremental adjustments but also deeper reconsiderations of underlying assumptions [7], [8]. The relevance of organisational learning is particularly pronounced in small- and medium-sized enterprises (SMEs). While SMEs are often key contributors to national economic development [9], they face structural constraints in leveraging internal knowledge and capabilities [10]. These firms rely heavily on the learning capacities of owner-managers and teams. At the same time, they operate in turbulent environments that demand adaptability [11]. The development of effective organisational learning capabilities has therefore been identified as a decisive factor in SMEs' success. In parallel, several authors have highlighted that staff engagement and education are central to developing a sustainability culture [2], [12]. Research within a large multinational company shows that sustainability learning should not be restricted to leaders and senior managers but should be cross-functional and embedded across business functions [13]. To strengthen both knowledge and learners' commitment, it should include technical content and active learning methods [13]. When considering tiny organisations, these principles remain critical, since power dynamics and hierarchies are equally present; inclusion cannot be assumed but must be intentionally designed.

2.2 Limits of traditional *ex-cathedra* training models

Despite the transformative nature of the sustainability transition, training formats in small manufacturing contexts often remain conventional. *Ex-cathedra* models based on presentations, slides, and standardised tests are widely adopted and are oriented toward the transmission and verification of factual knowledge. Such an approach is incoherent with the contemporary constructivist conception of learning [14], and the widely adopted competence-based education, which entails an active, social, and situated process of personal meaning-creation through which learners move beyond the reception of information to develop the holistic competences to address complex, real-world challenges effectively. Within this contemporary framing, the present study focuses exclusively on the knowledge dimension of competence, which can be analytically understood with the support of the *Taxonomy for Learning, Teaching, and Assessing* proposed by Anderson and Krathwohl [3] (Fig. 1). It is a two-dimensional framework that organises learning goals by intersecting: the **cognitive processes dimension**, which contains six increasingly complex cognitive processes: remember, understand, apply, analyse, evaluate, and create; the **knowledge dimension**, which contains a continuum from concrete to abstract of four categories: factual, conceptual, procedural, and metacognitive. The taxonomy provides a detailed framework for intended learning outcomes at the intersection of a specific type of knowledge and the cognitive process required to master it, offering a precise definition that ensures alignment among teaching, learning, and assessment [3]. Traditional *ex-cathedra* approaches primarily activate lower-order cognitive processes (i.e., remembering and understanding) and convey factual or conceptual knowledge. Sustainability competence requires the activation of higher-order processes, including analysing, evaluating, and creating, as well as engagement with the metacognitive knowledge dimension: employees must become acquainted with critically evaluating organisational practices, assessing trade-offs, and envisioning alternative modes of action.

Earlier design-based innovation training, such as the diffusion of design thinking in the 2000s, often showed a knowledge-worker bias, focusing on them (i.e., white-collar) staff and excluding manual or skilled trades workers (i.e., blue-collar) from strategic processes [15]. If sustainability transformation concerns the entire organisation, higher-order thinking must be distributed across roles, requiring inclusive pedagogical models. Reflection is a central mechanism: in SMEs, practitioners can question assumptions in action and reinterpret experience retrospectively. Structured reflection externalises tacit knowledge and transforms it into shared organisational resources, helping to bridge professional cultures. *How can learning experiences be designed to foster shared reflection on sustainability transition across diverse organisational roles within small design firms?* To address this question, a

training intervention was implemented within the *Ecodeck* project (www.ecodeck.polimi.it) in a small Italian fashion company, drawing on Anderson and Krathwohl's Taxonomy to examine the activation of distributed reflective practices.

These insights are relevant to engineering and design education: while Anderson and Krathwohl's taxonomy is already applied to undergraduate (UG) and postgraduate taught (PGT) learning outcomes, sustainability teaching often remains limited to lower-order processes and specialist cohorts, reflecting a knowledge-worker bias. The immersive, design-based approach offers a transferable model for higher education that integrates reflection, narrative, and cross-functional dialogue. It encourages alignment between learning outcomes and pedagogy, and the inclusion of reflective, learner-led assessment alongside standard evaluation.



Figure 1. Revised Bloom's Taxonomy adapted from Heer, R. (2012) Iowa State University Center for Excellence in Learning and Teaching. Licensed under CC BY-NC-SA 3.0.

3 METHOD: INTERVENTIONIST SINGLE CASE STUDY

This research uses an interventionist single-case study, where the researcher acts as a change agent, supporting organisational transformation while observing it [16]. This approach suits real-life contexts, such as activating reflective practices in a small Italian fashion firm, where pedagogy and organisational sense-making intersect. Given the complexity of linking professional cultures for sustainability, a single case offers a holistic view without fragmenting data. Using a training programme as the case, the study frames reflection within action-based research, drawing on Anderson and Krathwohl's taxonomy to generate grounded insights. This enables analysis of how tacit knowledge becomes shared organisational resources in a small firm. Data were collected during testing in fall 2025 with a company of about 20 employees and five participants. Methods included observations by facilitators and external observers, plus daily open questionnaires on sustainability meanings and actions. Results are based on qualitative interpretation of these sources. Data analysis followed a deductive thematic approach: notes and questionnaires were coded against nine Intended Learning Outcomes (ILOs) from the taxonomy, linking reflections to cognitive processes and knowledge dimensions. Two researchers coded a subset independently and resolved differences through discussion. A key limitation is potential bias, as researchers were also designers and facilitators; external observers provided a partial check on these interpretations.

4 CASE STUDY: TRAINING PROGRAMME IMPLEMENTATION

4.1 Setting the learning goals: the intended learning outcomes

The training activities were designed to be delivered across three training days. In terms of the Intended Learning Outcomes (ILOs) related to knowledge about sustainability, the activities were developed using a progressive logic within the Anderson and Krathwohl taxonomy (Tab. 1).

Table 1. Outline of the ILOs analysed through Anderson and Krathwohl's Taxonomy

Training Day		Intended Learning Outcomes (ILOs) Analysis			
ID	Title	ID	Extended ILOs	Cognitive Process Dim.	Knowledge Dim.
1	Understanding individual sustainability competences and values	1.1	Classify sustainability actions, competences, and values according to the provided frameworks.	Understand	Conceptual
		1.2	Predict how personal sustainability competences influence the impact of individual actions in organisations.	Understand	Metacognitive
		1.3	Examine one's own sustainability values in relation to actions undertaken to face everyday sustainability challenges.	Analyse	Metacognitive
2	Analysing values and organisational actions	2.1	Distinguish past organisational actions for sustainability.	Analyse	Factual/ Conceptual
		2.2	Break down past sustainability actions by analysing when, why, what changed, and resulting impacts.	Analyse	Procedural/ Metacognitive
		2.3	Reflect on the evolution of sustainability actions, the cognition of sustainability challenges, and the values that these actions entail.	Evaluate	Metacognitive
3	Evaluating and prioritising strategies for transition	3.1	Classify alternative organisational strategies to address sustainability challenges.	Understand	Procedural/ Conceptual
		3.2	Select the most promising sustainability strategies to be implemented in one's own organisation.	Evaluate	Procedural/ Conceptual
		3.3	Reflect on the organisation's sustainability intention to inform the organisation's transition.	Evaluate	Metacognitive

4.2 Designing the learning experience: an immersive and screen-free approach

The training programme adopted an immersive, screen-free approach to foster engagement throughout the learning journey. Rather than relying on traditional ex-cathedra formats, participants were positioned as active protagonists within a narrative experience. At the core was a speculative storytelling framework inviting them to imagine entering an alternative world where sustainability operates under different rules. In contrast to their “world of origin,” where sustainability is perceived as a cost or constraint, this world framed it as an accelerator of innovation and a strategic lever. To deepen immersion, each day included carefully designed check-in and check-out rituals. Participants crossed a symbolic door, received a personalised “pass”, and engaged in short reflection activities. The physical environment supported this, reinforcing continuity between sessions. The programme privileged hands-on, low-tech interaction. Paper-based tools, value cards, templates, markers, and co-creation canvases stimulated discussion and collective sense-making. The deliberate absence of screens encouraged active participation and creativity, strengthening the collaborative and embodied nature of the learning process.

4.3 Detailing the instructional design: The learning activities and contents

4.3.1 DAY 1: Understanding sustainability values and systems

Day 1 included two main activities centred on individual sustainability competences and actions. The first activity aimed to raise awareness of the environmental, social, and economic dimensions of sustainability. Through a narrative simulation based on real organisational dilemmas, participants engaged with an AI-generated scenario, selected relevant competencies from a shared framework, and collaboratively identified potential sustainability actions informed by each competence. Iterative rounds of listening, reflection, and mapping fostered understanding of how competencies shape individuals' actions within an organisational context. The second activity focused on making participants' sustainability values explicit and prioritised. Using canvas and card-based tools, they mapped actions onto sustainability value areas, reflected on their behaviours, and built a shared value constellation. This process highlighted convergences, divergences, and tensions across environmental, social, and economic dimensions. At the end of the day, participants received an investigation kit (i.e., instructions, canvases to be filled) and were invited to collect evidence of sustainable change in their company for the next session.

4.3.2 DAY 2 – Analysing values and organisational actions

Day 2 included two collaborative activities focused on sustainability actions, competences, and values at the organisational level. In the first activity, participants mapped and critically examined their company's past sustainability-related actions, starting from real change stories. Actions were formalised and organised across temporal, environmental, and social dimensions, allowing the group to visualise patterns, gaps, and systemic effects. Working in pairs and plenary, they developed a shared analytical representation of the organisation's sustainability trajectory and reflected on its complexity. The second activity built on this mapping to examine the sustainability values underpinning organisational behaviours. Using a predefined set of value cards, participants associated values with the mapped actions and constructed a visual value constellation, making alignments and inconsistencies explicit. A closing reflection reconnected values, competences, and actions, and introduced an observation kit for investigating external organisations' sustainability actions before the next session.

4.3.3 DAY 3 – Evaluating and prioritising strategies for transition

Day 3 included two activities focused on sustainability strategies and the organisation's future positioning. Participants shifted focus beyond their own company to explore sustainability transformations in other organisations. They presented cases analysed with the kit through immersive role-play, enabling comparison of change trajectories. Participants then linked them to sustainable development clusters and examined strategies using furniture and fashion case sheets. The activity concluded with a facilitated discussion in which participants identified the priority strategies most relevant to their future development. The second activity used a forward-looking synthesis process to consolidate learning and define a shared strategic commitment. Introduced through the narrative metaphor of the "Sextant," participants revisited the organisation's past and present actions, values, and insights. They then adopted a future-oriented perspective, identifying sustainability challenges and selecting strategic directions aligned with the earlier clusters. The session culminated in the co-creation of a manifesto-style commitment statement and the selection of a limited set of guiding values.

4.4 Discussing the results: The assessment

Across the training, researchers observed that participants consistently engaged in reflective and analytical discussions, demonstrating progression toward the intended learning outcomes (ILOs). During the early sessions, participants demonstrated a solid conceptual understanding of sustainability competences, values, and actions, correctly classifying elements within the provided frameworks and even suggesting actions beyond the initial dilemmas (ILO 1.1). They predicted how their personal sustainability competences could influence the impact of individual actions in the organisation (ILO 1.2) and reflected on their own sustainability values in relation to everyday work practices (ILO 1.3). Researchers noted moments of metacognitive awareness, for example, when participants expressed surprise at recognising non-obvious values such as "Democracy, nonviolence, and peace," signalling a shift from recognition to reflection on prior assumptions. During mapping exercises, participants distinguished and deconstructed past organisational sustainability actions (ILO 2.1), analysing when, why, and what changes occurred, as well as the relationships that enabled them (ILO 2.2). They began connecting values to concrete actions: for example, interpreting "reduction of working hours" as socially driven and "water-based adhesives" as environmentally driven, demonstrating early evaluative sense-making (ILO 2.3). Reflections occasionally extended beyond the workplace, indicating the emergence of metacognitive internalisation. In later sessions, participants actively engaged with external cases and classified alternative organisational strategies (ILO 3.1). They discussed how these strategies were relevant or transferable to their own context, weighing options, and prioritising potential directions (ILO 3.2). In the final synthesis activity, in which participants collectively formulated a strategic commitment and translated it into a visual narrative, researchers observed negotiation, the articulation of assumptions, and shared reflection on future sustainability intentions, confirming achievement of ILO 3.3. Participants remained motivated and curious, demonstrating commitment to applying learning beyond the training. Overall, observations across all days suggest that participants progressed from conceptual recognition of sustainability competences and actions to reflective evaluation and strategic planning, fulfilling the training's ILOs across conceptual, procedural, and metacognitive dimensions.

5 CONCLUSIONS

This exploratory study shows how sustainability training in SMEs can be designed to activate higher-order and metacognitive processes across roles. Grounded in sustainability culture and organisational learning, and structured through Anderson and Krathwohl's taxonomy, the intervention demonstrates how visually mediated reflection can support a shift from conceptual understanding to shared evaluative agency. Learner-led reflection was key in surfacing tacit knowledge and enabling collective sense-making. The findings also inform engineering and design education. The taxonomy-based, reflective approach offers a transferable model for UG and PGT sustainability modules, supporting the development of evaluative and metacognitive competences beyond knowledge transmission. However, the study involved a single small firm and a limited group, restricting generalisability and capturing only short-term effects. While learning outcomes were achieved, longer-term behavioural and organisational change remains uncertain. Future research should adopt longitudinal approaches across diverse SMEs to assess sustained impact.

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STRATEGIC USE OF FORMATIVE ASSESSMENT IN NEURODIVERSE CLASSES WITHIN ENGINEERING

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ABSTRACT

The proportion of neurodiverse students in STEM subjects, especially engineering, is significant. Evidence from literature consistently shows higher rates of disadvantage in neurodiverse students' grades. Nonetheless, researchers found that neurodiverse students showed higher rates of creative problem-solving ability. The reasons behind lower performance are often attributed to time-management issues, task avoidance, implicit requirement ambiguity, executive functioning overload, and cognitive fatigue. These challenges represent a non-comprehensive list of day-to-day difficulties students face, but they cover some of the issues this study focuses on. Within engineering education, the strengths of neurodiverse students can play a significant role in achieving positive outcomes. The approach of this study involves functional formative assessments and structured gradual learning of skills to tackle some of the main stressors in neurodiverse students. The structure follows a progressive and practical learning framework to allow flexible, paced learning, and a set of formative assessments to provide practical feedback for an equivalent task in summative assessment. The addition of formative assessments marked a positive shift in mean grades and a normal distribution with reduced presence of low-range outliers. The introduction of in-person weekly tutorials in addition to the reinforced formative assessment resulted in further positive shifts in grades and learning outcome fulfilment. A survey of neurotypical and neurodiverse students showed positive engagement with both learning structure and assessment. The study shows how introducing a practical approach to learning and realistic trialling of assessment structure for students improved learning outcomes and relieved stress in neurodiverse students.

Keywords: Neurodiversity, formative assessment, Universal Design for Learning, inclusive pedagogy

1 INTRODUCTION

The representation of neurodiverse individuals in STEM fields is garnering increasing scholarly attention. Neurodiversity, a term encompassing Autism Spectrum Disorder (ASD), Attention Deficit Hyperactivity Disorder (ADHD), dyslexia, dyspraxia, and other neurological variations, is increasingly recognised as natural human cognitive diversity rather than a deficit to be corrected [1]. Hamilton and Petty [1] argue that neurodiversity challenges stigmatising accounts of neurodevelopmental differences, advocating for the creation of contexts in which neurodivergent individuals can thrive. Within the engineering students specifically, prevalence rates of neurodivergent conditions have been reported at levels exceeding those found in the general population [2]. This higher representation presents both opportunities and challenges for educators seeking to maximise learning outcomes for all students. Despite notable strengths in creative problem-solving, pattern recognition, and systems thinking [3], neurodiverse students consistently demonstrate lower academic performance when measured through traditional assessment mechanisms [4]. The reasons for this disparity are multifactorial and well-documented in the literature. Chief among these is time management, task avoidance behaviours triggered by ambiguous or implicit task requirements, functioning overload when confronted with complex multi-step assessments, and cognitive fatigue resulting from sustained attention demands [5], [6]. Importantly, these difficulties often reflect a mismatch between assessment environments and cognitive profiles of neurodiverse learners, rather than an absence of understanding or capability. The Universal Design for Learning (UDL) framework provides a pedagogical foundation for addressing these challenges [7]. UDL advocates for multiple means of engagement, representation, action and expression, creating learning environments that are accessible to the widest possible range of learners without the need for individual accommodations. Laurillard [8] frames teaching as a design science, proposing that pedagogical patterns should be systematically constructed to support learning through

technology and structured activities. Her framework emphasises the iterative alignment of learning objectives, activities, and assessment, a principle directly informing the intervention in this study. The creative and iterative nature of engineering aligns well with cognitive strengths associated with neurodivergence. However, the assessment of engineering competencies frequently relies on summative assessments that demand sustained performance under time pressure, which disproportionately disadvantages neurodiverse students [9]. The gap between a student's capability and their ability to demonstrate that capability under assessment conditions represents a significant equity concern. This study addresses this gap by presenting an intervention based on the introduction of functional formative assessments and a structured, progressive learning framework within an engineering design module. Drawing on Wiliam's [10] conception of embedded formative assessment, the formative tasks were designed to be integral to the learning process rather than merely preparatory exercises. The progressive learning structure was designed to break complex design tasks into manageable stages, reducing executive functioning load and providing clear, explicit expectations at each step. The motivation for this study is twofold. Firstly, it seeks to quantify the benefit of additional formative assessments prior to summative evaluation in terms of improved learning outcome achievement. Secondly, it aims to explore the potential of such interventions to reduce stress levels among neurodiverse students, contributing to a more equitable learning experience. The study is situated within the discourse on inclusive pedagogy in engineering and draws on UDL as its theoretical framework.

2 LITERATURE REVIEW

The engineering student population has been identified as having elevated rates of neurodivergent conditions compared to the general student body. Studies by Wei et al. [2] reported that students with ASD were disproportionately represented in STEM, with engineering being among the most commonly chosen disciplines. Similarly, Sedgwick et al. [11] found that individuals with ADHD demonstrated a preference for applied, hands-on disciplines, which may explain higher enrolment in engineering. The cognitive profiles associated with conditions such as ASD and ADHD, including strong systematising abilities, visual-spatial reasoning, and divergent thinking, align with the demands of engineering problem-solving [3]. However, academic outcomes for these students frequently fall below those of their neurotypical peers. Römhild et al. [4] found that students with learning differences and ADHD achieved lower grade averages despite comparable intellectual ability. The discrepancy is frequently attributed not to lack of understanding but to assessment structures and learning environments that fail to account for the executive functioning of neurodiverse learners [5]. Hamilton and Petty [1] emphasise that the onus is too often placed on neurominority students to find alternative routes to meet neuro-normative expectations, highlighting the need for systemic change towards universal design approaches.

2.1 Challenges faced by neurodiverse learners

Executive functioning, encompassing skills such as planning, organisation, task initiation, working memory, and self-monitoring, represents a core area of difficulty for neurodiverse students [6]. In the context of engineering education, where assignments frequently require management of complex projects over extended periods, deficits in executive functioning can significantly impair performance. Cognitive fatigue, resulting from additional efforts required by neurodiverse students to process information and sustain attention in non-optimised environments compounds these difficulties [12]. Task avoidance is another well-documented phenomenon, particularly when assignments contain implicit or ambiguous requirements [13]. Neurodiverse students struggle to infer unstated expectations, leading to procrastination or disengagement. This effect is amplified in design courses where open-ended tasks, while pedagogically valuable, create uncertainty that triggers avoidance behaviours. Time management difficulties exacerbate these issues, as neurodiverse students often underestimate time required for complex tasks or struggle to allocate effort appropriately across competing demands [5].

2.2 Universal Design for Learning and Pedagogical Design

The UDL framework, discussed by Burgstahler et al [9] [7], provides three guiding principles for inclusive curriculum design: multiple means of engagement (the “why”), multiple means of representation (the “what”), and multiple means of action and expression (the “how” of learning). When applied to engineering education, UDL principles support the creation of assessment structures that are transparent, scaffolded, and offer multiple pathways to demonstrate competence [9]. Laurillard [8] extends this thinking by positioning the design of teaching and learning activities as an evidence-based,

iterative process. Her framework for pedagogical design science emphasises the importance of aligning learning activities with desired outcomes through cycles of acquisition, inquiry, discussion, practice, and production. This approach resonates with the interventions in this study, where formative assessments were designed to provide structured practice opportunities that directly mirror the demands of the summative assessment, enabling students to iteratively develop competence.

2.3 Formative Assessment and Feedback Literacy

Formative assessment is a key mechanism through which inclusive pedagogical principles can be implemented. Wiliam [10] argues that formative assessment should be embedded within the fabric of teaching, functioning as a continuous process through which evidence of learning is elicited, interpreted, and used to make decisions. This embedded approach moves beyond the notion of formative assessment as a discrete event and positions it as an integral component of learning. The role of feedback within formative assessment is critical. Nicol [14] advocates for a shift from monologue to dialogue in feedback processes, arguing that effective feedback requires systems that promote student engagement with feedback rather than passive reception. Henderson et al. [15] identify the persistent feedback challenges, that it is frequently perceived by students as unclear, untimely, or disconnected from opportunities for application. The design of the formative assessments in this study sought to address these concerns by providing timely, task-aligned feedback within a structure that allows for immediate application.

The concept of feedback literacy has emerged as a key construct in understanding how students engage with assessments. Hoo et al. [16] demonstrate that self and peer assessment interventions can develop student feedback literacy, enabling learners to make productive use of feedback. Carless [17] situates feedback within a broader educational framework, emphasising that effective feedback processes are those that support students in becoming self-regulated learners. Winstone et al. [18] provide a comprehensive taxonomy of recience processes, identifying the ways in which learners can exercise agency in their engagement with feedback. Their review highlights that proactive recience, where students actively seek out, engage with, and implement feedback, is associated with improved learning outcomes. The integration of these perspectives on formative assessment and feedback literacy underpins the design of the intervention examined in this study. By providing structured formative tasks that mirror the summative assessment, students were afforded opportunities to develop both domain-specific competencies and the metacognitive skills necessary to self-regulate their learning.

3 METHODOLOGIES

The study was conducted within an undergraduate engineering design module delivered at a UK university. The module requires students to demonstrate competence in design methodology, computer-aided design, and communication of engineering solutions through technical documentation. Prior to the intervention, the module relied on a single summative assessment to evaluate student learning. The intervention introduced a series of formative assessments designed to provide students with structured opportunities to practice and receive feedback on tasks directly aligned with the summative assessment. Consistent with Wiliam's [10] embedded formative assessment approach, these tasks were integrated within the module's teaching structure rather than treated as standalone preparatory exercises. Each formative task mirrored a component of the final assessment, allowing students to develop familiarity with expectations, format, and standards. The progressive learning structure broke down the overall module competencies into staged learning objectives, with each stage building upon the previous one. This scaffolded approach, informed by Laurillard's [8] design science framework, was designed to reduce executive functioning load by providing explicit structure and clear milestones. The course was structured over 1 semester spanning 12 weeks, with students given 2 weeks for each formative assessment and 6 weeks (including holidays) for the summative assessment.

Feedback on formative tasks was designed to be specific, timely, and actionable, reflecting the principles outlined by Nicol [14] for effective feedback in higher education. The feedback aimed to support students in developing their feedback literacy [16], enabling them to make increasingly independent judgements about the quality of their own work. In subsequent academic years, in-person weekly tutorials were added to the module structure, providing students with additional contact time for guided practice, peer interaction, and individualised feedback. These tutorials complemented the formative assessments by offering real-time support and reducing the isolation that neurodiverse students may experience when working independently on complex design tasks. Formative assessments feedback was

given as verbal feedback on a 1-to-1 basis in class, while summative feedback was given as marks with detailed mark scheme and individual written feedback.

3.1 Data Collection and Analysis

Assessment data was collected across multiple academic cohorts: a baseline year prior to the intervention, a year following the introduction of formative assessments, and a subsequent year incorporating both formative assessments and weekly tutorials. Grade distributions were analysed to identify shifts in mean performance, distribution shape, and presence of low-range outliers. A student survey will be administered in further iterations of the study to capture perceptions of the learning structure and assessment approach, with responses collected from both neurotypical and neurodiverse students. Statistical analysis focused on comparing grade distributions across cohorts and examining attendance patterns in formative versus summative assessments. Attendance data was collected to contextualise performance trends, particularly where differential participation in formative activities may have influenced aggregated results.

4 RESULTS

The introduction of formative assessments in the first year of the intervention was associated with a positive shift in the mean grade and a grade distribution that more closely approximated a normal curve with a reduced presence of low-range outliers. This suggests that the opportunity to practise and receive feedback prior to the summative assessment was associated with improved performance in the class, the assumption made was that each first-year cohort was of the same entry level ability as prior years. The subsequent introduction of in-person weekly tutorials alongside the formative assessments resulted in a further positive shift in grades and enhanced fulfilment of learning outcomes. The combination of structured formative practice and regular tutorial support appeared to provide a cumulative benefit, consistent with the scaffolded learning principles of Laurillard [8]. A further positive observation is that the effect remains even with an increased class size, which occurred in the second and third year of data. *Figure* shows the distribution percentage of students obtaining equivalent percentage grades. The data is split over three years of data collected, first without formative, second with a Summative assessment post Formative assessment (SpF) and the third set as SpF with in-person tutorials introduced.

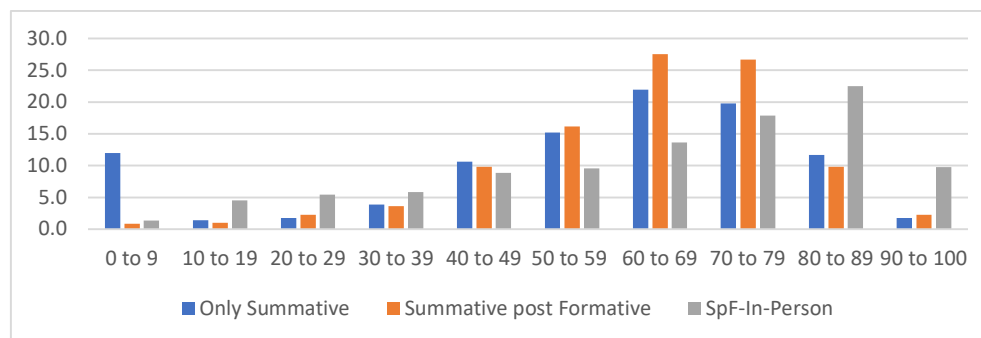


Figure 1. Grade distribution over three consecutive years where data is presented as percentage of class obtaining the grade range in order to normalise the data to account for class size changes

Analysis of attendance records revealed a notable discrepancy between formative and summative assessment participation: the formative assessment attracted only 40% of students in the SpF In-Person year, while the summative 99%. Nonetheless, the result shows that final year with the most available resources enhanced the student outcome regardless of consumed resources by the students. The stress survey will be performed in further iterations of the study to further understand the effects of the learning structure in the student population.

5 DISCUSSIONS

The need for unified yet accessible learning methods that serve both neurodiverse and neurotypical students in engineering education is a pressing concern in contemporary higher education [1]. The results of this study contribute to the growing evidence base supporting the integration of formative assessment and scaffolded learning structures as mechanisms for improving equity in engineering

programmes. The positive shifts observed in earlier intervention years align with Wiliam's [10] arguments for the efficacy of embedded formative assessment in enhancing student performance. The reduction in low-range outliers is particularly noteworthy, as it suggests that the intervention may have its greatest impact on students who are most at risk of underperformance, a group likely to include a disproportionate number of neurodiverse learners [4]. The UDL-aligned design of the intervention, which provided structured practice opportunities without requiring students to disclose disability status or seek individual accommodations, represents an inclusive approach consistent with the compassionate pedagogy advocated by Hamilton and Petty[1].

The feedback processes embedded within the formative assessments reflect the dialogue-centred approach advocated by Nicol [14], moving beyond transmission-based models towards a system where feedback serves as a catalyst for student self-regulation. The development of feedback literacy, as conceptualised by Hoo et al. [16] and Carless [17], appears to have been supported through the iterative cycle of formative practice and feedback, though further empirical investigation is required to quantify this effect. The results from the most recent cohort, however, introduce important nuances. The system implemented with the addition of in-person sessions and low formative attendance did not show significant differences in grades in this instance. If the students who attended the formatives were already among the more engaged and higher-performing members of the cohort, the aggregate data may not capture the benefit experienced by those individuals. Conversely, the majority of students who did not attend the formative sessions were assessed solely through the summative, without the preparatory benefit, may still have benefitted by in-person tutorials, further supporting pedagogical theory.

This attendance differential raises important questions about the voluntary nature of formative assessment. While a low-stakes, non-compulsory approach is consistent with UDL principles of learner autonomy [9], it may inadvertently create a self-selection effect in which the students who most need the scaffolding are least likely to engage with it. Henderson et al. [15] identify this as a persistent challenge in higher education feedback systems: the students who stand to gain the most from feedback opportunities are often the least likely to access them. Future iterations of the intervention may benefit from exploring strategies to increase formative attendance, such as integrating formative tasks more tightly into the module schedule, providing incentives for participation, or embedding formative activities within tutorial sessions where attendance may be higher. The variability in results across cohorts also underscores the importance of longitudinal data collection in educational interventions. Single-year results, whether positive or negative, may reflect cohort-specific factors such as baseline preparedness, attendance culture, or external stressors. The overall trajectory of the intervention, viewed across multiple years, remains broadly positive and consistent with the theoretical framework underpinning its design. It is noted that a formal stress analysis has not yet been conducted, which limits the ability to directly quantify the intervention's impact on neurodiverse students' stress levels. The survey data provide preliminary qualitative evidence of reduced anxiety, but future work should incorporate validated stress measurement instruments to strengthen this aspect of the evaluation.

6 CONCLUSIONS

This study evaluated the introduction of functional formative assessments within a structured engineering design module, with the aim of reducing executive overload and clarifying expectations, particularly for neurodiverse students.

Earlier intervention years showed improved mean grades and fewer low-range outliers, with additional gains following the introduction of weekly in-person tutorials; however, the most recent cohort displayed lower engagement with formative sessions and uneven access to their benefits. While still maintaining satisfactory learning outcome levels.

Although later years overall indicate more positively achieved learning outcomes, low attendance at voluntary formative activities remains a challenge, warranting further research into stress, cognitive load, retention, formative engagement, and feedback literacy; nonetheless, the findings support structured formative assessment as an inclusive strategy in engineering design education.

In further iterations of the study a student survey to determine variations of stress between neurotypical and neurodiverse students will be conducted, the results will help determine the effects of formative assessments in stress reduction for summative assessments.

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AI – A PROBLEM SOLVER IN ENGINEERING EDUCATION? OPPORTUNITIES FOR MORE INCLUSIVE PRODUCT DEVELOPMENT TEACHING

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ABSTRACT

Since the introduction of large-scale generative AI systems such as ChatGPT (GPT-3.5) in 2022, artificial intelligence has rapidly expanded across professional, educational, and societal domains. In engineering and product development, AI tools are increasingly integrated into engineering workflows, supporting tasks from early conceptual design to detailed development processes. However, their accelerating adoption raises critical questions: How can students be taught to use AI responsibly? How can ethical, democratic and societal values be preserved when intelligent systems influence decision-making? This paper investigates the application of AI tools within engineering design and product development education, with a particular focus on inclusive teaching approaches.

Through a structured survey among mechanical engineering students, the study evaluates the current usage, attitudes, and perceived usefulness of AI. The research identifies practical application fields - such as ideation, requirements engineering, concept evaluation, simulation assistance, and documentation, but also reveals a significant gap between informal academic use and structured professional application. Findings show that while students frequently use AI for research and text generation, domain-specific engineering tasks and critical evaluation skills remain underexposed.

The contribution of this work lies in its combined analysis of AI-augmented engineering methods and its framework for integrating inclusive, responsible AI education. The paper highlights the need for sustainable educational strategies to ensure that students become active, ethical decision-makers in an AI-augmented professional world.

Keywords: AI in engineering processes, education, inclusive opportunities, AI survey in engineering

1 INTRODUCTION

A new generation of students (Generation Z) is entering universities and engineering programmes. Having grown up with digital technologies and AI-based applications, these students are highly familiar with such tools. However, it remains unclear whether this familiarity translates into the ability to apply AI effectively and responsibly in professional engineering contexts.

AI is also reshaping educational environments. Recent studies show that students increasingly use AI tools for learning, research, and problem-solving activities [1], [2]. Consequently, engineering education must respond to these developments and prepare students for an AI-augmented professional world [3]. Based on this background, the following research questions define the scope of this paper:

- Which AI-augmented engineering methods currently exist?
- Is Gen Z able to use AI in a professional work environment?
- How do students use AI tools in their studies?
- For which tasks do students primarily use AI?
- Which competencies should be taught more intensively in engineering education than they are taught at the moment?

2 CONTEXTS IN ENGINEERING STUDIES

Mechanical engineering students encounter structured design and development processes early in their studies. They learn classical tools and methods such as creativity techniques (e.g. brainstorming, morphological box), CAD systems, and systematic product development methodologies.

Despite the increasing relevance of AI in industrial practice, these technologies are still only marginally integrated into many engineering curricula, resulting in a persistent gap between academic teaching and industrial application [4], [5], [6]. Educational research therefore emphasises that AI literacy should become a core element of modern education systems [3], [7]. Without structured learning opportunities, students tend to rely on self-taught and unsystematic use of AI tools, which may lead to uncritical or ineffective applications. To address this gap, AI integration in engineering education should follow principles of human-centred design and usability, ensuring that AI remains a supportive rather than dominating technology [8].

3 CURRENT RULES ON TEACHING AI USAGE

Universities within the European Union are required to ensure adequate AI literacy among students and staff when providing access to AI systems, for example through university-operated platforms or institutionally hosted AI services. This obligation derives from the EU Artificial Intelligence Act, with the relevant provisions becoming applicable on 2 February 2025. The specific implementation measures remain at the discretion of individual university administrations [7], [9], [10].

4 USABILITY OF AI IN ENGINEERING TASKS

Some typical and relevant use cases for applying AI are described in the following sub-sections.

4.1 Usability of AI while searching for literature

One of the most common academic applications of AI is the support for literature research. Large language models can help students to identify relevant keywords and research topics, summarise articles, generate structured overviews of research fields, and suggest potential sources.

Tools such as Elicit, ResearchRabbit, and AI-enhanced search engines provide faster access to scientific knowledge. However, generative AI also entails risks, particularly the generation of “hallucinated” references, i.e. non-existent or inaccurate publications. AI-conducted literature research can also be incomplete. Students must therefore be trained to critically verify AI-generated information using established academic methods [1], [2], [11].

4.2 Usability of AI while applying creativity methods and human-centred design

Creativity and ideation are core elements of product development. AI tools can be integrated into traditional creativity techniques to increase both the quantity and diversity of ideas [12], [13], [14], [15].

Possible AI-supported activities include:

- AI-assisted brainstorming (large numbers of initial ideas, alternative solution concepts)
- Morphological box support (filling matrices with solution principles).
- Analogical reasoning (solutions from other domains).
- Customer needs analysis (transforming interviews into structured requirements), including market and competitor analysis [14], [15].
- Concept evaluation (support for evaluation matrices and multi-criteria decision methods).
- Textual formulation of ideas (turning rough concepts into professional descriptions).

However, research shows that while AI increases idea quantity, human judgement remains essential for assessing originality and feasibility [12].

4.3 AI in Computer Aided Engineering (CAE)

Beyond text-based applications, AI is increasingly embedded in professional engineering software environments. These applications directly influence technical design activities [13].

The authors identify the following as particularly promising AI-supported activities:

- AI-supported CAD modelling (geometry generation from functional requirements).
- Generative design and topology optimisation (optimised geometries for given loads and constraints).
- Simulation assistance (proposal of boundary conditions and mesh settings).
- Error detection in models (design rule violations, manufacturability issues).
- Code generation for engineering tools (scripts for MATLAB, Python, ANSYS).
- Data analysis.
- Tutor bots that assist applying engineering tools and support learning in general.

5 SURVEYS ON AI USAGE AMONG ENGINEERING STUDENTS

Recent publications on AI integration in engineering lectures - covering areas such as engineering design, quality management, and scientific writing, have reported positive trends and introduced new teaching concepts [14], [15]. However, these studies focused on one special aspect or sub-disciplines of mechanical engineering. A comprehensive study capturing general AI usage among mechanical engineering students at DHBW Ravensburg has not yet been conducted. To address this gap, a structured survey was carried out to gain empirical insight into AI use in both academic and professional contexts, assessing frequency of use, attitudes, perceived usefulness, application fields, and cohort-specific differences.

5.1 Survey Design, Methodology and Demographic Overview

The questionnaire was distributed to two consecutive cohorts: TMK23 (47 third-year students) and TMK24 (57 second-year students). The questionnaire covered demographic data, AI usage behaviour, perceived usefulness, application fields, use within partner companies, specific tools employed, and attitudes toward AI-supported CAD/PLM systems, with the aim of obtaining a comprehensive overview of current AI usage across academic and professional environments.

Participants represented typical dual-study mechanical engineering cohorts, alternating between academic studies and industrial practice every three months. Most respondents were aged between 19 and 26 years. Partner company sizes ranged from small enterprises (<100 employees) to large corporations (>100,000 employees), with company size strongly influencing access to AI tools and digital infrastructure: students from larger organisations more frequently reported access to internal AI solutions, while those from smaller companies often indicated a complete absence of structured AI tools.

5.2 General Attitudes toward AI

One central element of the survey was the question of whether students perceive AI as useful in engineering contexts. Across both cohorts, the majority of respondents rated AI as at least moderately useful. However, opinions varied significantly:

- Some students expressed strong enthusiasm and curiosity about AI tools.
- Overall, 89.7% use AI (TMK23: 91.7%, TMK24: 87.7%).
- Overall, 52.7% see AI as extremely useful or useful in engineering design (TMK23: 44.7%, TMK24: 60.0%).
- Others remained sceptical or indifferent (overall 47.3% see AI as only partly useful or useless - TMK23: 55.3%, TMK24: 40.0%).
- Despite of regarding AI usage sceptical, 33% of those use AI (TMK23: 23.1%, TMK24: 42.9%).
- A small group rejected AI usage entirely, arguing that “traditional thinking” or “human intelligence” should remain central. Some addressed fear of losing understanding for parts of the results (overall 4.1% address such fears - TMK23: 6.4%, TMK24: 1.8%).

5.3 Actual Usage of AI Tools

A gap emerged between positive attitudes and actual usage. While many students believed AI could be useful in engineering design, only a portion reported regular use applying typical engineering design tasks, ranging from daily to occasional; a considerable number did not use AI tools at all. TMK24 students reported slightly more frequent use than TMK23, pointing to a possible timing effect.

Students who reported using AI tools were asked for which tasks they mainly applied them. The answers show a clear pattern. In academic contexts, AI was mainly used for research and information retrieval, understanding complex technical topics, summarising texts and lecture materials, exam preparation, and writing or improving academic texts (literacy). Students primarily viewed AI as a learning and knowledge-support tool, not as a direct design tool.

In professional contexts, many students stated that their companies do not officially use AI tools or that they were unaware of any usage. Around 35% mentioned specific tools, with Microsoft Copilot and internal AI solutions being most common, mainly for calculations, documentation, information search, and support in design-related questions. Structured AI integration into engineering workflows (e.g. AI-supported CAD or simulation) was rarely reported. In some cases, this may be the result of a lack of awareness or knowledge, presuming that especially the second-year students haven't yet worked on

larger projects in their companies. This indicates that, at least in the companies represented in this survey, AI in engineering is still at an early stage of adoption.

5.4 Comparison between Cohorts TMK23 and TMK24

One explicit goal of the survey was to compare two cohorts at different stages of their studies. Table 1 summarises the key results and differences identified between TMK23 and TMK24.

Table 1. Key results and differences identified in student cohorts

Aspect	TMK23	TMK24
Average age	21.64	21.11
Reported AI usage in Engineering design (e.g. creativity methods)	37.5%	49.1%
Reported AI usage in other contexts	87.5%	86%
Openness/ trust toward AI (scale 1: very positive to 5: very sceptical)	M=2.69 (more sceptical)	M=2.34 (more positive)
Awareness of AI in companies (see below)	limited	slightly higher
LLM in companies	31.3%	33.3%
Knowledge of CAD/PLM with AI	2%	12.3%

Interpretation

- TMK24 students appear more open and accustomed to AI tools. They reported using AI more frequently for engineering design tasks and for tasks like learning and problem solving.
- TMK23 students tended to be more cautious, especially in tasks where they are liable for the outcome. Some of them expressed doubts about the reliability or necessity of AI.

This suggests a cohort effect: as AI tools become more common in schools and everyday life, new student cohorts integrate them more naturally into their workflows. The timing between AI-acquaintance cohorts may be very small. However, despite these differences, both groups shared one common feature: formal training on AI usage was almost completely absent or with no major perception.

5.5 Critical Perspectives and Concerns

Several students expressed concerns regarding the reliability of AI-generated results, over-dependence on AI, ethical implications, data protection, and restrictive company policies. Statements such as “I have no idea how to use AI properly” highlight the need for structured guidance, transparency, and ethical reflection in AI education.

5.6 AI in CAD and Engineering Software

A specific question addressed whether AI-supported CAD or PLM tools are used. Here, the results were very clear. Almost all students answered “No” (48.4%) or “I don’t know” (31.4%). Only a very small number reported actual use of AI features in CAD environments (14.4%). The remaining 5.8% of respondents did not answer this question.

This shows that, although AI in engineering software is a growing industrial trend, it has not yet reached everyday practice for most students. However, it cannot be determined if there is no usage or just missing knowledge. Here the question arises, if students are not aware of the usage of AI tools, if the usage is not communicated or if the students are not trained in the usage of the tools.

5.7 Implications for Engineering Education

The survey results lead to several important conclusions:

1. AI tools are already part of students’ daily lives, mainly for learning, literacy and research.
2. Usage is largely informal and self-taught.
3. There is a significant gap between potential applications and actual structured usage.
4. Students lack guidance on how to use AI effectively, how to evaluate AI-generated results and knowledge about where AI can be meaningfully applied in engineering tasks.

Therefore, engineering education should introduce systematic AI literacy courses, teach critical evaluation skills, integrate AI tools into project-based learning and show concrete engineering use cases rather than only general-purpose applications.

This raises the question of whether universities should require students to take such courses. During the “Long Evening of Literacy” at our campus, students were given the opportunity to attend voluntary workshops. However, participation fell short of expectations (10-12%). This leads to another important question: Is it possible to encourage greater engagement in voluntary programmes, and if so, how can this be achieved?

5.8 Limitations of the Survey

The survey has several limitations: it is limited to one university, relies on self-reported and subjective data, and captures a rapidly changing field at a single point in time. The time difference between the two cohorts (TMK24 in early February, TMK23 in late December) further restricts comparability. Nonetheless, the findings provide a useful starting point for AI-oriented teaching concepts.

5.9 Summary

The survey shows that while AI is widely known and used by engineering students, its application is largely limited to academic support tasks. Professional engineering applications remain rare, and structured AI education is largely absent. These findings underline the need to systematically and responsibly integrate AI competencies into engineering curricula.

6 CONCLUSION AND OUTLOOK

AI technologies are rapidly transforming engineering practice and education. This study indicates that AI offers considerable potential to enhance learning processes, support creativity, and foster more inclusive product development teaching.

The survey findings address the research questions outlined in the introduction. A broad range of AI-augmented engineering methods already exist - spanning literature research, ideation, and CAE - yet Gen Z students, despite their digital familiarity, apply these methods largely informally and without structured training. Usage remains predominantly limited to academic support tasks such as research and text generation, while professional engineering applications remain rare. In company contexts, general-purpose tools such as Microsoft Copilot dominate over engineering-specific AI solutions. These findings reveal a clear competency gap: critical evaluation of AI outputs, prompt engineering, and domain-specific AI application in engineering design require more systematic and intensive coverage in future curricula, alongside clear guidelines for academic integrity and didactic concepts that keep human judgement central.

The formerly performed surveys mentioned in the introduction of Chapter 5 underline the survey observation of this paper in the general AI application, but the above survey additionally points out a lack of AI skills in engineering design applications, assessed in the actual cohorts. Due to this observed deficit of AI skills in engineering design applications, it is highly recommended to counter steer and develop a sustainable and integrative AI educational strategy, e.g. “train the trainers”, respectively lecturers, and students in more additional lectures, exercises, use cases, workshops and trainings.

Future work will focus on developing concrete teaching modules and best-practice frameworks for AI-supported product development courses. Long-term studies are needed to evaluate how AI influences learning outcomes and professional competencies.

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EXAMINING REFLEXIVITY: QUESTIONING VALUES THROUGH VISUAL-VERBAL DESIGN MODELS

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ABSTRACT

Design models have been a foundational method to properly understand design praxis and theory, while also perpetuating priorities and knowledge for the discipline. These models, both visual and verbal in nature, embody design values and serve as an important medium for collaboration and setting expectations among designers and non-designers. Indeed, designers of all experience levels use these models to understand and enact the design process. This study assesses the visual and verbal characteristics of 38 design process models to better understand the projection of traditional pragmatism versus more reflexive elements in design process dissemination. The findings of this study demonstrate that there is a myopic history of prevailing design models, even amidst the presence of evolving methodological and theoretical exploration within the design discipline. This is indicated through pragmatic language, single-outcome orientations, and narrow perspectives on the design process. Through this study it is revealed that prevailing design models contain verbal patterns and visual cues that focus primarily on pragmatic processes and outcomes and generally omit reflexive and pluralistic practices that could place the designer amidst their work, their users, and the larger development of designed knowledge. Here, researchers suggest creating and testing alternative models that challenge existing model structures and languages in favour of more contemporary paradigms, such as reflexive practice and pluriversal design. This research also prompts further inquiry into model usage in education and practice, including their function, development, and interpretation in the academic space for design students.

Keywords: Design models, reflexivity, design education, design process, design methodologies

1 INTRODUCTION

Visual design models have been a foundational method to properly understand design praxis and theory. Not only do these widespread models embody values, as discussed by Wynn and Clarkson [1], but they serve as an important medium for collaboration and setting expectations for designers [2]. Designers are typically familiar with a multitude of models, such as the Double Diamond (Fig. 1) and its variants. The importance of design models cannot be overstated, as designers of all experience levels use them to understand their work and processes. However, modern and historical models tend to contain visual cues and verbal language that focus primarily on pragmatic processes and outcomes [3][4], and omit reflexive practices, among other omissions. Indeed, the purpose of design models in recent decades has focused primarily on “assuring a re-usable and transparent road from A to B in a given process” [2][5]. Reflexivity, on the other hand, encourages self-positioning within design praxis and theory, seeks to address power imbalances within the complex systems a designer works within [6], and encourages social change [7][8]. This study gathers, codes, and visually analyses widely-applied design models, with a focus on reflexivity, as opposed to pragmatism, and addresses what is broadly omitted from these models. For example, we find that design models omit reflexivity for process linearity, resulting in models that are difficult for design students to decipher and apply effectively without context and further explanation. Additionally, this article suggests that there is an opportunity for design models to adopt pluriversal design practices [9], even within the most abstracted models. Finally, this article suggests that further research should consist of the creation and application of new, alternative design models that embrace reflexivity and plural outcomes.

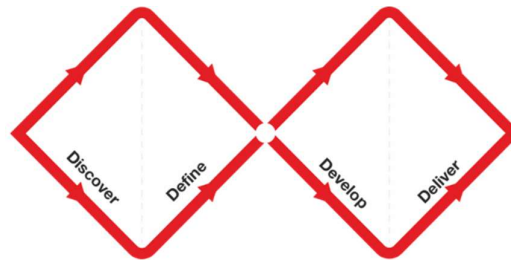


Figure 1. Double Diamond Model [10]

2 METHOD

The study was conducted using a basic sequence of defining, gathering, coding, and analysing various design process models. This section will dive briefly into each of these steps, articulating what was involved, why decisions were made, and what the limitations might have been. Finally, this section will include some examples of the models that were assessed, although not all could be efficiently displayed or referenced due to the nature of the submission.

2.1 Defining

There were a number of terms that needed to be defined for the sake of coding, interpreting, and communicating data. Primarily, reflexivity was defined as the act of consciously positioning oneself in the design process, in addition to also recognising and addressing power imbalances [6], user realities, and inequality in hopes of social change [7][8]. Consequently, reflexive actions were defined as encouraging these ends through deliberate reflection, communication, and recognition of plural realities. Complementarily, pragmatism was defined alongside Dalsgaard as a perspective centred on changing situations through intervention, then determining design value by the ability to further those changes [11]. Actions and concepts associated with this perspective lead to more product focused models, which emphasise testing, single-solution outcomes, convergence, and clear input-output relationships. Lastly, the models of interest were defined as visual-verbal representations of the design process applicable to existing disciplinary design practice.

2.2 Gathering

70 models were initially gathered as an exploratory sampling, which was later refined to 38. Models that were task specific, incomplete processes, or lacking visuals were omitted and deemed outliers from the interest sample. Researchers worked together to develop the list and agreed on the remaining 38 models that would be assessed.

2.3 Coding & Analysis

Each model was assessed on the surface using a number of basic characteristics. These attributes included: visual features, type of outcome (plural, singular, or hybrid), human-centred or not, more visual or verbal, and explicit communication or feedback. Each of these was selected because of their relation to the definitions of reflexivity, pragmatism, and process models previously discussed. Each of the models was then assessed by both researchers in a few ways, responding to the following questions: 1) What were explicit and implicit directions within the model? 2) what was omitted or missing from the model? and 3) where could reflexivity have been implied or even implemented within the model? These questions were meant to spark the results and discussion that conclude this study, leading to correlations that inspire additional questions for later research.

3 RESULTS

3.1 Visual vs Verbal & Visual Features

21 of the models communicated the process more visually than verbally. Conversely, 17 used words as the primary means of communication. The 38 models that were assessed were diverse in many respects, but retained an element of consistency in some areas of visual language. For instance, 31 of the 38 included arrows of some sort, while even more included lines if not explicitly arrows. Additionally, 22 used explicit shapes (rectangles, squares, circles, etc.) as indicators of various steps or actions in the

design process. Outliers that only appeared 1-3 times in the assessment included illustrations, spirals, and symbols (e.g. gears, wheel, etc.).

3.2 Outcome Types

27 models depicted a single, defined outcome as part of the design process. 11 models reflected plural outcomes, meaning multiple outcomes from a single process, or circular and hybrid outcomes, meaning ongoing iteration based on continual outcomes. Out of the 27 single outcome models, 7 included visually or verbally repeatable steps.

3.3 Human-centred or Empathy

6 models included explicit steps including phrases like “human-centred” or “empathy”.

3.4 Reflexive Communication and Documentation

Actions that explicitly involve reflexivity generally revolve around communicating and/or documenting designer and user positions throughout the process. 4 of the 38 models included conclusive elements, language, or steps that contained reflexive underpinnings. More on this will be included in the discussion.

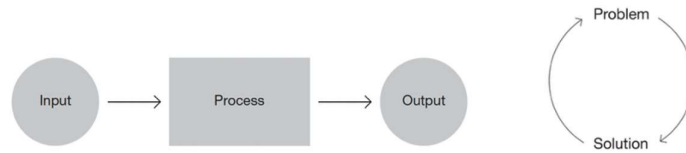
3.5 Model Patterns

The majority of the qualitative discussion will be included in the following section, but for the sake of clarification a few major patterns are worth mentioning. The first topic is the perspective of the model, whether that be product-focused, research-centred, or something more abstract. There were no explicit predefined perspectives for this section, as it was an exploratory space for assessing the models; however, it was chosen as a topic because of its potential relationship to the other basic assessment characteristics. In essence, the perspective of the model seemed to influence visual and verbal elements, and ultimately, its communication. Second, models were dissected into implied and explicit elements. For instance, some visual elements were interpreted alongside verbal elements to create implied meanings, which were included in the final dataset. Lastly, models were evaluated partially on their overall direction, whether they be more linear, circular, or something in-between. This aligns partially with the outcome metric, but was expounded upon as an essential element of visual communication.

4 DISCUSSIONS

4.1 Graphical Elements and Linearity

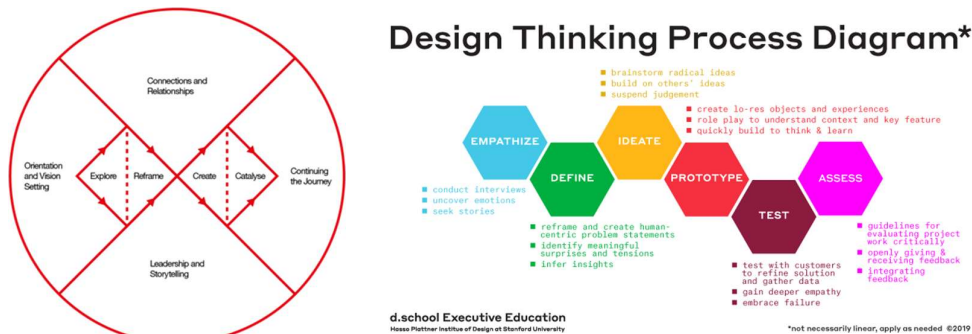
Throughout the models assessed, there were graphics, patterns, symbols, and shapes that were used across most of them. The most prominent of these are the line and the arrow. Lines and arrows can reflect a variety of basic linear movements – a step-to-step process, the passing of time, progression, and more. Although a line represents movement, an arrow is even more direct in its exclamation of moving forward to the next step, typically without retracing in the case of most of the models. Typically, linearity implies a simple, pragmatic process that begins and ends. Model 3 (Fig. 2) is perhaps the simplest representation of the design process in its linear, pragmatic sense. It lays out a line from left to right that begins with a single input and ends with a single output. The single output owes itself to an ambiguous, abstracted, and non-repeating “process.” However, we observed that there are 3 main movements across the design models assessed. Some models were explicitly linear, with an input, process, and output format. Others were semi-circular in their retracing and reconsidering of previous steps, and others were fully circular. Semi-circular and circular models allow for repeatable processes, including forms of reflexivity, but often end in singular outputs, such as model 15 (Fig. 3). More precisely, almost all of the design models visualised a singular design outcome, even in the circular or semi-circular visual. Overall, graphical elements generally favour pragmatic sequences and steps, such as prototyping, testing, and defining. While there are certainly areas where reflexivity may be implemented or explicitly advocated, particularly in areas of circularity or during steps of evaluation [12], there are few models in the design field that explicitly or implicitly outline steps that focus on the positionality or reflexive activities of the designer in relation to their users, context, or process.



Figures 2. & 3. Simple Design Process Models [13]

4.2 Model Perspectives and Subjects

Models use both verbal and visual languages to illustrate an abstraction of a point, and in doing so, generally imply a dominant perspective [14]. For instance, in comparing the Design Council's model (Fig. 4) with IDEO or Stanford's models (Fig. 5), the language alone indicates priorities through a simple fill in the blank exercise. IDEO's model predominantly uses words like synthesise, ideate, prototype, test, and deliver, which all can be followed by the phrase "the product" or "the solution". Conversely, the Design Society's includes words like relationships, storytelling, and reframe, each of which can be followed up by phrases like "with people" or "the question". This is notable not because one is better, but because it reveals that even through individual words values shine through. In most cases with design models these values are pragmatic and solution focused, which is also aligned with most of historical design as well as epistemological perspectives on design research [15][16]. If designers want to change what values their products project and perpetuate, it seems logical that the language that guides them could also be shifted [17].

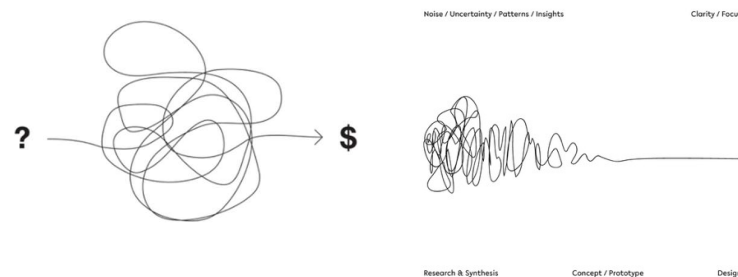


Figures 4. & 5. Models from Design Council and d School [18][19]

If you take the same models and assess the visuals, it is clear that although they all have linear elements, model 23 has a divided circle encompassing the smaller steps, hinting at holistic and almost timeless elements to the process. In fact, the right portion of the model indicates an ongoing journey, one beyond the final product or system. Conversely, most other models share a primarily linear series of shapes and steps, which is incongruent with the actual reality of the process [20]. While most conventional models are product or outcome centred, some deliberately focus on other elements with both their visual and verbal elements. As methodological and theoretical knowledge evolves in the design field, models that reflect traditional pragmatic values will likely not be enough to adequately inform designers who want to expand their priorities and emphases during the design process. There is a disconnect between recent developments in design perspectives, including pluriversal, transition, and more-than-human centred approaches, and the models that are perpetuated through modern design practice and education. Anne-Marie Willis addresses some of the weaknesses of conventional design education, stating that, "conventional discipline-based design education cannot contribute to substantial change unless students are inducted into understanding theories of power, social structure and social change, and the like," [21]. Our analysis demonstrates that conventional design models, and their accompanying educational context, do not address plural perspectives adequately, including theories of power and social change. For instance, if a designer hopes to value multiple concurrent outcomes and an overall plural perspective, including their positionality and reflexivity in general, are the existing models the best tools for helping that designer or student succeed? In the simplest of terms, the tool needs to match the job, and designers are more than capable of creating new tools to work with to respond to ever-changing social needs.

4.3 Using Design Models

As stated above, design models are an abstraction of real-world events or processes. Because of this abstraction design students are more likely to miss the events or processes that are implied or even omitted from models, while experienced designers may be more capable of inferring what isn't directly represented in a model [22]. This leads us to the discussion of how to educate designers using design models. How much is up for interpretation and influence, and how much is prescribed by the model itself? What is the role of the model maker, the user, and the third-party observer in evolving model usage to fit new paradigms and contexts? As an example, consider the most abstract models, 2 and 40 (Fig. 6 & 7). These models are simplified to the point that it can be hard to infer that design is even being referred to, let alone the events and processes that design consists of. A lot is assumed and much is left for the user and third party to fill in. Many models embrace ambiguity, as it is a core tenet of design [4]. However, consistent analogous omission may cause students and early designers to assume that all the gaps between steps are also identical. Future design models should therefore be presented alongside context and explained in more detail, particularly within educational settings, to help differentiate themselves from other paradigms. Although it is not possible, nor helpful, to design a visual model of design at a 1:1 scale, it could be helpful to include more details in model development and dissemination according to the level of education, interest, and experience that the audience possesses.



Figures 6. & 7. Squiggle Design Models [13][23]

4.4 Plurality in Design Models

We found that linear models were inherently pragmatic, leaving little room for reflexivity. Semi-circular and circular models did allow space for reflexivity, but it was rarely explicit, either visually or verbally. Despite there being room for multiple cycles in semi-circular and circular models, there was typically a singular output among all models. This ignores the reality that design outcomes are often pluralistic. For example, we might perceive the outcome of a particular design model to be a product or monetary gain, but other outcomes exist, such as any knowledge that is created throughout the design process, or specific and reflexive lessons learned by the designer. Indeed, in educational settings it is not typically the end product that is primarily valued; the output in educational settings is the experience gained by the design practitioner themselves [24]. This leads us to consider if design models could represent a plurality of outcomes, including not only products, but new knowledge created, experience gained by the designer, and even relationships and behaviours. Both new knowledge and designer experience is valuable, particularly in semi-circular or circular models where the designer is repeating the design process. Would it be possible to apply this pluralistic approach to industry settings, improving the rate and depth of a designer's learning curve? Perhaps revisiting the outlined outcomes of the design process via models could reduce the gap between academic and industry processes, expanding the way design can impact commercial and social spheres.

5 CONCLUSIONS

The study demonstrates that there is a myopic history of prevailing design models, even amidst the presence of ongoing methodological and theoretical exploration within the design discipline. This is indicated through pragmatic language, single-outcome orientations, and narrow perspective on the design process. These findings lead to two possible subsequent layers of investigation for the research area of design models. The first is to begin creating and testing alternative models that challenge existing model structures and languages using more contemporary paradigms, such as reflexivity and positionality. Secondly, this research prompts further inquiry into model usage in education and practice.

Students may be able to learn model interpretation and creation earlier in design curriculums to help assist in responsive and reflexive design methods later on. The model has a consistent but underexplored narrative in design practice, and further research could help bolster future models and applications.

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ADAPTING GUIDELINE-BASED ENGINEERING TRAINING FOR CULTURALLY DIVERSE TEAMS: INSIGHTS FROM INDUSTRIAL CAD/PLM TRANSITIONS

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ARTECH Consulting GmbH, Germany

ABSTRACT

Engineering organisations undergoing CAD/PLM transitions can benefit from guideline-based training, which supports learning and harmonises engineering practices across distributed teams. However, in global engineering environments, cultural backgrounds, professional experience and reasoning strategies can affect how these guidelines are understood and implemented. This paper examines guideline-based learning from the perspective of cultural cognition within an industry-led CAD/PLM transition involving geographically and culturally diverse engineering teams. Adopting a qualitative, practice-oriented approach, the study analyses how participants interacted with shared instructional artefacts during training and operational activities. The findings emphasise the need to balance organisational standardisation with interpretative flexibility when designing learning frameworks for global engineering and product design environments.

Keywords: CAD/PLM transition, global teams, cultural cognition, guideline-based learning

1 INTRODUCTION

The practice of engineering and product design is increasingly influenced by globalisation, digital integration and organisational complexity. Design activities are now often carried out by geographically distributed teams with diverse cultural, educational and disciplinary backgrounds. Meanwhile, both the industry and education sectors are facing the rapid evolution of digital design environments driven by the widespread adoption of integrated Computer-Aided Design (CAD) and Product Lifecycle Management (PLM) systems. These technological advancements mean that designers must not only master new tools, but also adapt to standardised workflows, collaborative processes and data-driven practices throughout the entire product lifecycle [1], [2].

Guideline-based learning is often adopted in industrial training to facilitate transitions, providing a structured learning approach that fosters consistency and facilitates knowledge transfer between teams. Design guidelines, procedural rules, and modelling conventions help to align training with organisational standards, enabling designers to apply their skills in real-world contexts. These guidelines serve as learning resources and reference materials, facilitating knowledge transfer across diverse user groups and teams.

However, although guideline-based learning approaches are usually presented as neutral and universally applicable, they are actually shaped by learners' cultural and contextual backgrounds. Research in cultural cognition has demonstrated systematic differences in how individuals from different cultures perceive structure, interpret rules and solve problems. These variations can have a significant impact on the interpretation and application of design guidelines, particularly in teams that are distributed across the globe [3].

In global engineering environments, in particular, there is a critical need for a guideline-based learning framework that can accommodate cultural diversity. Misinterpretation of guidelines can lead to modelling inconsistencies, misunderstandings and reduced confidence in new workflows. This emphasises the importance of understanding how practitioners from different backgrounds interact with shared instructional artefacts during training and further development processes.

This paper examines guideline-based learning from the perspective of cultural cognition in the context of an industry-led CAD/PLM transition. Building on prior research, the study explores the influence of cultural thinking patterns on designers' engagement with structured learning artefacts. The paper highlights the challenges of adapting guideline-based learning frameworks for use with culturally diverse teams and offers insights that contribute to the broader discussion on diversity and inclusivity in engineering and product design education.

2 CONCEPTUAL BACKGROUND AND POSITIONING

This section outlines the study's conceptual framework by situating guideline-based learning within discussions on CAD/PLM transitions, workplace learning, and engineering design education. It also introduces cultural cognition as an analytical approach to understanding how globally distributed engineering teams interpret shared instructional artefacts.

2.1 Guideline-based learning in CAD/PLM transitions

The growing complexity of digital engineering environments has emphasised the importance of structured learning approaches during CAD/PLM transitions. In industrial contexts, guideline-based learning is commonly employed to support the adoption of modelling conventions, workflow procedures, and collaborative practices associated with integrated digital engineering systems [4]. Rather than focusing on software functionality, this approach integrates learning into real engineering activities and organisational processes.

Guidelines usually formalise modelling principles, procedural rules, and coordination mechanisms designed to promote consistency among engineering teams. During CAD/PLM transitions, these artefacts often serve operational and educational purposes, supporting standardisation while facilitating learning and knowledge transfer among users with varying levels of expertise and professional experience. From a workplace learning perspective, guidelines can be understood as artefacts that facilitate participation in professional practice by mediating interaction between organisational expectations and individual engagement [5]. Similarly, research on learning objects highlights the role of structured instructional resources in facilitating the transfer and reuse of knowledge in different learning situations [6]. Within communities of practice, such artefacts also facilitate the negotiation of shared meanings and professional identities among practitioners [7]. Previous industrial experiences with structured learning approaches have similarly highlighted the potential of guideline-centred training to support procedural understanding, knowledge transfer and scalable learning during complex software transition processes.

From an educational perspective, guideline-based learning can be viewed as a type of scaffolded workplace learning that links abstract system knowledge with practical engineering experience. This approach aligns with experiential and practice-oriented learning theories, which emphasise integrating conceptual, procedural, and reflective knowledge through authentic task engagement [8], [9]. Recent discussions in engineering education also highlight the importance of contextualised, practice-based learning environments in supporting collaborative engineering work and developing digital competencies.

At the same time, guideline-based learning differs from instructional or tool-oriented training approaches because it relies heavily on interpretation. Rather than providing exhaustive coverage of every possible modelling situation, guidelines are designed to be interpreted and adapted by users within evolving engineering contexts. Therefore, the effectiveness of guideline-based learning depends on both the quality of the guidelines and how learners engage with them. This is particularly important in globally distributed engineering environments, where teams may have different approaches to structure, ambiguity, and professional judgement.

2.2 Cultural cognition and diversity in engineering design practice

Research in cultural cognition suggests that reasoning processes and decision-making strategies are influenced by culturally embedded norms, educational traditions and professional practices [3]. Rather than assuming that all learners interpret information in the same way, this perspective recognises that individuals may prioritise different forms of coherence, justification and problem solving when engaging with complex engineering tasks. These differences can affect how design engineers organise activities, interpret procedures and evaluate acceptable solutions in collaborative engineering

environments. Additionally, research on design teamwork has shown that diversity in learning styles and cognitive approaches can impact team interaction and engineering problem-solving processes [10]. These aspects become particularly relevant when formalised learning artefacts, such as modelling guidelines or workflow conventions, are introduced to regulate engineering practices. Although these guidelines aim to reduce ambiguity and promote consistency, their implementation is neither neutral nor uniform. Design engineers interpret and apply guidelines through the lens of their prior experience, local practices and culturally influenced expectations regarding autonomy, rules and professional judgement. Consequently, identical guidelines may lead to different interpretations and modelling behaviours across teams, even when the formal instructions themselves remain unchanged.

From an engineering and product design education perspective, these dynamics challenge learning models that focus solely on standardisation. Educational research increasingly highlights that effective learning environments should accommodate diverse reasoning strategies, modes of participation and professional perspectives, rather than assuming a single ideal approach to learning and problem solving. In communities of practice, learning emerges through compliance with formal rules, negotiation, interaction and shared meaning-making among practitioners. Similarly, recent discussions on inclusive, cross-cultural design learning emphasise the importance of creating collaborative learning environments that support multiple forms of participation and interpretation within globally distributed teams [11], [12].

These considerations align closely with current discussions surrounding diversity and inclusivity in engineering education. Inclusive learning environments require more than the dissemination of standardised procedures; they must also recognise and support the various ways in which people understand and engage with engineering knowledge. In globally distributed engineering teams, cultural diversity should not be viewed as an obstacle to standardisation, but as a factor that must be explicitly considered when designing learning frameworks that rely on shared artefacts and collaborative interpretation.

Figure 1 illustrates the conceptual relationship between organisational standardisation objectives, guideline-based learning and culturally influenced interpretation in engineering environments across the globe. It presents guideline-based learning as a framework that connects shared organisational practices with diverse reasoning strategies, workplace learning processes and collaborative meaning-making among engineering teams.

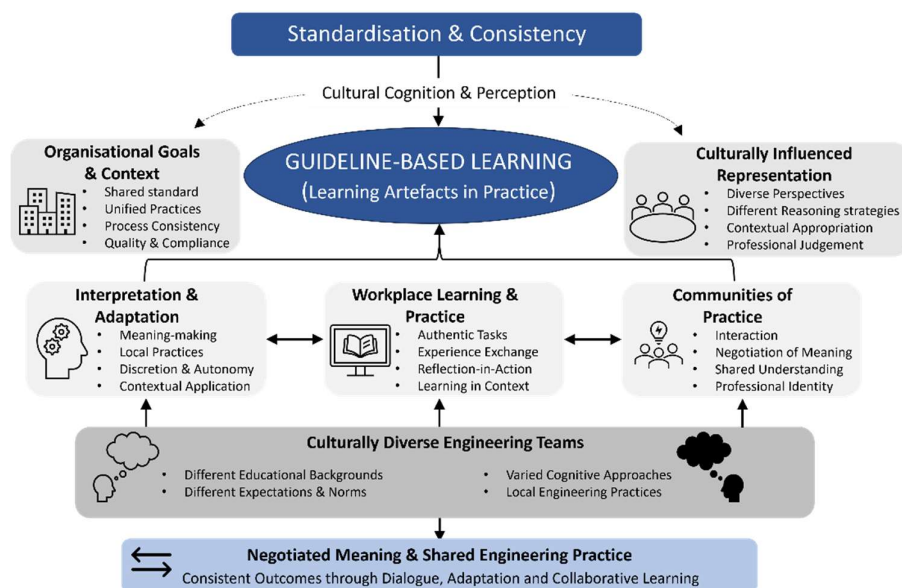


Figure 1. Guideline-based learning as a mediating framework

Adopting this perspective, the present study conceptualises guidelines as interpretative resources, the effectiveness of which depends on how they are negotiated within culturally diverse learning environments, rather than viewing them as static sets of instructions. This conceptual positioning provides the basis for analysing how guideline-based learning can support standardisation and inclusivity in global engineering and product design.

3 INDUSTRIAL CONTEXT AND METHODOLOGICAL APPROACH

This study is based on a CAD/PLM transition project led by industry and carried out within an international engineering organisation operating across geographically distributed sites. The project involved deploying shared modelling conventions, workflow procedures and training guidelines to support the harmonisation of engineering practices within a global digital engineering environment.

3.1 Industrial project context

The transition programme was based on a guideline-driven learning strategy. Rather than focusing exclusively on software functionalities, the training programme integrated modelling rules, workflow conventions, and procedural recommendations directly into practical engineering activities. The guidelines therefore functioned as both operational reference documents and learning artefacts, supporting knowledge transfer and collaborative interpretation among users.

The guidelines were developed and deployed through an iterative and participatory process involving project managers, key users, engineering specialists and the external consulting team. Initially, experienced users contributed to defining and validating modelling conventions based on operational requirements and existing engineering practices. These guidelines were then disseminated progressively to broader engineering teams through structured training sessions, collaborative workshops, and workplace support activities.

The guideline documents combined procedural descriptions, workflow recommendations, and structured organisational information, all of which were intended to support practical engineering activities. Figure 2 illustrates an example of the structure and organisational content of the guideline documents used during the CAD/PLM transition project.

Guideline for Document Template	Content
Version: XX	1. Introduction 5
Last Review Day Month Year	1.1. Definition and purpose of part families 5
Date: Day Month Year	1.2. Advantages of using part families 5
Accountable Manager: Name of the Manager	1.3. Areas of application of part families 5
Owner: XXXXXXXXXXXX	2. Create and handle part families in Siemens NX 6
Scope: All Engineers of XXXXXXXXXXXX	2.1. Prerequisites 6
Purpose	2.2. Creating a master component 6
This guide ensures that the appropriate site is selected for the project and that the templates and system parameters specific to that site are used for the design.	2.3. Defining variants 8
Scope	2.4. Working with part families using external spreadsheets 12
This design guideline applies to all areas of XXXXXXXXXXXXXXXX.	2.5. Creating child components 14
	2.6. Managing part families 15
	3. Working with part families in Siemens NX 16
	3.1. Changing variants 16
	3.2. Creating drawings and parts lists 17
	3.3. Using part families in assemblies 17
	3.4. Managing part families in a team 19
	4. Best practices for part families in Siemens NX 19
	4.1. Standardization of designations and structures 19
	4.2. Effective use of attributes and formulas 21
	4.3. Integration with PLM Teamcenter 21

Figure 2. Example structure of a guideline document used during the CAD/PLM transition

3.2 Methodological approach

The study takes a qualitative, practice-oriented approach, focusing on how guideline-based learning was interpreted and implemented in the context of industrial software transition processes. Rather than quantitatively measuring learning outcomes, the objective was to identify recurring patterns in the way engineering teams engaged with shared instructional artefacts during training and operational activities. The findings presented in this paper are derived primarily from feedback, observations, and experience reports produced by the external experts and trainers who were involved in implementing and supporting the transition project. These observations were made during training sessions, collaborative workshops, user support activities, and discussions with project stakeholders, which were conducted throughout the deployment process. Therefore, the study does not rely on controlled experimental observation of participants, but rather on interpretative analysis of practices, interactions, and recurring issues identified during implementation of the learning framework.

The analytical process focused on identifying recurring themes related to:

- engagement with structured guidelines;
- expectations regarding levels of prescription and autonomy;
- interpretation of modelling conventions;
- collaborative clarification processes;
- adaptation of shared practices within culturally diverse engineering teams.

These themes were interpreted through the conceptual perspectives introduced in Section 2, particularly cultural cognition, workplace learning, and communities of practice. The objective was not to categorise participants according to national culture or demographic characteristics, but rather to explore how reasoning patterns influenced by culture and professional contexts shaped interactions with shared learning artefacts.

3.3 Scope and limitations

As the study is based on a single industrial CAD/PLM transition project, it reflects a context-specific learning environment. While the project involved geographically distributed teams and culturally diverse engineering contexts, the findings should not be interpreted as being applicable to all industrial sectors or engineering organisations.

Additionally, the study primarily relies on qualitative interpretations derived from industrial practice, rather than quantitative learning assessments or controlled comparative analyses. Consequently, the paper does not attempt to establish causal relationships between cultural background and specific learning outcomes. Instead, it seeks to identify recurring interpretative dynamics and practical considerations relevant to guideline-based learning within global engineering environments.

Nevertheless, the project's industrial scale, the diversity of the engineering teams involved, and the systematic implementation of structured learning artefacts provide a meaningful basis for discussing how guideline-based learning frameworks may support standardisation and inclusivity in engineering and product design education. Future work could build on this research by comparing multiple industrial contexts and combining qualitative observations with quantitative indicators related to learning performance, modelling consistency, and collaborative efficiency.

4 FINDINGS AND IMPLICATIONS

The analysis revealed recurring patterns relating to engagement with guidelines, the interpretation of modelling conventions and collaborative learning processes within culturally diverse engineering teams. Despite working with the same instructional materials and organisational objectives, the analysis revealed that engineering teams did not engage with guideline-based learning in a uniform manner. Differences in interpretation of modelling conventions, approach to procedural instructions, and balancing of formal rules with professional judgement emerged repeatedly. Some users preferred highly structured and explicit guidance, treating the guidelines as authoritative references primarily intended to minimise ambiguity during the transition process. Others took a more flexible approach to the guidelines, focusing on understanding the rationale behind modelling conventions and adapting recommendations to specific engineering situations and local practices.

These differences were not necessarily linked to levels of expertise or technical competence; rather, they reflected different expectations concerning the structure of engineering work, autonomy, and approaches to problem solving. Both engagement patterns contributed to effective learning when supported through collaborative interpretation and contextual explanation. In practice, the guidelines rarely functioned as static repositories of instructions. Instead, they became focal points for clarification, negotiation and collaborative interpretation during training sessions and operational activities. Questions relating to exceptions, contextual adaptations, and the interpretation of modelling rules often sparked discussion among users and trainers, fostering shared understanding and flexible standardisation across teams.

Therefore, the findings support the perspective introduced in Section 2 that guidelines operate not only as procedural documents, but also as learning artefacts, the meaning of which emerges through interaction and situated practice. In globally distributed engineering environments, the effectiveness of guideline-based learning depends on the quality and clarity of the guidelines, and on learning environments accommodating diverse reasoning strategies and collaborative interpretation processes.

From an engineering and product design education perspective, these observations emphasise the importance of designing structured learning frameworks that balance standardisation with interpretative flexibility. While shared modelling conventions and workflow procedures are necessary for

organisational consistency, inclusive learning environments should also facilitate discussion, contextual explanation, and various forms of engagement with engineering knowledge. The findings suggest that culturally responsive, guideline-based learning frameworks could strengthen organisational harmonisation and collaborative learning within global engineering contexts.

5 CONCLUSIONS

This paper examined guideline-based learning in the context of an industry-led CAD/PLM transition involving geographically dispersed engineering teams. The findings show that shared guidelines are not uniformly interpreted, but are instead shaped by various reasoning strategies, professional practices, and expectations concerning structure and autonomy. Rather than functioning solely as procedural documents or static sets of rules, the guidelines operated as mediating learning artefacts, the meaning of which emerged through interaction, discussion and situated engineering practice.

The study highlights the importance of balancing organisational standardisation with interpretative flexibility in global engineering environments. Although structured guidelines are important for harmonising engineering practices, effective learning frameworks must also support collaborative interpretation and accommodate various approaches to professional problem solving. The findings suggest that productive learning can be supported by different modes of engagement with guidelines when accompanied by opportunities for discussion, contextual explanation and reflection.

Although this study is based on a single industrial case and relies primarily on qualitative interpretations derived from practice-oriented observations, it provides insights into how culturally responsive, guideline-based learning could support inclusivity and knowledge transfer in engineering and product design education. Future work could build on this research by comparing multiple industrial contexts and combining qualitative observations with quantitative indicators related to learning performance and collaborative engineering practices.

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UNDERSTANDING MOTIVATIONS IN INDUSTRIAL DESIGN GRADUATE EDUCATION: A MULTI-STAKEHOLDER ANALYSIS

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ABSTRACT

Graduate education in industrial design is evolving to meet diverse student needs and career pathways. This study examines the motivations, challenges and desired outcomes that influence enrolment and experience in a Master of Industrial Design programme. The research pays particular attention to differences between students with undergraduate design backgrounds (Track 2) and those entering from non-design disciplines (Track 3).

This research uses a multi-stakeholder approach, collecting data through workshops with current students (n=7) and faculty (n=4), supplemented by an alumni survey (n=6). The jobs students aim to accomplish, the pains they experience, and the gains they seek through graduate education are collected using the Value Proposition Canvas as a framework.

The findings reveal distinct motivations in which Track 2 students primarily seek technical skill advancement and career readiness, while Track 3 students focus on design process mastery and professional validation. The study identifies three key opportunities for programme enhancement: differentiated onboarding for Track 3 students, explicit research-to-practice bridges, and structured career transition support.

By systematically documenting the diverse drivers of graduate study in industrial design, this research establishes a foundation for evidence-based programme development and offers actionable guidance for programmes seeking to better serve diverse student populations.

Keywords: Design graduate education, Master of Industrial Design, value proposition canvas, multi-stakeholder research

1 INTRODUCTION

Industrial design as a discipline is constantly evolving. What began as a practice oriented toward the form and function of manufactured objects has evolved into a complex, multidisciplinary discipline that now encompasses human-centred design, systems thinking, service design, interaction design, and design research [1], [2]. Today's industrial designers operate across research, strategy, entrepreneurship and leadership that align and respond to social, technological, environmental, and cultural shifts [3],[4]. Designers are driving innovation within organisations and shaping systems, not just artifacts [1]. This expanding scope has placed pressure on design education to keep pace and graduate education has emerged as the critical site where the field must evolve [5].

In the United States, the Master of Industrial Design (MID) degree functions as advanced professional training for practicing designers, a credential for those seeking academic or leadership roles, a pathway for students transitioning into design from other disciplines, and preparation for doctoral study [6], [7], [8]. Because of this breadth, many US programmes have developed multiple curricular tracks to acknowledge different student starting points and learning needs [9],[10]. Generally, there is one pathway for students with undergraduate degrees in industrial design, and another for students entering from non-design backgrounds. This structural diversity reflects a commitment to broadening access to graduate design education, but it also raises a fundamental question: what value does the MID degree offer, and to whom?

Choosing to pursue a graduate degree is a significant decision that requires consideration of time, financial investment, and long-term impact. The diversity of career directions available to MID graduates, spanning product design, UX, consulting, service design, design research, and academia, complicates straightforward return-on-investment assessments. While scholars have examined industrial

design career competencies and job market qualifications [11] and graduate programme thesis outputs [7], there is limited published research examining what motivates diverse students to pursue graduate industrial design degrees, what challenges they face upon enrolment, and what outcomes they hope the degree will provide. Davis (2012) similarly observes that graduate design programmes show little differentiation from undergraduate outcomes, leaving the profession with limited understanding of what graduate study provides and creating confusion about the value of master's degrees in design. This ambiguity has consequences. Programmes that cannot clearly articulate their value proposition struggle to attract and retain the diverse cohorts they seek, and students who cannot accurately assess a programme's fit with their goals are at greater risk of misalignment between expectations and outcomes. A structured approach is needed to understand what different student populations are seeking from graduate ID education and how well programmes are currently positioned to deliver it. A multi-stakeholder view is essential to moving beyond any single vantage point. Current students bring enrolment-moment motivations, alumni offer career-validated assessments, and faculty hold the curriculum design perspective that shapes what the programme delivers.

This study examines the motivations, perceived challenges, and desired outcomes of students and faculty in a Master of Industrial Design programme at North Carolina State University. Using the Value Proposition Canvas framework [12], the researchers conducted a collaborative workshop with current students and faculty to understand how each group understands the value of the MID degree. These workshop insights were supplemented with survey data from programme alumni to capture career-informed perspectives on the programme's value.

2 METHODOLOGIES

The study was reviewed by North Carolina State University's Institutional Review Board and determined to be exempt (IRB # 27726). This study employed a qualitative approach to examine student, alumni, and faculty perspectives on the value of a Master of Industrial Design (MID) degree. Using the Strategyzer Value Proposition Canvas as a framework [12] the research team conducted a structured workshop with students and faculty to identify the "jobs, pains, and gains" that influence enrolment and programme experience in industrial design. Within this framework, "jobs" refer to the goals or outcomes students seek to accomplish through graduate study; "pains" represent perceived obstacles, risks, or frustrations; and "gains" describe desired benefits and measures of success.

Workshop participants included current MID students (n=7) and industrial design faculty members (n=4). Participants were divided into faculty and student working groups. The student group was further subdivided into those with an undergraduate degree in industrial design (n=2) and students without an undergraduate degree in industrial design (n=5).

Each workgroup received access to a digital version of the Strategyzer Value Proposition Canvas, via a Miro board [13], along with digital sticky notes to document their responses. Participants were also provided with digital and printed question prompts aligned with the canvas categories. One researcher facilitated the student groups, explaining the definitions of the jobs, pains and gains prior to data collection. A second researcher similarly facilitated the faculty group.

Participants discussed and documented key motivations, challenges, and expected outcomes related to pursuing an MID degree. Responses were recorded on digital notes on each canvas. After identifying jobs, pains and gains, each participant group was prompted to articulate corresponding pain relievers and gain promoters. The structured data collection session lasted 1.5 hours, with approximately 20 minutes allotted to each section. Each group then presented a verbal summary of key insights to the larger group. This took an additional 30 minutes, for a total workshop time of 2 hours. While pain relievers and gain creators were discussed, this paper focuses on presenting the customer profile dimension (jobs, pains, gains) as foundational understanding of student needs. The development of complete value propositions requires additional iterative refinement and analysis beyond the scope of this initial study. Following the workshop, the research team clustered similar responses and identified emerging themes. Data were analysed using thematic analysis, with codes generated inductively from emerging patterns. Themes were refined through iterative discussion among the researchers to ensure consistency and alignment.

To incorporate longitudinal perspectives, the research team also developed and distributed an alumni survey targeting graduates of both MID tracks. The goal was to capture retrospective motivations for enrolment, reflections on programme experiences, and perceived professional impact. The survey included four sections: background information (e.g., graduation year, track designation, undergraduate

preparation, current employment), pre-programme motivations and anticipated outcomes, reflections on experiences during the programme (including track-specific questions), and post-programme impact (including Likert-scale items assessing perceived career transition and readiness). Questions were both multiple-choice and open-ended. The survey was distributed via email to MID graduates and yielded six responses (n = 6), including two Track 2 graduates and four Track 3 graduates. Closed-ended items were analysed using descriptive statistics and open-ended responses were analysed using thematic analysis.

3 FINDINGS

3.1 Track 2 Students (Undergraduate ID Background)

Track 2 students articulated a strong interest in skill refinement and career readiness. Their primary ‘jobs’ centred on refining hard skills and technical competencies, specifically product sketching, rendering, digital visualisation, high-fidelity prototyping, and CAD modelling. In addition, they desired to build professional readiness and construct a competitive portfolio. Students expressed a desire to validate their career direction, identify an area of specialty (such as UX or design research) and to be perceived as driven, purposeful designers. Entrepreneurial ambition was also a common motivating factor for this group.

The most significant pains reported by Track 2 students were structural and pedagogical. Students expressed frustration with what they perceived as an overemphasis on research phases relative to tangible product design work, insufficient instruction in industry-standard software (e.g., SolidWorks, Keyshot). Several students felt projects did not advance the work far enough toward commercialization including patents or manufacturing. Career exposure gaps were a theme, where students noted limited industry recruitment presence and the absence of an ID-specific career fair. Regarding critiques, students desired more direct and candid feedback from faculty.

Among the gains, Track 2 students highlighted access to free digital fabrication resources (3D printing, laser cutting), spacious and well-equipped studio environments, and positive relationships with faculty. Teaching assistantships were recognised as a meaningful avenue for professional and pedagogical growth. Notably, Track 2 students also identified learning alongside Track 3 peers as a gain, valuing the diverse professional backgrounds and perspectives that non-design students brought to collaborative work.

3.2 Track 3 Students (Non-Design Background)

Track 3 students entered the programme with a broader set of motivations centred on identity formation, interdisciplinary positioning, and creative self-actualisation. Their primary jobs included developing a comprehensive design skill set, improving execution across all stages of the design process, understanding industrial design’s relationship to adjacent fields, and finding a professional niche. Several students perceived themselves as translators or liaisons between design and other disciplines, leveraging their hybrid educational backgrounds. Personal motivations were included as ‘jobs’, where students pursued autonomy, self-expression, validation, and the completion of tangible creative work.

Track 3 pains were concentrated around assessment ambiguity and prioritisation of feedback. A particularly salient pain was the experience of assumed foundational knowledge at the conclusion of their first year of study, where students felt the curriculum continued as though they had design foundations they had not yet developed. Several also noted tensions between their previous disciplinary modes of thinking and design thinking approaches, as well as the opportunity cost of committing to a graduate degree without a clear sense of where it would lead professionally. Limited mentorship structures, and the number of eligible graduate-level design electives were additional concerns. Emotional struggles, including fear of failure, a sense of being lost in the research process, and feeling underrecognised, also emerged as notable pain points.

Track 3 students valued the programme’s open culture, the accessibility and expertise of faculty, access to sponsored studios, and the freedom to pursue elective coursework unavailable in their undergraduate programmes. Facilities, including the materials lab and studio workspaces, were consistently praised. Alumni connections and industry relationships were identified as meaningful programme assets.

3.3 Faculty

Faculty jobs centred on balancing the demands of teaching, research, and service simultaneously. In the classroom, faculty worked to meet students at varied experience levels, provide meaningful feedback, critique work, and support students through personal and academic challenges while building their

creative confidence. Beyond individual courses, faculty were responsible for coordinating content and sequencing across the curriculum, balancing track-specific needs with industry sponsor requirements, and integrating emerging technologies while reinforcing design fundamentals. Faculty also maintained active research and professional engagement responsibilities, including conducting and disseminating their scholarly work, connecting students to industry professionals. Faculty also played a broader institutional role, collaborating across departments, managing admissions, and engaging in interdisciplinary opportunities within the college and university.

Faculty pains included challenges of serving a diverse student body within a constrained teaching environment. Managing students with significantly different skill levels and prior knowledge baselines made it difficult to calibrate expectations and pacing across the cohort. Faculty also noted the sensitivity required when providing honest, critical feedback. The students' varying emotional readiness and mental health needs sometimes made direct critique feel risky, creating tension between the desire to push students and the need to support them. Faculty also navigated competing research and teaching demands and uncertainty about how and when to integrate emerging technologies such as AI into their courses.

Faculty gains reflected high satisfaction with observable student outcomes such as strong visualisation, communication skills, problem-framing and problem-solving competencies. The faculty also valued the broader impact of the programme on students' understanding of how design relates to societal and industry trends. On the professional and community side, gains included meaningful networking and industry relationships, opportunities to bring in speakers from other universities, connections with industry professionals through sponsored projects, and an engaged alumni community that remained connected to the programme. The faculty also valued collegial interactions and active classroom discussions as part of a supportive departmental culture.

3.4 Alumni Survey Findings

Respondents graduated between 2019 and 2022 and had an average of 5.5 years since graduation at the time of participation. Alumni 'jobs' centred around three motivations. Career transition was the dominant driver for Track 3 alumni, who sought to pivot into design-adjacent roles by developing design skill sets and professional identities. Track 2 alumni were motivated by skill advancement and disciplinary exploration, particularly the desire to deepen their design thinking and transition into adjacent fields such as UX. Across both tracks, alumni sought professional contacts, industry exposure, and a credential that would make them more competitive in the job market.

Track 3 alumni described a persistent technical skills gap, particularly in sketching, SolidWorks, and digital rendering, that created a prolonged catch-up dynamic throughout the programme. Several noted that too much time spent in the problem-framing phase limited their ability to develop portfolio-ready work. Track 2 alumni reported fewer structural pains but cited weak career transition support, including limited guidance around job searching, portfolio development, and pathways into specific roles such as consulting.

The most consistently cited gain across both tracks was the development of a process-oriented design thinking framework that alumni continued to apply in their professional work regardless of role or industry. Track 2 alumni also reported meaningful growth in professional confidence and a smooth transition into UX design. Track 3 alumni valued the research mindset and the ability to blend their prior disciplinary knowledge with design approaches, giving them a distinctive perspective in the workplace. Across both tracks, alumni cited the collaborative programme culture, faculty relationships, access to facilities and sponsored projects, affordability, and teaching assistant opportunities as significant gains. Likert ratings confirmed the strongest agreement on research capability development and leadership preparation, with more variation on career transition support and network expansion.

4 DISCUSSION & CONCLUSIONS

4.1 Different Motivations Across Entry Points

The findings show that the MID degree serves distinct functions for students depending on their prior education and careers. The programme does not deliver a single value proposition, and what students gain depends significantly on where they start, what they expect, and where they are headed professionally. For students entering with an undergraduate degree in industrial design (Track 2), motivations are centred less on identity formation and more on refinement and validation. These students sought deeper technical execution, stronger portfolios, greater exposure to professional contexts, and clearer pathways into competitive or adjacent roles. Their concerns were about becoming more

competitive, more specialised, and more prepared. Concerns were often tied to perceptions of rigor, industry relevance, and the balance between research-oriented work and tangible product development. Importantly, Track 2 alumni reflections seem to contradict these frustrations. While some current students perceived research emphasis as limiting their making time, alumni frequently identified the programme's process-driven and research-oriented mindset as a professional asset. This shift suggests that certain programme benefits may only become fully evident after students enter practice. The contrast highlights how a value perception may change over time, where elements experienced as constraint during instruction may later function as sources of professional differentiation and adaptability.

For students entering from non-design disciplines (Track 3), the MID serves a more foundational role. Their motivations centred on acquiring a comprehensive design skill set, forming a professional identity within design, and translating prior disciplinary expertise into a new domain. Tracey and Hutchinson (2018) observed that academic discourse has remained largely silent on professional identity development in design education[14]. This absence is significant given that many graduate students, especially those from Track 3, seek validation, community, and clarity about their role in the design field.

Much like Track 2 students who question the research focus while in the programme but come to value it in retrospect, current Track 3 students frequently described feeling disoriented by the research process, particularly when foundational design skills felt underdeveloped. Track 3 alumni, however, consistently identified research capability as one of the most transferable and professionally differentiating aspects of their education. This parallel pattern across both tracks suggests that the research emphasis may be pedagogically sound but insufficiently scaffolded for students who are still developing foundational design fluency.

4.2 Faculty Role in a Two-Track System

Faculty perspectives describe the structural complexity of delivering a single degree across heterogeneous student populations. Faculty are tasked with balancing rigor and support, calibrating critique across varied skill levels, maintaining research productivity, and responding to rapidly evolving technological and professional landscapes.

An interesting finding is the shared concern around critique. Students across tracks expressed a desire for more direct and candid feedback. Simultaneously, faculty described the pedagogical challenge of delivering direct critique within a small cohort context where students vary widely in confidence, experience, and readiness for critical feedback. The programme's culture of support, frequently cited as a gain, may influence how rigor is experienced and interpreted by students. Faculty also act as a bridge between academic design and industry expectations. Their professional networks, sponsored projects, and research engagement serve as a connection between the academy and practice.

4.3 Implications for Graduate Industrial Design Education

This study is limited by the small sample size at a single institution. The workshop included a relatively small cohort of current students and faculty, which constrains the generalisability of the findings. While alumni respondents were several years removed from the programme, allowing for more reflective assessment of long-term professional impact, the limited number of responses means their perspectives should be interpreted as illustrative rather than representative. The findings function as an exploratory analysis rather than a comprehensive evaluation of graduate industrial design education. Future research across multiple institutions and larger student samples would strengthen the transferability of these insights.

Considering current student, alumni, and faculty perspectives, the findings highlight three distinct opportunities for curricular development. First, differentiated onboarding for Track 3 students could address foundational knowledge gaps early, without conflating Track 3 development goals with those of Track 2. Second, a more explicit research-to-practice bridge which may help students understand while in the programme why the research orientation matters for their specific career trajectories. This may also reduce the frustration current Track 3 students experience and accelerate the retrospective value that the alumni report. Third, structured and track-specific career transition support, including portfolio guidance, industry connections, and pathways to non-traditional design roles, would address one of the most consistent pains across both current students and alumni.

Using the Value Proposition Canvas framework proved effective as a multi-stakeholder assessment tool, surfacing not only what students and faculty value but where expectations and programme structures are not yet aligned. Programmes seeking to strengthen recruitment, retention, and curriculum design may find it a productive starting point for structured reflection, particularly where a single programme serves meaningfully different learner populations.

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HUMAN-CENTERED DESIGN FOR ENVIRONMENTAL EDUCATION: CO-CREATING PLAYFUL TOOLS TO ADDRESS TEXTILE WASTE IN CAMPANA-ALTAMIRA

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ABSTRACT

Fast-fashion textile waste has become an increasingly pressing environmental issue, particularly in vulnerable urban contexts where waste-management systems are limited. In the Campana Altamira Initiative in Monterrey (Mexico), textile residues constitute up to 40% of the waste found in the Arroyo Seco, a situation intensified by structural constraints, local consumption habits and deficiencies in municipal waste-collection infrastructure. Responding to this challenge, this study conducted by undergraduate design students at Tecnológico de Monterrey in Mexico presents the development and implementation of a Human Centred Design (HCD) strategy aimed at reducing the environmental impact of textile waste while promoting sustainable education among children through an interactive community-based product. The research employed ethnographic observations, user analysis and semi-structured interviews to examine the social and cultural dynamics of the community, with a particular focus on children and young people who participate in activities at the community hub “El Oasis”. These insights informed the design of a series of four educational workshops that combine principles of education for sustainable development, hands-on activities with recycled materials, and an interactive pedagogical set of games. The games were designed to support children’s cognitive, psychomotor, and socio-emotional development, introducing key concepts related to water conservation, waste management, and textile reuse through collaborative and play-based learning activities. This work details the students’ design process, highlighting how participatory methods and contextual research shaped the development of both the workshops and the interactive set of games.

Keywords: Higher education, innovative education, design for social impact, environmental education, Human-Centred Design

1 INTRODUCTION

Fast-fashion textile waste has become an increasingly pressing environmental issue. Since its rise, the textile industry and the waste it generates have become increasingly important. The textile industry pollutes the land and water, not only with the chemicals used in the garment manufacturing process but also with the amount of waste left behind after use [1]. This industry utilises enormous amounts of water, as it is responsible for the consumption of about 20% of industrial wastewater worldwide. [2] In addition, the short lifespan of fast fashion clothing and the lack of discarding and recycling policies leads to the formation of massive textile waste landfills, which can take decades to decompose [3]. Moreover, the excessive amount of textile waste and the lack of care when disposing of it often results in accumulation in nearby bodies of water due to pollution from runoff, particularly, this phenomenon is common in vulnerable urban contexts where waste-management systems and policies are limited.

In the Campana Altamira Initiative (CAI) in Monterrey, Mexico, textile residues constitute up to 40% of the waste found in the Arroyo Seco (Dry Creek), a situation intensified by structural constraints, poor policies, local consumption habits and deficiencies in municipal waste-collection infrastructure [4]. This initiative is a community-based effort among a territory of fourteen neighbourhoods that seeks to sustainably improve the quality of life for the residents of the area [5]. This social and economically marginalised community is located a few kilometres away from Tecnológico de Monterrey and they are both connected by the path of the Arroyo Seco (Dry Creek) but presenting a strong contrast between the

two territories. Most households in the area typically lack stable infrastructure and basic services such as electricity and running water. This area is home to around 19,543 residents, of which around 33.87% are minors [6]. Despite the great challenges that the inhabitants face, Campana-Altamira is an engaged and participatory community that is constantly seeking to improve their living conditions [7].

Responding to this textile waste collection challenge, this study conducted by undergraduate design students at Tecnológico de Monterrey in Mexico presents the development and implementation of a Human Centred Design (HCD) [8] strategy aimed at reducing the environmental impact of textile waste while promoting sustainable education among children through an interactive community-based product. The research employed ethnographic observations, user analysis and intercept interviews to examine the social and cultural dynamics of the community around water use practices and textile waste management, with a particular focus on children and young people who participate in activities at the community hub “El Oasis” [9]. These insights informed the design of a series of four educational workshops that combine principles of education for sustainable development, hands-on activities with recycled materials, and an interactive pedagogical set of games. The purpose of designing games was to support children’s cognitive, psychomotor and socio-emotional development, while introducing key concepts related to water conservation, waste management and textile reuse through collaborative and play-based learning activities. Using toys and play as a conduit for education encourages children’s brain development. It promotes exploration and curiosity and makes the education process not as tedious for the children [10]. Children’s natural curiosity allows them to experiment, explore, problem solve, and stay engaged in meaningful activities, developing critical thinking skills through problem-solving [11]. This work details the design process, highlighting how HCD and participatory methods [12] shaped the development of both the workshops and the interactive set of games aimed to raise awareness among the residents of Campana-Altamira.

When discussing the impact of fast fashion, although most consumers claim to be knowledgeable about sustainability-related issues, most of them lack precise and accurate knowledge on aspects linked to production, supply chain, materials, recycling, or re-use of fashion items [13], [14], [15] as part of an awareness that seeks to address the textile waste problem at its root, by teaching the children about the importance of water conservation and textile waste management [16],[17].

2 METHODOLOGIES

The project was developed by two students coursing the 7th semester of the Design bachelor at Tecnológico de Monterrey in Mexico who conducted the research employing participatory methods to design educational game-based solutions to tackle the need for sustainable education among the children from Campana-Altamira, presented in a series of workshops. The use and adaptation of HCD was crucial to develop suitable results along with community members, allowing the design students to prioritise respect and empathy [18].

The individuals considered for this research were mostly young boys and girls between the ages of 8 and 12 coursing basic education, living in the Campana-Altamira community in the vicinity of the Arroyo Seco (Dry Creek) increasing their condition of vulnerability; with a particular focus on children and young people who participate in activities at the community space “El Oasis”.

Figure 1 shows the Design process followed for the project: during the first stage (1) *Discovery* on site ethnographic observations and semi-structured interviews were conducted to understand the perceptions and the level of knowledge of the community about water conservation practices and textile waste management [8]. During the second stage (2) *Define*, specific needs were identified by analysing the ethnographic results and at the same time, gaps in sustainable education and waste management were framed.

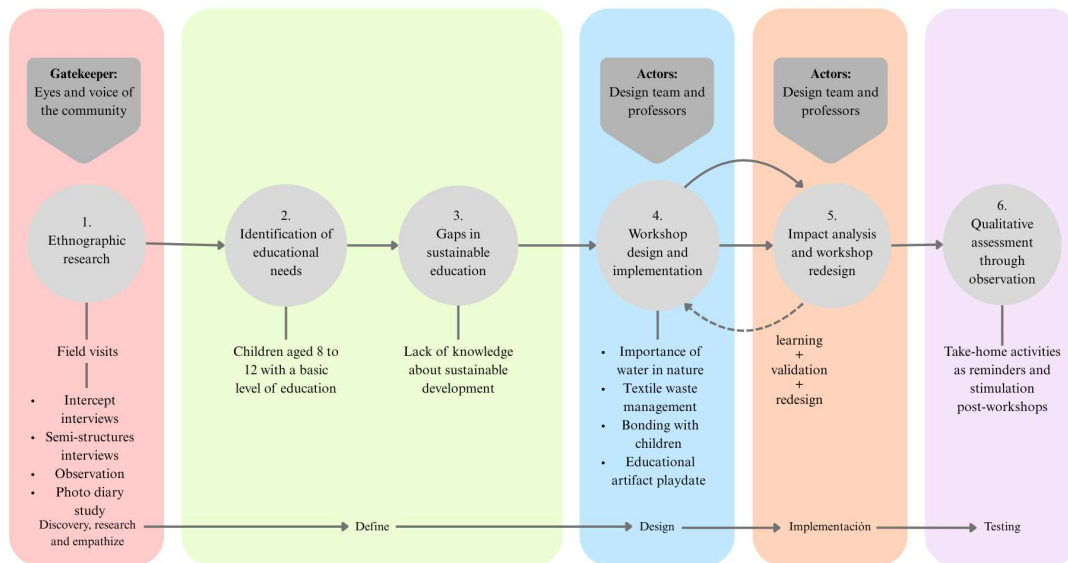


Figure 1. Human-Centred Design (HCD) process diagram. Adapted from established HCD frameworks; author's own elaboration

At the (3) *Design* stage an extensive sustainable education practices literature review was carried out to design two workshops that were implemented with the participating kids at El Oasis to address the identified challenges. During the (4) *Testing* stage (workshops 1 and 2) observations and intercept interviews were carried out with the children to understand their perspectives and opinions. Ethnographic information was analysed using an affinity diagram to categorise the findings and identify key patterns from previous experiences. After that, an iteration of the workshops occurred during stage 4, leading to a more game-based activities orientation. During the last stage (5) *Implementation* workshops 3 and 4 were prototyped and tested considering the previews of learnings and including the use of the set of games as a learning tool. As an additional instrument, a colouring activity sheet was designed to observe the children's learning outcomes.

As shown in Table 1, the first two-hour workshop, a brief presentation about the importance of water in nature was given by four instructors. Afterwards, the participants were given around one hour to complete an activity involving recycling materials. The instructors were always available to help and answer any questions. The second workshop took place a week after the first workshop. A brief presentation about textile waste management was given, and the participants had around an hour to complete an activity that used recycled materials to illustrate the information given in the workshop.

The third workshop was a presentation of an illustrated story developed by design students to showcase how waste disposal in rivers and bodies of water can affect the environment and the creatures living in it. After the presentation, activity sheets such as mazes, connecting dots, and character drawings were given to bond with the children while promoting recycling as a community. The activities were designed with the intention of being continued at home. These served as a reminder to keep recycling and conserving water, even after the workshop is done.

The fourth workshop was the presentation of the educational games the students developed based on the information gathered through observing and talking with the children in the previous workshops. These games are designed to support children's cognitive, psychomotor, and socio-emotional development, introducing key concepts related to water conservation, waste management, and textile reuse through collaborative and play-based learning dynamics [11]. Through observation of the participants interacting and participating in the games, we could see an increase in the interest in water conservation and waste management.

Table 1. Workshops

Workshop	Main objective	Additional Resources	Outcome
Small actions today can lead to big changes in the future: Nature & Water	Learn about the water bodies, their importance, and care.	Videos on the topics, and plastic bottles to make plant pots.	Significance of water conservation and actions at home that can help preserve it.
Did you know your clothes can pollute water?	Understanding textiles, textile pollution, and how to recycle clothing.	Videos on the topics, and fabric cases for hand painting.	Importance of sustainable development and preventing textile pollution.
The Water Guardians	Bond with children through games and drawings promoting recycling.	Activity sheets such as mazes, connecting dots, and character drawings.	Importance of recycling as a community.
La Juegateca	Learn about waste sorting, recycling, and sustainable development.	Artifact featuring 5 mini games.	Cooperation among children, coexistence, and learning together.

3 RESULTS

Semi-structured interviews were carried out before and after the intervention, with the help of supporting drawing and colouring activities to gain an understanding of the children's perception of textile waste and water use in their community [8]. Results show a clear difference in the responses before and after the intervention, as the children started incorporating textile waste into their responses when asked what main types of trash are found in the creek and how to dispose of them correctly. There is also a difference in the responses received that refer to recycling, as more children incorporate reusing textiles to support their community, as evidenced in the colouring activities implemented.



Figure 2. Participatory Design Community Intervention

Findings from pre- and post-intervention community perception assessments suggest that integrating participatory design with environmental education can foster meaningful shifts in awareness and

behaviour. The study contributes to ongoing discussions in design education by demonstrating how student-led, human-centred interventions can generate social and environmental value in underserved urban communities.

The artifact consists of five games made with HCD that each tackle different important developmental areas for the children: including a cooperation game, an executive function game, a fine motor skill game, a spatial awareness and cognition game, and a hand-eye coordination game. All the games used topics of recycling and water conservation, teaching important lessons while being used to develop children's social and motor skills.

4 DISCUSSION AND CONCLUSION

The findings of this study confirm existing research suggesting that awareness of sustainability does not necessarily translate into informed action. Pre-intervention interviews revealed that community members possessed a general understanding of textile waste accumulation but lacked specific knowledge regarding disposal and recycling practices, aligning with consumer awareness gaps [12]. This disengagement between general concern and practical knowledge became a key driver for the design of the workshops, reinforcing the need for targeted environmental education in vulnerable urban contexts.

Observations throughout the workshops indicate that children initially recognised the importance of water conservation but did not perceive textile waste as a significant environmental threat. Following the intervention, participants began incorporating textile waste into their descriptions of pollution in the Arroyo Seco (Dry Creek) and suggesting reuse practices within their households. This shift supports the idea that children can act as agents of change when provided with structured sustainability education [14], [17]. The effectiveness of the game-based approach further supports research on playful learning as a trigger for engagement and cognitive development [10], [11]. The transition from presentation-based sessions to interactive storytelling and collaborative games resulted in increased participation and motivation. The designed artefact, integrating cooperation, executive function and motor skill development, demonstrates how educational tools can simultaneously strengthen environmental understanding and developmental competencies [16].

At a systemic level, textile waste in Campana–Altamira remains embedded in broader industrial; infrastructural and policy challenges identified in prior environmental studies [1], [3] and local documentation [4],[6]. Educational interventions alone cannot resolve these structural constraints. However, the application of Human-Centred Design and participatory methods [12], [18] illustrates how design can function as a catalyst within complex systems, translating contextual research into accessible, community-responsive strategies.

In conclusion, this study contributes to product design education by evidencing that student-led, human-centred interventions can generate tangible social and environmental value. Grounded in Research by Design approaches [15], the project demonstrates how academic initiatives can bridge universities and vulnerable communities while fostering environmental awareness and collective responsibility. Although systemic change requires multi-level action, empowering younger generations through participatory and playful design represents a viable and replicable pathway toward long-term cultural transformation. Next steps for this research would encompass the pursuit of strategies to improve the waste management infrastructure of Campana–Altamira, which can only be achieved by the collaboration between the government, academia, and the community.

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AI-ENHANCED GAMIFICATION IN ERP SIMULATION: THE MxREP AND VIRTUAL PLANT APPROACH

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ABSTRACT

The growth of Artificial Intelligence (AI) has profoundly impacted educational innovation, particularly in teaching complex, integrated industrial concepts such as Enterprise Resource Planning (ERP) and supply chain dynamics, which traditionally require extensive practical experience. Tecnologico de Monterrey and Mälardalen University jointly developed an AI-enhanced gamified simulation infrastructure centred on the MxREP ERP process simulator. As equal partners in design, implementation, and evaluation, the two institutions built a system capable of operating across their differing curricular structures. The simulator models assembly processes within a fictional manufacturer and incorporates Virtual Reality and Augmented Reality modules (collectively referred to as the Virtual Plant) to capture rich, granular data on student behaviour, including assembly sequences, task completion times, and demand-forecasting decisions. The collaboration's core objective is to transform simulation data into actionable learning intelligence. AI serves a dual function: predictive modelling, exemplified by refining demand-prediction algorithms and anticipating quality failures; and providing a personalised learning experience by comparing student performance against expert benchmarks. The embedded AI provides adaptive feedback, suggesting optimal strategies and highlighting subtle decision signals frequently overlooked in traditional instruction. The system evaluates the application of both disciplinary and transversal competencies during decision-making. The research validates that AI-enhanced gamification, coupled with the Virtual Plant simulation, improves undergraduate engineering learning outcomes by transforming a passive tool into a dynamic, adaptive resource that bridges theoretical knowledge with the practical development of professional competencies.

Keywords: Gamification, ERP simulation, artificial intelligence, extended reality, engineering education

1 INTRODUCTION

The learning styles of engineering students born after 2000 differ substantially from those of previous generations. Where earlier cohorts developed competencies through textbooks, physical laboratories, and proximity to industry-experienced instructors, today's students arrive with high expectations for immersive, technology-mediated engagement. This reality places new demands on instructional design, particularly in Industrial and Systems Engineering (ISE), where core concepts such as Enterprise Resource Planning, supply chain optimisation, quality control, and manufacturing dynamics have traditionally required hands-on experience in industrial facilities to be learned effectively.

The global pandemic accelerated the search for credible alternatives. In response to this shared challenge, this research collaboration gave rise to the MxREP ERP process simulator, extended through XR modules into what the team terms the Virtual Plant. The environment was designed from the outset to function across both institutions' curricula, within Tecnologico de Monterrey's TEC21 challenge-based model and Mälardalen University's engineering design programmes, and this dual-institution scope shaped its modular architecture. Student teams manage a fictional manufacturing firm, configure production lines, manage inventory, respond to demand variability, and assemble physical products in VR, while competing on real-time financial dashboards.

The present research emerges from a sustained academic collaboration between Tecnologico de Monterrey (TEC) and Mälardalen University (MDU), who have jointly developed the simulation

architecture, lesson design methodology, and AI integration strategy described in this paper. Building on the central argument that the true value of simulation is not the experience it provides, but the rich behavioural data it generates, and that AI is the mechanism that transforms those data from records of outcome into signals of process. Consequently, this paper describes the architecture of that integration, its shared pedagogical rationale, and its observed effects on competency development across undergraduate engineering cohorts at both institutions.

2 STATE OF THE ART

2.1 Gamification in Engineering Education

Gamification is defined as the application of game-thinking and game mechanics to engage users and solve problems [1][2][3]. Within engineering education, it is important to distinguish between gamification, serious games, and game-based learning. Gamification incorporates game design elements into educational contexts to enhance engagement; serious games are technology-driven designs with primary purposes beyond entertainment; and game-based learning uses existing games as pedagogical vehicles.

The research team's experience, accumulated over more than fifteen years of implementation at TEC, identifies three categories of gamification application: Hard GameBoards (board games and physical devices), Soft GameBoards (digital platforms including simulators and puzzle-based tools), and XR GameBoards (activities based on virtual, augmented, and mixed reality). Survey data collected between 2020 and 2023 across project management cohorts confirmed that 91% of students engage in gaming and 83% favour gamified classroom activities, validating the motivational premise of this instructional approach.

The design of effective gamification activities is guided by three critical variables: Competency Development, Learning, and Engagement. This framework is operationalised as the Wow Experience equation: $\text{Wow} = (\text{Activity} + \text{Creativity} + \text{Gamification}) \wedge \text{Emerging Technologies}$ [4]. The equation captures the amplifying role of technology: without instructional creativity and targeted activity design, technology alone does not produce learning.

2.2 Digital Twins and Virtual Laboratories in Engineering Education

Virtual laboratories have emerged as a credible alternative to physical industrial access following the pandemic's disruptions. The Virtual Plant constitutes a high-fidelity Digital Twin of an automotive assembly environment, jointly developed and deployed across both institutions. It enables students to interact with causal industrial logic, where inventory levels affect throughput and quality deviations propagate to customer outcomes, without physical or financial risk.

Previous work by this research group has demonstrated the pedagogical value of integrating immersive reality into project management education. The TEC21 Car Assembly activity, based on a Meccano Buggy model, teaches CPM and PERT network optimisation through a competitive assembly challenge. The MxREP simulator extends this logic into ERP territory, requiring teams to configure production parameters, respond to demand signals, and manage supply chain decisions with direct financial consequences visible on shared dashboards [5][6].

In parallel, Berglund's work [7][8] on the adoption of Extended Reality (XR) in engineering and product design education highlights both its pedagogical potential and the structural constraints that hinder integration, particularly the resource intensity, curriculum misalignment, and added cognitive and technical load associated with standalone XR implementations. The present collaboration addresses these challenges by embedding XR within a curriculum-aligned simulation infrastructure, making it an integrated learning mechanism that supports rather than competes with existing learning outcomes.

2.3 AI in Educational Environments

There is a growing trend of utilising AI as an integrated and more sophisticated AI tool when preparing and designing learning environments [9]. Still, AI has been applied in educational contexts through two primary mechanisms: adaptive content delivery, which adjusts instructional material based on performance signals, and predictive analytics, which identifies students at risk of poor outcomes based on behavioural patterns. The latter has shown promise in STEM contexts, where early indicators of misconception, such as a persistent bias in demand forecasting, would otherwise remain invisible until formal assessment.

The present work extends this logic to operational decision data generated within a simulated industrial environment. Unlike Learning Management System interaction data, simulation behavioural data captures the reasoning process embedded in decision sequences, providing a qualitatively richer signal for both prediction and personalisation [10].

3 METHODOLOGIES

3.1 System Architecture

The MxREP simulator functions as a multi-user ERP environment in which student teams assume managerial roles within a fictional automotive manufacturer. Teams configure production lines, manage inventory and procurement, respond to demand variability, and compete on financial performance metrics displayed through real-time dashboards. The competitive structure, which includes inter-team leaderboards, production rankings, and revenue optimisation objectives, provides motivational scaffolding without displacing academic objectives.

The Virtual Plant extends this environment through XR modules in which students perform embodied assembly tasks, develop CPM and PERT networks, and interact with process simulations, including a robotic Voluntary Milking System (VMS) developed with DeLaval at the CAETEC agricultural research facility [10]. These modules are not a visualisation supplement; they are integrated into the ERP environment's operational decision-making structure, so that assembly efficiency directly affects simulated financial outcomes.

The international collaboration between TEC and MDU was foundational to the system's design, not a later addition. Both institutions contributed to lesson conceptualisation, modular architecture decisions, and cross-institutional pilot testing. This joint ownership produced an environment that is curriculum-adaptable rather than tied to any single institutional model, supporting deployment across the Industrial Engineering, Mechanical Engineering, Mechatronics, Data Science, and Business cohorts of both universities.

3.2 Data Capture

Every student interaction generates structured log data. In the ERP modules, this includes inventory configuration decisions, demand-forecasting inputs, and supply-chain parameter adjustments. In the XR assembly modules, it captures the sequence of steps, the task latency, and the deviation from optimal assembly paths.

In the agricultural simulation, variables include cow health indicators, milking cycle data, and breeding decisions. All data streams are stored in relational databases that serve as the foundation for AI processing [10]. Teachers configure the simulator to align with the lessons' specific objectives.

A quality control lesson emphasises statistical process control and the traction subsystem of a Meccano F1 device, which is a project evaluation lesson that targets the creation of an economic dashboard resulting from investment decisions. This configurable structure means that each lesson generates a distinct data profile tailored to the competencies under development.

3.3 AI Processing Pipeline

AI integration follows a three-stage pipeline. In the first stage, real-time data from XR and ERP interactions is extracted and normalised. In the second stage, machine learning models compare individual student performance trajectories against expert-defined operational benchmarks and against aggregated historical performance from prior cohorts. This comparison reveals behavioural signals that precede poor outcomes, such as persistent assembly sequence errors or systematic overestimation of demand. In the third stage, the system generates personalised feedback for students and flags emerging patterns for instructor review.

A prototype conversational tutor, currently under evaluation, responds to student queries about parameter configuration using context derived from accumulated session data. This component is designed to provide on-demand scaffolding without requiring instructor intervention for routine clarifications, freeing the instructor's attention for complex pedagogical decisions.

3.4 Educational Design Constraints

All lessons are designed under three explicit constraints: conceptual mastery of disciplinary content, development of transversal competencies including systemic thinking and decision-making under uncertainty, and maintenance of sustained engagement. These constraints correspond directly to the three variables of the Wow Experience framework. The instructor's role within this model shifts from primary content deliverer to interpreter of AI-generated insight, determining which flagged patterns warrant direct intervention and which represent productive struggle.

3.5 Application of the MxREP and virtual plant

Over the past 5 years, we have implemented the virtual plant an average of 9 times per year in different learning units (UF) within TEC. Every UF has two groups, each group has an average of 31 students. Improvements have been implemented in the last 3 years, such as changes in the distribution centres for the logistics module and the additional products that can be assembled (e.g., drones), which have increased the ability to influence a greater number of students. 1

Since last semester (August - December 2025), it has been possible to share the simulator as it is hosted on Roblox. For the present contribution, the results of the last teaching units of the Industrial and Systems Engineering program are analysed, involving two groups of 26 (Group #1) and 29 (Group #2) students taking the UF IN3001B Design of a Smart Organisation. Both groups had to solve a problem-based scenario focused on designing a drone manufacturing plant, requiring them to learn to calculate line capacity and to design the plant layout, including the total number of machines and employees. The IN3001B is the capstone unit in the Industrial and Systems program, and the challenge for these students is to design a smart manufacturing system for drone assembly.

A pre-test was developed, consisting of 20 questions randomly selected from a pool of 50. Subsequently, the students completed the entire exercise, which included hands-on practice with physical drones, followed by use of the simulator and access to the virtual and augmented reality lessons. The lesson ended with a post-test also consisting of 20 questions randomly assigned from a pool of 50 questions to minimise the risk of copying or identical exams.

4 RESULTS AND DISCUSSION

4.1 From Outcome Monitoring to Behavioural Prediction

The most practically significant outcome of AI integration was the shift from post-hoc performance review to real-time behavioural monitoring. In prior simulator implementations, instructors could evaluate teams only through final financial outcomes. The AI layer made it possible to identify, for instance, that a team's end-of-session inventory failure was preceded by a systematic pattern of demand overestimation visible in the first third of the session, well before any financial consequence had materialised. Instructors reported that this early signal allowed them to redirect student attention before misconceptions became entrenched.

This shift has direct implications for instructional practice. Rather than diagnosing learning problems after the fact, instructors can intervene at the moment of misconception. The system thus functions as a distributed diagnostic tool: the AI processes data that exceeds any individual instructor's capacity for attention and surfaces the subset of signals that require human pedagogical response.

4.2 Competency Assessment

The AI-enhanced system enabled evaluation of both disciplinary and transversal competencies. Disciplinary competencies assessed included demand-forecasting accuracy, application of statistical process control, CPM/PERT network optimisation, and supply-chain configuration. Transversal competencies, including decision-making under uncertainty, team coordination, and systemic risk analysis, were evaluated through behavioural pathway analysis.

The system could distinguish between teams that achieved good outcomes through structured reasoning and those that arrived at similar scores through trial-and-error iteration, a distinction invisible to outcome-only assessment. This granularity is particularly relevant in competency-based educational models such as TEC21, which require evidence of the reasoning process rather than outcome performance alone.

Qualitative observations across cohorts indicated improved student confidence in interpreting industrial data dashboards and greater willingness to iterate on complex problems when feedback was specific and timely rather than deferred to end-of-session review. Formal assessment data comparing cohorts with and without AI-enhanced feedback is currently being collected and will be reported in subsequent work.

4.3 Scalability and Cross-Institutional Transfer

The cloud-based architecture of the Virtual Plant allowed consistent deployment across both institutions without requiring duplication of local laboratory infrastructure. Students at MDU and TEC engage with the same simulation environment and data pipeline, enabling genuine cross-institutional comparison of competency development. The parallel deployment has also stress-tested the system's modularity: differences in curricular structure, academic calendar, and disciplinary emphasis between the two universities required the architecture to flex without losing analytical coherence, and on that count, it has performed well.

The agricultural VMS simulation is a notable example of this adaptability. Data from real DeLaval robotic milking operations at CAETEC was integrated into the simulation environment, allowing AI algorithms to process cow health and milk quality variables that students must interpret to make breeding and milking cycle decisions [10]. This cross-domain extension confirms the generalisability of the AI integration architecture beyond its original manufacturing context.

4.4 Application of the MxREP and Virtual Plant Approach

The statistical results are shown by applying a pre-test on the knowledge of line capacity analysis to the students from group #1. As seen in Figure 1A, most of the data are left-skewed with a low average; 8 of 25 students scored 45 out of 100.

After conducting the Simulation Session, the vast majority of students achieved a maximum score of 100 (Figure 1B). A paired t-test was done to analyse the significance of the application. The results show that the hypothesis that traditional learning and learning based on immersive technologies with an ERP component are the same in students is rejected, with a t-value of -9.78, a p-value of 7.58E-10, and 95% of confidence level. This indicates sufficient evidence that traditional learning and immersive learning based on the MxREP simulator, combined with XR technologies in a stressful environment, are not the same.

Furthermore, according to the confidence level, it can be concluded that immersive learning based on the MxREP simulator, combined with XR technologies in a stressful environment, generates better knowledge among students.

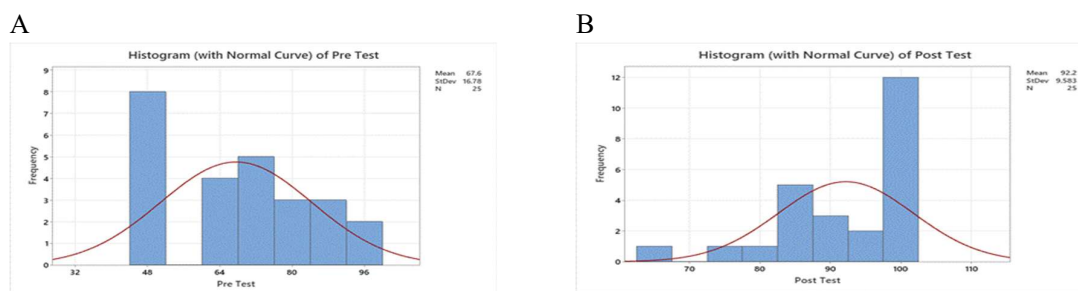


Figure 1. Distribution comparison between Pre (A) and Post Test (B)

5 CONCLUSIONS

Integrating AI directly into a gamified Digital Twin environment can significantly enhance the pedagogical information available to engineering educators. The core innovation lies in the system's capacity to transcend traditional outcome-based assessment. By meticulously converting students' granular simulation interaction logs into sophisticated behavioural prediction models, the framework redefines assessment. It shifts the focus from merely evaluating what products or results students generated to a deeper analysis of how they reasoned, made choices, and navigated complex systemic constraints. The development and validation of the Virtual Plant ecosystem, which hosts the AI-enhanced gamification, is a testament to sustained and equal collaboration between TEC and MDU. This partnership was foundational, ensuring the resulting architecture possessed exceptional scalability and institutional neutrality; this way, it can serve the distinct pedagogical needs, programme structures, and educational traditions of both institutions with parity.

While the preliminary results are highly promising, a crucial and acknowledged limitation of the current study is the systematic absence of a fully controlled, large-scale quantitative assessment. Addressing

this gap constitutes the central focus of current and ongoing research efforts. Future development priorities are structured around three core pillars: (1) achieving more granular, individual-level behavioural modelling to identify and address student-specific misconceptions in real-time; (2) establishing formalised, quantitative cross-institutional competency benchmarks that allow for direct, objective comparison of student performance across TEC and MDU; and (3) extending the validated predictive architecture to encompass additional critical simulation domains, including complex sustainable energy systems design, smart logistics and supply chain optimisation.

Ultimately, the findings reinforce two essential and immutable pedagogical principles. First, gamification itself does not generate knowledge in isolation; true, durable learning arises from the careful, meticulous design of activities that strategically harness core game mechanics (e.g., scoring, badges, rapid feedback loops) to directly support explicit, predetermined learning objectives. Second, AI is not a substitute for the irreplaceable expertise of the instructor. Rather, AI functions as a powerful force multiplier, exponentially increasing the instructor's diagnostic capacity by providing deep, real-time insights into student reasoning processes that are otherwise invisible. The integration of these two principles represents the enduring and significant contribution of the collaboration between Tecnológico de Monterrey and Mälardalen University.

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FROM CLASSROOM TO CONCEPT: BUILDING AN INCLUSIVE PRODUCT DESIGN STUDIO FOR GRADUATE STUDENTS

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ABSTRACT

The following paper explores the process of planning and leading an inclusive product design studio co-led by Carolina Gill, Professor of Industrial Design at NC State University, and Sara Weir, an Advisory UX Innovation Researcher, focused on accessible design at Lenovo. The studio was conducted as a nine-week project within a graduate level course in the Department of Design with 10 final year master students. Each student was paired with an “accessibility expert” participant who is an individual who self identifies as having a disability and experiences unique accessibility needs. Throughout the semester, the student-participant pairs worked collaboratively to identify a challenge and develop a corresponding design solution, resulting in 10 unique product concepts. The structure of this studio allowed students to gain hands-on knowledge of working with individuals with accessibility needs, experience adapting their research and design methods to meet the needs of diverse end-users, and lessons on accessibility best practices to apply to future projects. Building on the structure and outcomes of the studio, this paper provides a replicable framework for integrating participants lived experiences as a core element of design education. While developed within an industrial design context, the framework can be adapted across disciplines that seek to incorporate inclusive, participatory approaches within project-based learning environments.

This paper will highlight:

- The end-to-end process of planning an inclusive product design studio from idea to final outcomes
- Industry expert guidance on real world applications and benefits for designing inclusive products
- The importance of collaboration across academia, industry and community

Keywords: Designer-user collaboration, inclusive design, lived experience

1 INTRODUCTION

The primary objective of the studio project was to provide students with experience designing for accessibility by partnering directly with participants who identify as having a disability to address real-world challenges. The participants provided expert knowledge of their lived experiences as a central component of the design and research process, fundamentally reshaping how students define problems and develop solutions. The emphasis on lived experiences within this studio highlights a broader opportunity within design education and industry. Individuals with disabilities have a unique but often under recognised skillset. The challenges and obstacles they must overcome on a daily basis to navigate their physical and digital environments make them master problem-solvers [1]. Their mastery comes from their lived experiences of thinking outside the box to identify unconventional solutions, perseverance to be adaptable through setbacks in different situations, and being able to notice minute details [2]. For this reason, companies and organisations are increasing their emphasis on inclusive design and research practices by incorporating individuals with disabilities into their processes [3]. The success of these efforts can be seen today in projects like Google Research’s Project Euphonia which included individuals with hearing and speech impediments to improve voice recognition through open source datasets [4], Microsoft’s line of adaptive accessories that utilised the perspective of individuals with mobility disorders to expand the scope of the project to benefit more users [5], and Ikea’s project ThisAbles which created thirteen accessible furniture add-ons by partnering with a disability nonprofit [6]. These projects are just a few examples that highlight the impact individuals with disabilities can

have on products and services. However, if individuals with disabilities were brought into the design process from the beginning of a project, it would allow these individuals to maximise their impact by not only contributing to testing or data collection but problem identification and solutioning [3]. The studio was created to be a tangible, real-world example of including individuals with disabilities throughout the entire design and research process, from problem identification to concept evaluation.

2 CENTERING LIVED EXPERIENCES AS THE COURSE MOTIVATION

Through collaboration with participants throughout the design process, students develop empathetic design research skills, learn to identify and understand accessibility challenges from the participant's perspective, and create innovative solutions that meaningfully respond to authentic needs. This experience will prepare students to center user needs and design products that meaningfully improve accessibility for diverse populations. By the end of the studio, each student delivered a final concept that demonstrated thoughtful consideration of accessibility, design principles, and innovation. Figure 1 outlines the steps taken to prepare and plan the studio project prior to its initial start.

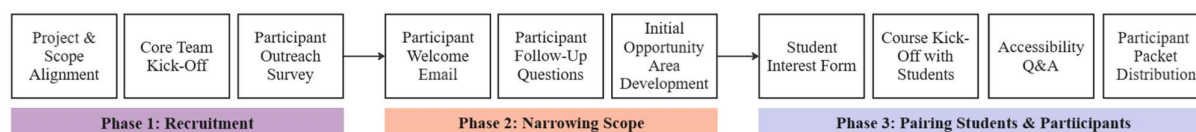


Figure 1. Pre Studio Workflow

2.1 Phase 1: Recruitment

In order for the studio to be successful, we had to find the participants who were willing to be open and share about their lived experiences with a disability. In order to help us find participants, we partnered with ablr. Ablr is a full-service disability inclusion organisation that specialises in accessibility training, education and testing [7]. By partnering with ablr we were able to identify 10 individuals who are blind or visually impaired to participate in the studio.

2.2 Phase 2: Narrowing Scope

In order to set the students and participants up for success, the lead professor and researcher sent out a questionnaire to participants asking them about their disability status, outlook on accessibility, daily routine, challenges, technology use, and products that work and don't work for them. This created a foundational level of knowledge that was shared with the students that they could use as a tool to prepare to work with their participant. The information allowed students to prepare questions, conversation starters and generate initial ideas prior to meeting their participant.

2.3 Phase 3: Pairing Students and Participants

The studio was designed so that each student would work directly with one participant throughout the course of the project. Students and participants were matched based on interests and background. It is found that pairing researchers/designers together with participants to co-create solutions gives equal value to both the perspectives ensuring the participants have the opportunity to contribute meaningfully in all phases of the process [8].

3 INCLUSIVE DESIGN PROCESS

Centring the studio on participant's lived experiences and fostering a 1:1 collaboration between the students and participants was designed to build more meaningful solutions. Research shows that focusing on lived experiences can help identify pain points, explore emotions, improve storytelling, and create deeper engagement with participants [9]. To help establish a meaningful structure for the studio to engage students and participants, we relied on the inclusive design toolkit by the University of Cambridge which categorises design and research activities into three areas: explore, create, and evaluate [10]. Figure 2 illustrates how the studio's structure was created based on these categories.

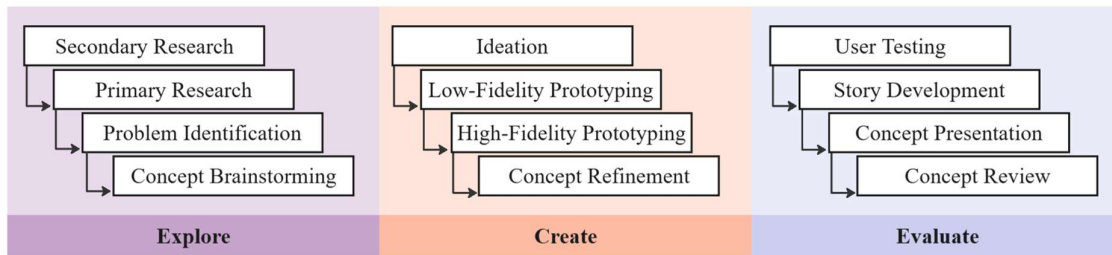


Figure 2. Overview of Process Flow, Based on the Inclusive Design Toolkit [10]

The studio was designed to have three main touchpoints between the students and participants.

1. Meet and Greet – The students and participants met for the first time to get to know one another, establish a working relationship, and identify a problem area.
2. Midway Progress Review – Halfway through the studio, the students and participants met to review their defined problem statement, proposed concept directions, and initial prototypes.
3. Final Concept Presentation – The students presented their final concepts to the participants, and the participants critiqued the concepts based on how well the students addressed their needs.

Table 1 provides a more detailed outline of activities included in the studio over the 9-week project.

Table 1. Implementation of Inclusive Design Process

Steps	Activity
1	Review project materials and prepare questions about accessibility, inclusive design, and working with individuals with disabilities.
2	Participate in an accessibility Q&A session with experts to build confidence and address assumptions or concerns.
3	Present early project thinking and receive participant assignments, including initial problem areas to explore.
4	Draft and refine interview questions, then conduct the first meeting with participants to understand needs, challenges, and opportunities.
5	Synthesise interview findings, identify key themes, and begin defining problem statements and early “how might we” directions.
6	Validate problem statements with participants and conduct secondary research, market reviews, and competitive analyses.
7	Develop and narrow initial concept directions, iterating based on internal feedback from peers and instructors.
8	Strategise and prepare a midway concept presentation for participants, focusing on how to communicate ideas clearly and accessibly.
9	Share midway concepts with participants, gather feedback, and refine ideas with input from design and accessibility professionals.
10	Prepare final presentations, culminating in a final showcase to participants, accessibility reps, faculty, and industry partners.

4 PROCESS REFLECTION

Designing and delivering an inclusive product design studio required navigating a range of practical and emotional challenges. These challenges shaped the structure and execution of the project. The following sections outline key challenges and the strategies used to address them, illustrating how the studio adapted to ensure meaningful collaboration and learning for all participants.

4.1 Limited Budget and Timeline

While we had full control of the content and structure of the studio, working within the constraints of the university restricted the project budget and timeline. The limited timeline resulted in moving the students and participants through the design and research phases quickly. Having more time could have allowed for further exploration and deeper problem identification at the beginning of the project. Additionally having access to a larger project budget could have allowed for more in-person touchpoints with the participants by having the resources to pay for their transportation to and from the university.

4.2 Overcoming Fears and Assumptions

For many students, this studio course was their first time working directly with a person with a disability. As a result, students had many questions about how to politely and effectively communicate and interact with the participants. As a way to overcome these fears and tackle assumptions we set up a Q&A session between the students and two accessibility experts from ablr. The discussion centred around the following questions generated by the students.

1. If someone is just getting started working in the accessibility space, what are the top 3 habits or mindsets that will help them work inclusively from day one?
2. What are the biggest misconceptions people new to accessibility tend to have? How can I avoid them in day-to-day work?
3. What are respectful ways to interact with people with different disabilities (e.g., offering help, language to use/avoid, pacing)?
4. What are simple things I can do to make meetings, emails, chats, and documents more accessible for everyone?
5. How should I offer help respectfully to someone with a disability?

The discussion provided the students with the confidence and information needed to begin the design and research process.

4.3 Communicating Ideas & Concepts

As exemplified above, the design and research process has many iterative rounds of developing and sharing ideas with participants. Traditionally in product design, students share ideas through visual means. This could include brainstorming ideas on post-it, sharing sketches of concepts on paper, and reviewing digital models of prototypes on PCs. Working with the blind and visually impaired community required alternate approaches to sharing and communicating ideas. Rather than relying on visual tools, the students learned to communicate ideas through defining and developing verbal narratives or concept walk throughs, physical prototyping, and focusing on textures and materials earlier in the process to communicate form and function. These methods overall resulted in successful communication between students and participants.

5 CONCLUSIONS

The success of this studio project was built on the equal and iterative collaboration between industry, academia, and the community. The structure, delivery, feedback and evaluation were developed iteratively between the three groups. Figure 3 highlights the successful key takeaways of the studio as a result of this collaboration.

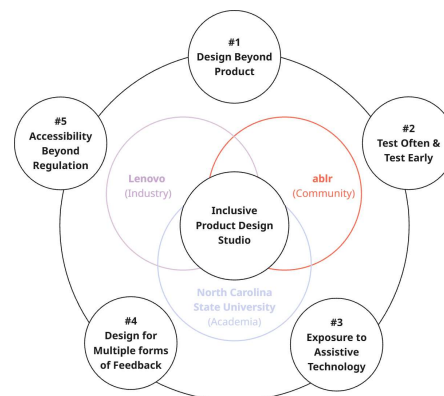


Figure 3. Studio Takeaways

1. Design Beyond Product – When designing inclusive and accessible solutions, students must not only think about the final product concept that the solution will embody but the entire experience, from how the product is purchased, setup, used, and stored. Creating an accessible solution requires thinking about the wholistic product experience.
2. Test Often and Test Early – Creating an iterative cycle of feedback between students and end-users as early in the process as possible allows for deeper exploration of needs which can lead to more

targeted solutions. Receiving feedback early allows students to not only receive the feedback as validation but respond to it and incorporate it into their designs.

3. Exposure to Assistive Technology – Students gained exposure and understanding to different forms of assistive technology including screen readers, text-to-speech, mobility aids, and voice recognition.
4. Design for Multiple Forms of Feedback – Students learned that including both primary and secondary forms of interaction with a product can increase accessibility by providing multiple different ways for users to receive the same information which can include auditory, tactile, haptic, visual, and other sensory cues. This highlights how a solution that works for one user might not work for the next.
5. Accessibility Beyond Regulation – While regulations and guidelines for accessibility are important and a vital consideration in the design process, accessible design must go beyond regulations to think about the specific needs of each individual user.

6 BEYOND THE CLASSROOM

Through the participation and completion of this studio, both students and participants worked collaboratively to identify a problem and design a solution. While these final concept solutions were designed based on a specific participant's needs, these solutions could be widely utilised by the general population as well. This phenomenon is referred to as the curb-cut effect. Today curb-cuts are widely used by cyclists, parents with strollers, travellers with luggage and older individuals but they were originally designed for those who used wheelchairs [11]. Since the installation of the first curb-cut in 1945, there have been many other products that were originally designed for those with disabilities but are used frequently by the wider population. These include fidget spinners originally designed for individuals with anxiety disorders, electric toothbrushes for those with restricted mobility, audiobooks for those who are blind or visually impaired, and speech-to-text for those with limited mobility [12]. These products exemplify how designing for one can have a positive effect for all. A more recent example are the Meta Ray-Bans. While not originally designed for the blind and visually impaired, the incorporation of speech, camera, and AI capabilities created a unique use case that had major impacts on the blind community, allowing users to read text, identify what's in front of them, and receive descriptions of images [13]. Together, these examples highlight how inclusive design not only addresses specific needs but also creates innovations that expand usability, access, and benefits for everyone. Ultimately, we hope this studio serves an example to equip emerging designers, researchers, engineers, and young professionals with the skills, awareness, and confidence needed to create more inclusive products that genuinely reflect the needs of diverse users. Table 2 outlines tips and recommendations for implementing a similar studio framework focused on implementing lived experiences in the design and research process.

Table 2. Tips and Recommendations for Embedding Lived Experiences in Design Education

Steps	Activity
Context	This framework could be utilised in other design fields such as graphic design and architecture that focus on both digital and physical prototyping as well as engineering labs.
Scalability	1:1 pairing may not be available in many instances. The same outcomes can be achieved by pairing groups of students (2-4) with an individual participant. This will allow students to be able to work together and share ideas as well as allowing the participant more involvement in the process.
Location	Having participants that are local allows for the potential of face-to-face interaction which resulted in stronger feedback and interaction between students and participants. For remote participants, pairs met virtually, and students mailed prototypes to the participant to have at their homes during feedback sessions.
Timing	Projects and classes that are operating within shorter timelines may face challenges incorporating as many touchpoints between students and

	participants. Opportunities for prolonged engagement allow for enough time to prep and plan student/participant engagements.
Ability Status	All participants in our studio identified as blind or visually impaired, if involving participants with multiple ability statuses more measures will need to be taken to ensure all participants can actively engage and collaborate with students.

ACKNOWLEDGEMENTS

The successful planning, running, and evaluation of this inclusive product design studio would not be possible without the collaboration from Professor Carolina Gill of North Carolina State University who led and was responsible for the course execution and John Samuel, the Co-Founder and CEO of ablr, who assisted in recruiting participants with disabilities to partner with the students. I look forward to further collaboration together to continue to promote accessibility across universities and corporations.

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DESIGN PROCESS FOR INTEGRATIVE REASONING: A MODEL FOR IDENTIFYING AND ENHANCING COMPETENCIES

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ABSTRACT

This research addresses persistent challenges in design and engineering education and practice, particularly the fragmentation of knowledge in contrast with the complexity of real-world product development problems. Assuming that different modes of thinking can strengthen learning and decision-making processes, the study presents the Integrative Reasoning Model, a circular framework developed to identify and articulate competencies required to address complex problems in product design contexts. The model structures three complementary modes of thought: Design Reasoning, Scientific Reasoning, and Common-Sense, demonstrating how the integration of these perspectives can support more comprehensive approaches to project analysis and development. The research adopts a qualitative and exploratory approach structured through applied workshops conducted in a corporate environment. The activities were carried out within product design departments of a large company in southern Brazil, involving professionals engaged in product development processes. During the workshops, a visual canvas-based tool derived from the proposed model was used to support the identification and discussion of the different modes of thinking present in project decision-making. Results indicate that the model helped make explicit the different cognitive perspectives mobilised during product development processes, enabling participants to identify how design-based, scientific, and everyday experience-based approaches influence project decisions in complex situations. The applications also revealed competencies related to the integration of perspectives, critical reflection, and adaptation in the face of uncertainty. Participant feedback contributed to the refinement of the model and confirmed the usefulness of the canvas as a reflective support tool in professional product design contexts. The study contributes to the field of design by proposing an integrative approach capable of supporting reflection and decision-making processes in product development environments characterised by complexity, interdisciplinarity, and multiple forms of knowledge.

Keywords: Reasoning, design education, modes of thinking, competencies, design process

1 INTRODUCTION

Contemporary organisations face increasingly complex challenges characterised by multiple variables, uncertainty, and interdependencies between technical, social, and economic factors. In this context, approaches based on disciplinary fragmentation are often insufficient to address problems that require the integration of different types of knowledge.

In the field of design and product development, this complexity becomes particularly evident. Product development processes involve the articulation of engineering, technology, user experience, market dynamics, and organisational strategies. As a result, professionals must mobilise different forms of reasoning and competencies to understand problems and develop innovative solutions.

Several authors highlight the role of design as a field capable of integrating multiple perspectives in complex problem-solving processes. Buchanan [1] argues that design connects different areas of knowledge when addressing wicked problems, characterised by ambiguity and the absence of definitive solutions. Similarly, Cross [2] describes design thinking as a specific way of reasoning oriented toward exploring complex problems through iterative cycles of analysis, synthesis, and experimentation.

This research investigates the concept of Integrative Reasoning as an approach aimed at identifying and developing competencies needed to address such complexity. Previous studies introduced the

conceptual framework of Integrative Reasoning, proposing the articulation of scientific reasoning, design reasoning, and common-sense reasoning as complementary modes of thinking [6].

In a later stage of the research, this framework was translated into a visual canvas applied in educational contexts to support project-based learning activities [10]. Results from these applications suggested that making different modes of reasoning explicit can stimulate reflective processes and broaden the understanding of how problems are approached.

However, the need emerged to explore the application of this model in professional environments, particularly in product development contexts where multidisciplinary teams must integrate technical, creative, and experiential knowledge.

Therefore, this article presents the development and application of a circular Integrative Reasoning Model Canvas (IRMC) used in workshops conducted within a product development organisation. The aim of the study is to investigate how this tool can support the identification and articulation of competencies involved in design and innovation processes.

2 THEORETICAL BACKGROUNDS

2.1 Complexity and problem solving

Problems faced by contemporary organisations often exhibit characteristics of complexity and ambiguity. Rittel and Webber [8] introduced the concept of wicked problems to describe situations in which problems cannot be clearly defined and solutions cannot be definitively validated.

Such problems require approaches capable of integrating knowledge from multiple domains. Simon [9] argues that design processes involve transforming existing situations into preferred ones through iterative cycles of analysis and solution generation.

Reports on the future of work indicate that competencies related to complex problem solving, critical thinking, and creativity are increasingly important across professional fields [11]. This reinforces the need for educational and methodological approaches capable of fostering these capabilities.

2.2 Cognitive processes in design

Several scholars have examined the cognitive processes involved in design practice. Cross [2] argues that designers develop particular forms of reasoning oriented toward constructing solutions in open-ended situations.

Lawson [5] describes design as a continuous movement between problem analysis and solution generation, where designers explore possibilities while simultaneously developing an understanding of the problem.

Schön [7] highlights the reflective nature of design practice, emphasising the concept of reflection-in-action, in which professionals develop knowledge through experimentation and iterative learning.

Dorst [3] further emphasises the role of abductive reasoning in design, which enables the exploration of new possibilities by proposing creative hypotheses connecting problems and solutions.

Together, these perspectives suggest that design involves the combination of analytical, creative, and contextual forms of reasoning.

2.3 Integrative Reasoning

Building on these discussions, this research proposes Integrative Reasoning as an approach that articulates different modes of thinking in complex problem-solving processes.

The model considers three primary forms of reasoning:

- **Common-sense reasoning:** grounded in everyday experience, intuition, and contextual understanding.
- **Scientific reasoning:** associated with systematic analysis, hypothesis formulation, and evidence-based validation.
- **Design reasoning:** related to creative exploration, experimentation, and iterative solution development.

The articulation of these forms of reasoning can broaden problem understanding and support innovation processes. Kolko [4] highlights the potential of design to integrate different forms of knowledge and generate new perspectives.

The Integrative Reasoning framework was initially introduced in previous studies examining the complementarity of these reasoning modes in learning and professional contexts [6]. It was later translated into a visual canvas applied in higher education environments [10].

3 METHODOLOGIES

This research adopts a qualitative exploratory approach structured through iterative cycles of model development and application.

The methodological process involved three main stages:

- Conceptual development of the Integrative Reasoning model through literature review.
- Development of visual tools to operationalise the model.
- Application and qualitative analysis in educational and professional contexts.

This article focuses on the application of the model in professional environments related to product development. The workshops were conducted in a company located in southern Brazil and involved professionals working in product development teams, including designers, engineers, and innovation managers. Participants used a circular canvas to map different modes of reasoning involved in challenges related to product development. Data collection included observation of the workshops, photographic documentation of the artifacts produced, and qualitative feedback provided by participants.

4 DEVELOPMENT OF THE CIRCULAR MODEL

The evolution of the research led to the development of a circular representation of Integrative Reasoning. The circular structure was adopted to represent the dynamic and iterative nature of design processes. Unlike linear models, the circular format emphasises continuous interactions between different modes of reasoning (Figure 1).

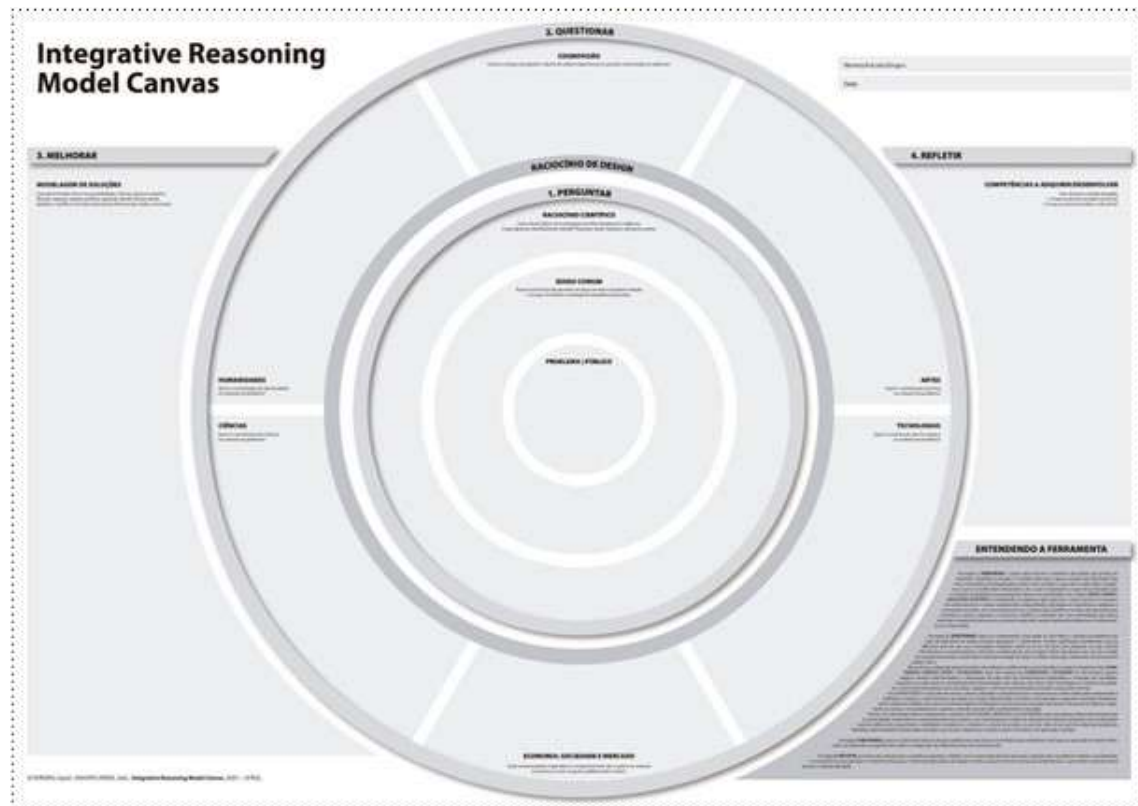


Figure 1. IRMC - Integrative Reasoning Model Canvas

In the model, scientific reasoning, design reasoning, and common-sense reasoning are positioned as interdependent dimensions that can be mobilised at different moments during the design process. This approach aligns with perspectives that describe design as an exploratory and reflective activity in which problems and solutions co-evolve [5][7].

The canvas also includes spaces dedicated to identifying competencies associated with each mode of reasoning, encouraging participants to reflect on the skills mobilised in product development processes.

5 WORKSHOP APPLICATIONS

Two workshops were conducted in product development units of a large company in southern Brazil: an industrial development team and a private-label product team. A total of 20 professionals participated, aged between 21 and 44, working as analysts, specialists, and coordinators.

Based on Dorst's levels of design expertise [3], participants in the first workshop were mostly positioned at the competent level, while the second group included both competent and proficient professionals, suggesting higher design maturity.

Regarding organisational roles in design practice, participants mainly identified with profiles associated with human-centred perspectives, technological facilitation, and network-building roles within organisations.

The competencies most frequently mentioned by participants were teamwork, resilience, curiosity, organisation, and proactivity, followed by critical thinking, adaptability, and problem-solving. Conversely, competencies such as leadership, assertive decision-making, originality, and entrepreneurial vision were less frequently cited and later identified as areas for development.

After introducing the Integrative Reasoning concept and the IRMC structure, participants were invited to discuss challenges related to product development in their teams.

In the first workshop, discussions focused on issues related to product development processes, cross-department collaboration, and decision-making throughout the design cycle (Figure 2).



Figure 2. Working with the IRMC – Product Development Department (Industry)

In the second workshop, discussions centred on the market positioning of private-label products, including challenges related to value communication, competition with international brands, and marketing investment constraints (Figure 3).



Figure 3. Working with the IRMC – Private Label Product Development Department

The IRMC guided discussions through four stages: Ask, Question, Improve, and Reflect, encouraging participants to analyse problems from multiple perspectives and identify competencies required to implement solutions.

6 DISCUSSIONS

The workshop results indicate that the IRMC can support integrative reasoning processes in product development contexts.

The tool helped broaden discussions by encouraging participants to consider technical, social, cultural, and economic factors simultaneously. This aligns with contemporary perspectives that describe design as an interdisciplinary practice addressing complex problems [1][2].

By structuring problem analysis across multiple knowledge dimensions, the IRMC makes relationships explicit that often remain implicit in design processes, fostering a more systemic understanding of problems and enabling collaborative solution development.

Another relevant aspect concerns professional competency development. The reflection stage of the canvas encourages participants to consider the skills necessary to implement proposed solutions, connecting design practice with broader discussions on professional capability development.

Additionally, the workshops revealed common tensions in product development environments, particularly the need to balance innovation, economic constraints, and market strategies.

7 CONCLUSIONS

This article presented the development and application of the Integrative Reasoning Model Canvas (IRMC), a tool designed to support integrative reasoning in design processes.

Workshops conducted with two product development teams demonstrated the potential of the model to structure discussions around complex challenges and encourage the integration of multiple perspectives. The results suggest that the IRMC can help make explicit the various factors influencing product development processes while promoting reflection on competencies required for implementing solutions.

The study is limited by the number of applications and the fact that workshops were conducted within a single organisation. Future research may explore the use of the IRMC in different industrial and educational contexts, as well as investigate digital versions of the tool to support collaborative design processes.

7.1 AI-assisted writing disclosure

ChatGPT (OpenAI) was used exclusively for language editing and improvement of textual clarity. The authors fully reviewed and validated the final content.

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IS THERE A DESIGN PATH TO CREATING VENTURES?

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ABSTRACT

Design graduates increasingly pursue self-employment, yet prevailing entrepreneurship models remain grounded in an either technology or market-anchored venture creation logic. These perspectives assume that ventures originate either from technological novelty or from an identifiable market need, which are assumptions that do not fully explain how many design-driven ventures emerge. Drawing on Danneels et al.'s [5] anchor-based framework, Vogel's [10] venture triggers, and Sarasvathy's [11] Bird-in-Hand principle, this paper explores whether an additional pathway better captures the early formation of design-led ventures. Through two qualitative Case Studies of early-stage design entrepreneurs, we examine how founders' articulate motivations, engage in creative processes, and make decisions during venture creation. The cases reveal that neither entrepreneur begins from a clear technological anchor nor a validated market gap. Instead, both founders' foreground product quality, their skillset, aesthetic expression, and user experience, while placing comparatively less emphasis on formal market analysis and financial forecasting. Based on these findings, we propose design-anchored venture creation as a third anchoring logic. This study contributes to entrepreneurial search theory and design entrepreneurship by demonstrating how identity-based and practice-based motivations can precede opportunity formation. We argue that recognising design anchoring has implications for entrepreneurship education and opens new avenues for theorising creative-led venture emergence.

Keywords: Design entrepreneurship, entrepreneurial journey, venture creation

1 INTRODUCTION

A substantial share of design graduates pursue self-employment after they graduate [1], leading to growing interest in how design education can better prepare students for venture creation and the commercialisation processes. Entrepreneurship education has traditionally focused on opportunity recognition, market validation, and technology commercialisation [2, 3, 4] as central starting points of venture creation. The methods are often problem based with inspiration from a market need, or new technology that could have alternating effects in the market [5]. Entrepreneurship research has commonly explained venture creation through two dominant starting logics: technological-driven ("technology push") and market-driven ("market pull") [5]. In technology-driven pathways, founders begin with a technological innovation and search for viable market applications. In market-driven pathways, founders start from an identified customer need or market gap and develop solutions accordingly. Recent work has formalised these as technology-anchored and market-anchored venture creation logics, showing that the initial anchor shapes subsequent search processes and influences which types of founder experience support early venture performance.

Design entrepreneurs have been described in prior literature as actors who operate at the intersection of creative practice and commercial activity, combining aesthetic exploration with entrepreneurial action [6], and their central challenge lies in reconciling artistic self-expression with the requirements of building a viable business [6]. Venture creation in design and creative fields is therefore often closely intertwined with artistic practice, aesthetic exploration, and the desire to materialise a creative vision through a tangible product or experience.

When entrepreneurship is embedded in design education however, it utilises the "narrow" view of entrepreneurship, with venture creation from a market perspective often including activities of making business plans, market research, IPR strategy, sales and finance [7,8]. This path again shows the relation

to models of that assume that venture formation begins in an external domain, often with market opportunity somehow embedded in the teaching to design students.

Empirical observations from design and creative entrepreneurship suggest that this assumption does not hold for all ventures, but it is also pointed to when it comes to art entrepreneurship. Art entrepreneurship research has similarly highlighted that venture creation is often driven by identity and personal creative vision, where the entrepreneurial pathway originates from within the individual rather than from external market or technological triggers. This paper builds on the observation that some ventures do not originate from technological novelty or clearly articulated market gaps. The research question guiding this paper is: *Is there a design approach to creating ventures that does not begin with identifying a market gap or developing new technology?*

This is an explorative study of two cases. In these cases, founders are primarily motivated to realise a particular aesthetic, experiential, or interactional vision. The venture serves as a vehicle for bringing a creative artifact or skillset into the world. Market demand and technological feasibility are acknowledged, but they function as enabling and constraining conditions rather than primary triggers of venture formation. In this paper we suggest a third anchor of venture creation, which we term design-anchored venture creation. In design-anchored ventures, the starting point is an inner creative and expressive drive rather than an external technology or market opportunity.

This study contributes to the design field and the design education field in a few different ways. We advocate for starting a new approach when it comes to venture creation in creative industries not only thinking that there need to be a market need or new technology and this can impact the way we approach teaching methods. This approach could also be used in design education. Our findings invite a rethinking of entrepreneurship as a deeply expressive and identity-forming activity, expanding the field's understanding of why and how ventures come into being, and also building on the concept of design-driven innovation [9], but not taking it as far as radical innovation.

2 THE ANCHORS OF VENTURE CREATION

Danneels et al. [5] distinguish two types of ventures based on founding intent: tech-anchored and market-anchored. Tech-anchored ventures begin with a specific technology and search for markets where it can be applied, whereas market-anchored ventures start from an unmet market need and then search for a suitable technological solution. This distinction aligns with technology-push and market-pull logics, and we also see these methods adapted in entrepreneurship education through technological focus and feasibility studies or market research as distinct activities. Founder experience determines how broad or narrow this search becomes: deep technological experience benefits tech-anchored ventures, while deep market experience benefits market-anchored ventures. Conversely, broad experience expands the search across both domains. We argue that the design entrepreneur has a different anchor than we see in the model of Daneels [5], see Figure 1.

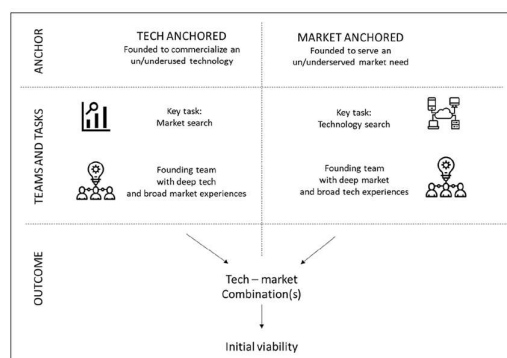


Figure 1. The model from Daneels [5] displaying the anchors of venture creation

Vogel [7] identifies three core triggers that explain why new ventures are initiated. First, resource-push triggers arise when founders possess a specific technology, capability, or resource they wish to commercialise. Second, market-pull triggers occur when an unmet customer need or market gap initiates idea generation. Third, some founders are motivated by a desire-to-start, where the aspiration to become an entrepreneur precedes any concrete idea. Together, these triggers explain the origins of venture ideas and mark the starting point of the entrepreneurial process. In contrast, Danneels et al. [5] classify

ventures based on founding anchors—either technology-anchored or market-anchored. Their framework does not focus on *why* individuals start generating ideas, but rather *where the venture begins its search*: from a technology seeking a market or from a market need seeking a solution. Whereas Vogel explains why ideas emerge, Danneels explains how early search unfolds given the initial anchor.

In addition to Danneels' et al. [5] and Vogel's [10] distinctions, Sarasvathy's [10] effectuation research introduces a third way to understand the early genesis of ventures: the Bird-in-Hand principle. This principle shows that expert entrepreneurs do not begin with a predefined market need or a specific technology, but with their means, described as *who they are, what they know, and whom they know*. Rather than searching for the "right" opportunity, they act using available resources and gradually shape opportunities through interaction with stakeholders and iterative experimentation. Sarasvathy's data demonstrate that even when expert entrepreneurs are given the same starting opportunity, they create radically different ventures by recombining their means, emphasising action over prediction.

Contrasted with Danneels, who classifies ventures by founding anchors, Sarasvathy shifts attention to founding means. While tech-anchored and market-anchored ventures begin with an external focal point, effectual entrepreneurs begin internally, letting opportunities emerge from their identity, knowledge, and networks. This suggests that design-driven entrepreneurs may follow a means-anchored logic distinct from both technology and market-anchored models.

3 CASE STUDIES

To explore how design entrepreneurs engage in venture creation, we adopted a qualitative, two case study design [12]. In our study, this approach made it possible to capture the nuanced ways in which identity, design practice, and entrepreneurial decision-making intersect during the creation of new ventures. We selected two entrepreneurs who share an educational grounding in design, though with differing specialisations and professional trajectories. Both individuals had also pursued limited formal training in business or entrepreneurship. The cases were chosen based on two criteria:

- A) Founding their own company within the design or creative industries.
- B) Active involvement in product development, branding, and business model formation, ensuring insight into early venture-creation processes.
- C) Venture is launched within the same region in order to ensure comparability of contextual conditions.

These criteria allowed us to focus on entrepreneurs whose ventures originate from creative practice but who simultaneously operate within commercial contexts.

We conducted semi-structured interviews with each entrepreneur, focusing on their motivations, identity orientations, design processes, and decision-making during venture creation. Interviews ranged from discussions of early ideation and product development to decisions about markets, organisational structure, and long-term aspirations. We were especially aware of letting the informant use their own disciplinary language. The interviews lasted on average 45 minutes and were transcribed verbatim. Interview transcripts were coded for themes related to why they started their venture, what was important for them, especially emphasising what wording they used, how they relate to market and how they talked about the entrepreneurial and creative process. We paid attention not only to what decisions were made, but why the entrepreneurs understood those decisions as meaningful or identity-expressive.

The researchers' positionality is informed by one researcher's background in design and several years of entrepreneurial experience, alongside both authors' extensive academic and research engagement within the field of entrepreneurship. This positionality shaped the interpretation and discussion of the findings, drawing on our combined perspectives and experiences.

4 CASE INTRODUCTION

The two Case Studies are entrepreneurs in the early stages of establishing businesses. The main difference is that one of the businesses, Hegren, sells mainly 'industrial design looking 'interior products and the other business, Lamovi, mainly sells consultancy services within product, service and marketing. Lamovi has a focus on both the aesthetic finish, but a passion for the user perspective and universal design. The two entrepreneurs have similar educational backgrounds in industrial design from different teaching institutions and are both in their mid to late 20s.

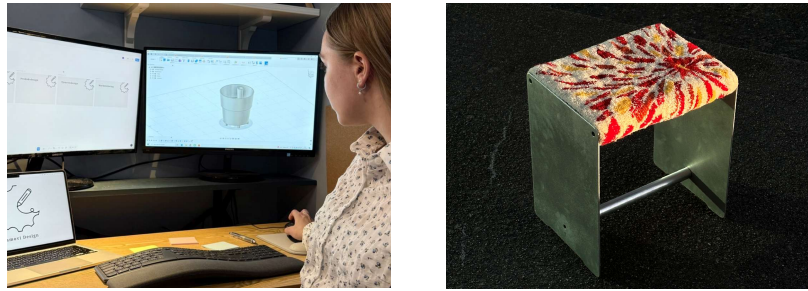


Figure 2. Pictures are from the entrepreneurs

4.1 The creator of products – one aspect of the design entrepreneur

Hegren was founded by Henrik Grevstad in 2025, shortly after completing his Industrial Design degree at a major Scandinavian university. Henrik had explored other startup ideas previously and taken several entrepreneurship courses, which he found broad in scope, though he recognised parallels between design methods and venture creation in their shared emphasis on iteration and problem-solving.

Henrik's motivation centres on creating tangible products with "meaning" and "a right to exist," drawing inspiration from conceptual art and design. His decision to establish Hegren was shaped by a concern about the outsourcing of Norwegian product manufacturing, and he built his business around locally available resources and constraints. During the first seven to eight months, he focused primarily on prototyping and product development, launching his first collection through his own online shop to gauge early market interest.

4.2 The provider of services – a second aspect of the design entrepreneur

Lamovi was founded by Lotta Linn Moen in 2025, following a bachelor's degree in Industrial Production and Management and a master's in Industrial Design. After working as a consultant in service design and gaining experience in a product-focused startup, she has always envisioned creating her own products. Lotta Linn is motivated by improving user experiences and developing solutions that "make a difference," with a particular interest in universal design and accessibility. Now seven months in, she has reached out to a small number of potential clients to understand their needs, though sales and pricing remain in an early and exploratory phase — something she acknowledges as a real challenge.

5 INITIAL FINDINGS

From the interviews, it is clear that both entrepreneurs place their primary focus on the product they aim to deliver. They are particularly attentive to the quality of the product's finish, functionality, and warranty period, as highlighted by Henrik. Lotta-Linn places even greater emphasis on her own competencies and how they can serve the needs of future customers, supporting them in creating user-friendly products.

Although both entrepreneurs have been developing their business ideas for more than six months, neither has yet carried out a structured market analysis, feasibility assessment, or formal business planning process. The processes of understanding the market have been more similar to user interviews with potential customers and more exploratory. Lotta Linn has initiated early conversations with a handful of potential customers to understand their needs, but these interactions appear to be preliminary and exploratory rather than part of a systematic approach. Similarly, Henrik has begun considering pricing for his products, but his current estimates seem primarily grounded in production costs and have not yet been validated through broader market research. During the interviews, both entrepreneurs frequently use user-centred language, often referring to "the user" rather than "the customer". In many contexts during the interview the user and the customer were effectively the same, which suggests that the mindset is more user centred.

Henrik's main motivation in being an entrepreneur is strongly linked to creating things: "I've always been fond of making things, always had a lot of ideas, and I like to work with a physical shape and create things". Lotta Linn also expressed a similar motivation and passion: "The big motivation is to create something that has a value for others, and she loves to create new things".

Overall, both entrepreneurs demonstrate a strong user-centred orientation and are highly concerned with ensuring high product quality, grounded either in user needs or personal aesthetic preferences.

They also mention their use of particular technologies, including language models for writing text and 3D-modelling tools, which they describe as *industry standard*, and not as a new technology that is entering the market.

Both further outline a range of creative processes that include drawing inspiration from external sources, sketching on paper, developing physical prototypes, and conducting user testing. Their specific methods vary depending on the nature of the project, but the overarching pattern suggests a similar approach to early-stage creative development. In addition, neither entrepreneur currently places strong emphasis on market data, purchasing criteria, or customer specifications, and both have carried out limited analysis regarding pricing. This is something they to some degree expressed was difficult, and something that they would focus more on further. Overall, the passion and values for the quality of the service and product was their main focus. From the two cases we suggest a new anchor in the current figure of Danneels et al. [5], suggested as “design-anchor” (see Figure 3). This is an addition to the other venture creation approaches that are anchored in the designer’s skillset and design vision where the designer has a drive to deliver a quality product or quality service.

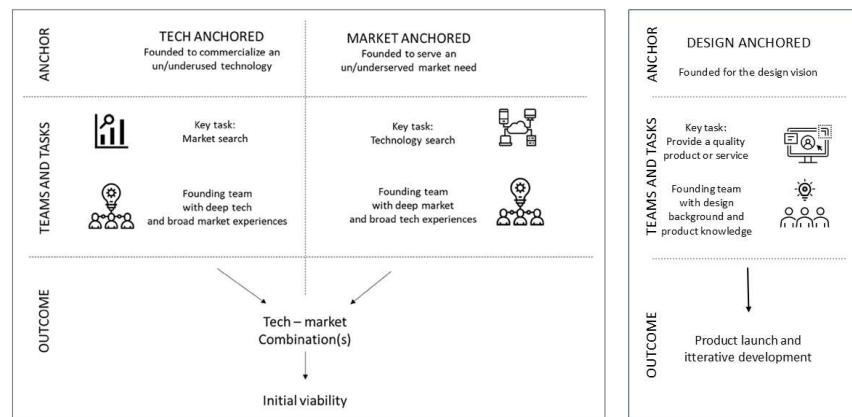


Figure 3. The model from Daneels [5] with an incorporated design-anchor for venture creation

6 DISCUSSIONS

The initial findings indicate that neither of the two design entrepreneurs begins their venture from a technology- or market-anchored starting point as described by Danneels et al. [5]. While Danneels’ model assumes that ventures originate either from a given technology seeking markets or a defined market need seeking technological solutions, the entrepreneurs in this study show limited systematic engagement with either domain. Their attention to market size, competitive positioning, or value proposition development appears minimal, and their technological choices rely on established, industry-standard tools rather than novel or proprietary technologies. Instead, both cases foreground product quality, user experience, and aesthetic expression as their central organising logics.

This orientation aligns more with Sarasvathy’s [11] Bird-in-Hand principle, in which entrepreneurs begin with their means, who they are, what they know, and whom they know, rather than with a predefined opportunity. Both entrepreneurs build on their existing competencies, personal design philosophy, and craft traditions, advancing their ventures through iterative making, prototyping, and user interaction. Commercial considerations are present, but secondary; both entrepreneurs prioritise meaningful work, aesthetic integrity, and product usefulness over financial optimisation. This echoes Vogel’s [10] observation that some ventures are triggered not by market pull or resource push, but by a desire to start, grounded in personal motivation rather than opportunity recognition.

Taken together, the findings suggest a third anchor of venture creation—an artistic- or potentially design-anchored logic—distinct from both technology- and market-anchored models. Here, the founding impulse is expressive: entrepreneurs create ventures to materialise a vision, enact a design identity, or bring a particular aesthetic or experiential concept into the world. In this pathway, the “given” at founding is neither technology nor market, but an inner creative orientation. Consequently, both technological and market domains become objects of *constrained search*, evaluated not for optimisation but for their compatibility with the intended expression or user experience.

This extends current entrepreneurship theory in three ways. First, it highlights how identity-based motivations can precede, and at times substitute, opportunity-driven logics. Second, it complements effectuation research by specifying how means-driven action unfolds within creative practice. Third, it advances understandings of entrepreneurship-as-practice by showing that making, crafting, and aesthetic judgment are not peripheral but central to venture formation in design-driven contexts. As such, design entrepreneurship reveals an alternative anchor of venture creation deserving further theoretical and empirical development, but for now we suggest there is something like a design-anchor for venture creation.

7 CONCLUSIONS

This study suggests that design entrepreneurship often originates from a means- and identity-anchored logic rather than the technology- or market-anchored logics described by Danneels et al. [5]. Across two cases, founders prioritised product quality, user experience, and aesthetic expression, advanced through iterative making, and only secondarily attended to commercial analysis. Read alongside Vogel [10] and Sarasvathy [11], the findings indicate that a desire to create—mobilising *who I am, what I know, and whom I know*—can precede opportunity search. With our initial findings we propose a design-anchoring as a distinct pathway of venture creation and call for larger comparative studies to examine its prevalence, boundary conditions, and performance implications.

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INCLUSIVE DESIGN: LEARNING THROUGH REAL-WORLD COMPLEXITY

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ABSTRACT

Inclusive design in apparel requires not only designing for diverse bodies but also understanding lived experience and embodied variation. Yet engineering and design education continues to rely on standardised body data and idealised sizing models, leaving significant user groups underrepresented. As the fashion sector faces increasing pressure to become more inclusive and sustainable, education must prepare future professionals to address variation as a structural condition rather than a deviation from a norm. This paper investigates how vignettes in case-based learning combined with data-driven design processes can strengthen inclusive product development. Students engage with empirically grounded case vignettes derived from qualitative interviews and paired with three-dimensional body-scan visualisations. The learning sequence foregrounds interpretation before measurement, activating empathic reasoning prior to technical analysis.

The findings show that integrating empathic, professional and systemic reasoning enables students to move beyond garment-level adjustments toward product portfolio-level restructuring. By embedding variation within existing range structures, students reorganised a traditional collection plan around identifiable body clusters without increasing product volume. Fit alignment improved through strategic redistribution of variation. The study proposes a systemic pedagogical framework that bridges design and engineering by integrating qualitative user insight, quantitative body data and organisational decision-making. Inclusive product development is reframed as organised complexity within fashion management systems, achieved through structural integration rather than reactive adjustment

Keywords: Data-driven product design, design variation, fashion education, Case-based learning

1 INTRODUCTION

Despite advances in digital body-scanning technologies and data-driven product development, the apparel industry continues to rely on standardised sizing systems structured around normative body assumptions. Although three-dimensional scanning has made population-level body variation increasingly visible [1], mainstream range planning remains grounded in statistical averages and proportional grading logic [2]. As a result, many consumers experience fit-related challenges, contributing to dissatisfaction, high return rates and material waste within fashion supply chains [3]. In this context, inclusive design is not only a social objective but also a strategic and sustainability imperative. However, industry responses often focus on extending size ranges or refining measurement rather than reconsidering how variation is embedded within product portfolio strategies. Design education plays an important role in shaping how future professionals address these challenges. Apparel engineering and product design curricula often prioritise standardised systems and inside-out approaches to product development over qualitative user insight. Research in situated and case-based learning suggests that professional judgement develops most effectively when learners engage with authentic, context-rich problems prior to formal abstraction [4]. Empathic reasoning—understood as structured interpretation of lived user experience—has also been shown to support decision-making in design contexts [5]. These findings suggest that pedagogical sequencing may influence whether students understand variation as deviation from a norm or as a fundamental design condition. This study investigates how visual and numerical data from fit and design research [6] can support students' understanding of inclusive product development in apparel education. The framework integrates qualitative user experience data, three-dimensional body-scan data and case-based learning into a cross-disciplinary approach bridging design and engineering. In contrast to traditional curricula that separate fit from design and rely on a single average body type, the proposed model combines design practice,

engineering analysis and user research to address embodied variation as a fundamental condition. Building on theories of transparent customisation [6], the study explores how user insight and body data can inform inclusive product development. Rather than focusing solely on garment-level design, the approach embeds embodied variation within product systems through product portfolio restructuring. The study contributes to fashion design education by proposing a pedagogical framework that connects empirically grounded user narratives with systemic reasoning in product development. By structuring learning as recursive movement between empathic, professional and systemic reasoning, the framework demonstrates how inclusive product strategies can be developed in a more evidence-based and context-sensitive manner.

2 METHOD AND EPISTEMOLOGICAL POSITIONING

This study adopts a qualitative, practice-based research design grounded in interpretive and situated learning perspectives. The methodological approach assumes that professional knowledge in apparel development emerges through engagement with complex, context-rich situations rather than through technical instruction alone. The workshop was therefore designed not to test predefined hypotheses, but to observe how students navigate the relationships between lived user experience, embodied variation and industrial system logic when working with empirically grounded data.

2.1 Empirical Foundation of the Vignettes

The vignettes were derived from prior doctoral research on apparel fit and sizing. The broader dataset comprised 150 qualitative interviews with women, field observations and 350 three-dimensional body scans [7]. The original research examined lived experiences of fit, sizing challenges and embodied variation across diverse body profiles. Qualitative and numerical data were statistically and thematically coded into recurring categories related to fit and style preferences, body shape variations and purchasing behaviour. From this dataset, two interview transcripts representing recurring and structurally distinct fit-related challenges were selected and developed into narrative vignettes. These cases were chosen because they illustrated identifiable patterns observed across the larger dataset while reflecting different embodied configurations. To complement the narrative material, 30 anonymised body scan visualisations were selected to represent a wide range of body forms, including the two interview participants. However, students were not informed which scans corresponded to the vignettes. This ensured that interpretation preceded confirmation and prevented direct matching between narrative and body data.

2.2 Participants and Workshop Structure

The workshop involved 40 Bachelor-level design students in their fifth semester across two educational locations. Both sessions followed an identical structure to ensure consistency. The workshops were audio recorded and photographically documented to capture discussion processes, clustering activities and visual mapping outcomes.

The workshop was organised into three sequential phases. In the first phase, students individually read the two vignette narratives and identified statements they considered relevant, surprising or unclear. Each observation was written on a separate note, making individual interpretations visible and allowing emerging themes to develop. In the second phase, students worked in groups of four to compare and cluster their observations thematically. Each group assigned descriptive headings to their clusters, articulating perceived patterns of embodied challenges. In the third phase, groups were presented with 30 body scan visualisations. No numerical measurements or contextual information were provided. Students were asked to discuss whether and how the bodies appeared to align with or deviate from prevailing normative sizing assumptions. Based solely on visual analysis, the students organised the scans into clusters according to perceived similarities and differences in body shape.

2.3 Analytical Focus

The sequencing of narrative interpretation prior to visual classification, and visual classification prior to technical measurement, was intentional. It was designed to activate empathic reasoning before analytical abstraction. This structure allowed observation of how students moved from qualitative interpretation to pattern recognition and, subsequently, toward systemic reconsideration of range planning strategies.



Figure 1. Photos from workshop session

2.4 Vignettes as Pedagogical Instruments

Within this study, vignettes function as structured narrative accounts of lived user situations that foreground meaning before measurement. Each vignette presents a condensed, context-rich account of a user's experience with clothing, fit and embodied variation without initially providing technical explanation or quantitative data. This deliberate withholding of metrics encourages students to engage in interpretive reasoning prior to analytical assessment. In case-based learning, such narrative constructions serve as entry points into situated understanding [8,9]. When encountering a lived dilemma, students must first interpret what is occurring, what forms of discomfort or exclusion may be present, and what knowledge is needed to understand the situation more fully. This process activates empathic reasoning and supports professional problem framing [10,11]. In the context of inclusive apparel design, the vignettes are not fictional anecdotes, but empirically informed constructs derived from qualitative interviews and user experiences. The pedagogical role is not to present data directly, but to generate the need for data. When later paired with 3D body-scanning information, they enable students to connect embodied narratives with morphological and quantitative analysis. In this way, the vignette functions as a bridge between user narratives and data-driven design development, supporting an approach in which body variation is anticipated and embedded within product development systems.

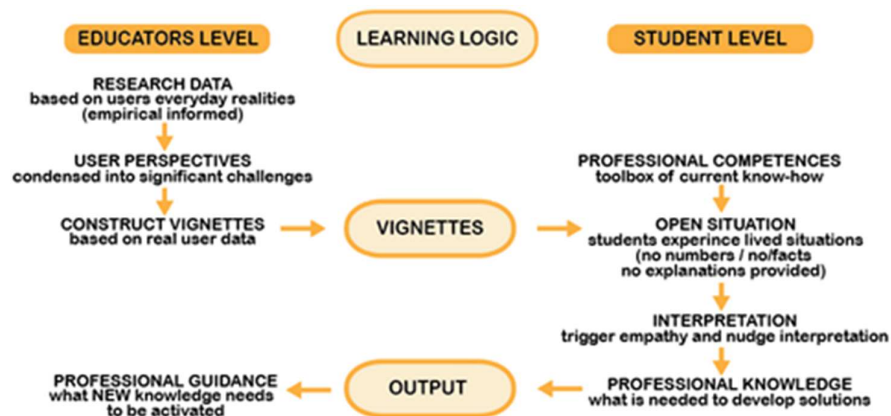


Figure 2. Vignette's dual structure

Figure 2 illustrates a dual structure that is data-informed in construction and interpretation driven in pedagogy. Educators construct vignettes based on empirical user data and condensed user perspectives, while students engage with open-ended situations without predefined solutions. This encourages students to mobilise prior knowledge, interpret user needs and identify which forms of information and data are relevant to the situation. The interpretive process may create productive uncertainty, generating

a self-identified need for further knowledge. Measurement and analysis therefore emerge as responses to identified challenges rather than as starting points, supporting a more empathic and user-centred design process.

2.5 Learning through Real-World Complexity – A Systemic Model

Based on insights generated through the workshops and analysis of the students' learning processes, we identified three interconnected and equally significant forms of reasoning. These insights enabled us to formalise the observed practices into a systemic learning model for inclusive product development situated within fashion management systems, illustrated in Figure 3. The model conceptualises learning as a dynamic and relational process in which user insight, industry systems, data and case-based learning interact to support inclusive product strategies. Rather than presenting product development as a linear sequence, the framework positions interpretation, analysis and strategic structuring as mutually informing processes. At the centre of the model, data functions as an integrative mechanism connecting user insight, industry systems and case-based learning. User insights represent lived experiences and embodied challenges derived from qualitative and quantitative research, while industry systems represent the organisational and strategic structures through which products are developed and evaluated.

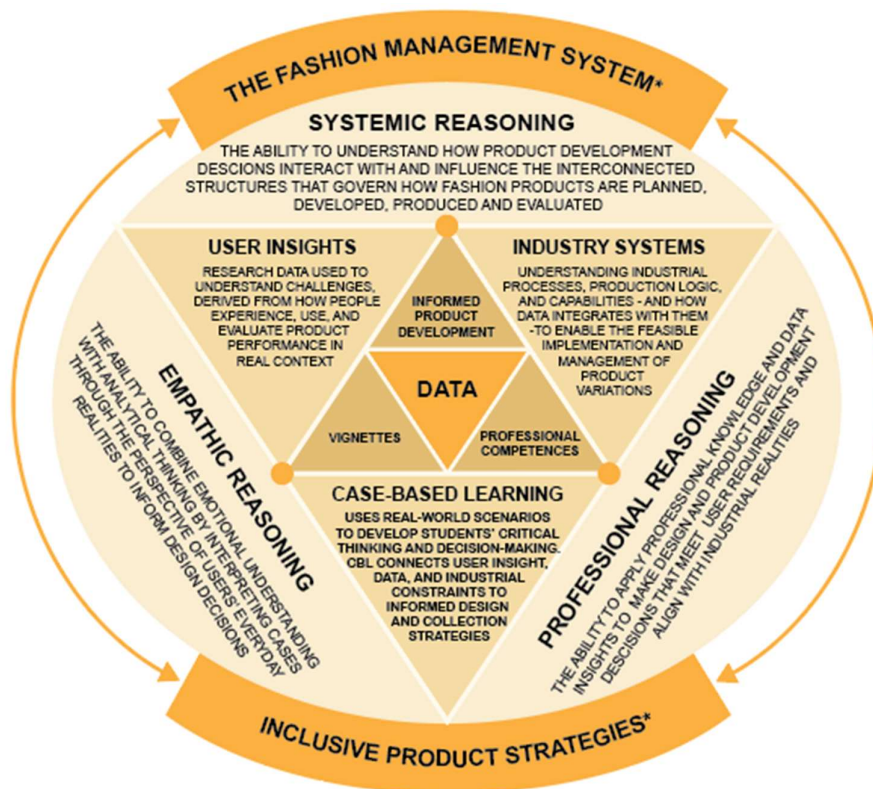


Figure 3. Learning Through Real-World Complexity – A Systemic Model

Case-based learning functions as the pedagogical domain in which these forms of knowledge are translated into situated learning processes through empirically informed vignettes. The vignette functions as a mediating mechanism that transforms experiential knowledge into contextualised scenarios that activate interpretation. Data supports analysis and implementation, but gains meaning through interpretation and professional translation. The outer frame* represents the fashion management system as the structural context within which all decisions are embedded.

Within this framework, each case activates recursive engagement with three interdependent modes of reasoning: empathic, professional and systemic. These modes do not operate sequentially but relationally. Empathic reasoning foregrounds lived and embodied realities and challenges normative assumptions. Professional reasoning translates interpretive insight into technically structured analysis through disciplinary knowledge. Systemic reasoning situates emerging solutions within the broader architecture of fashion management, including range planning, production frameworks and product

portfolio configuration. The learning logic emerges through iterative movement between meaning, data and implementation. Rather than reducing complexity to predefined variables, students are required to navigate the dynamic relationships between users, visualised embodied variation and production systems. Inclusive product strategies therefore emerge not as isolated product solutions, but as outcomes of systemic organisational change.

3 DISCUSSIONS: RETHINKING TRADITIONAL COLLECTION DEVELOPMENT

In Danish education and mass-market fashion, Collection Development (CD) is traditionally structured as a portfolio of product categories organised through design variations aligned with a brand's DNA and developed within a standardised sizing system. Target customers are typically represented through an average body model constructed through standard grading and limited fit variation within a push-to-market strategy. As illustrated in Figure 4, the traditional range plan consists of six product categories and 92 styles designed for a single standardised body type. Students were informed that only 12.8% of 350 body scans matched this standard (Terkildsen, 2020). To address this limitation, students worked with three predominant body shape categories identified in the study. While the number of product categories and styles remained unchanged, design variations were strategically redistributed to accommodate these body variants, shifting the focus from size variation alone toward integrated shape and design variation.

PRODUCT CATEGORY	PRODUCT VARIANT	Bodytype STANDARD	STYLES	TOTAL
TOPS	Sweat Shirts	●●●●●	5	25
	T-Shirts	●●●●●	5	
	Shirts	●●●●●	5	
	Tunics/blouses	●●●●●	5	
	Knit	●●●●●	5	
TROUSERS	Volume	●●●●●	4	20
	Straight	●●●●●	4	
	Relaxed	●●●●●	5	
	Jeans	●●●●●	5	
	Shorts	●●	2	
DRESSES	Bodycon	●●●●●	5	15
	Volume	●●●●●	5	
	Regular	●●●●●	5	
SKIRTS	Volume	●●●●●	4	12
	A-line	●●●●●	4	
	Straight	●●●●●	4	
BLAZERS/JACKETS	Formal	●●●●	3	10
	Casual	●●●●	4	
	Functional	●●●●	3	
OUTERWEAR	Formal	●●●●	4	10
	Casual	●●●●	4	
	Functional	●●	2	
				92

PRODUCT CATEGORY	PRODUCT DESIGN	Bodytype x Bodytype BX Bodytype BXD+xD	Bodytype x	Bodytype BX	Bodytype BXD+xD	STYLES	TOTAL
TOPS	Sweat Shirts	●●	●●	●●	●●	4	27
	T-Shirts	●●	●●	●●	●●	4	
	Shirts	●●	●●	●●	●●	4	
	Tunics/blouses	●●	●●	●●	●●	5	
	Knit	●●	●●	●●	●●	5	
TROUSERS	Volume	●●	●●	●●	●●	5	27
	Straight	●●	●●	●●	●●	6	
	Relaxed	●●	●●	●●	●●	6	
	Jeans	●●	●●	●●	●●	8	
	Shorts	●●	●●	●●	●●	2	
DRESSES	Bodycon	●●	●●	●●	●●	5	15
	Volume	●●	●●	●●	●●	4	
	Regular	●●	●●	●●	●●	6	
SKIRTS	Volume	●●	●●	●●	●●	4	11
	A-line	●●	●●	●●	●●	2	
	Straight	●●	●●	●●	●●	5	
BLAZERS/JACKETS	Formal bodycon	●●	●●	●●	●●	5	10
	Casual loose	●●	●●	●●	●●	3	
	Functional	●●	●●	●●	●●	2	
OUTERWEAR	Formal	●●	●●	●●	●●	3	7
	Casual	●●	●●	●●	●●	3	
	Functional	●●	●●	●●	●●	1	
		15	24	8	19	5	21
		15-24+8		15-19+(8+5)		15-21+5	
						92	

Figure 4. Traditional range plan vs Body Inclusive range plan (Terkildsen, & Pedersen (2023))

The figure compares a traditional range plan with a body-inclusive alternative, where each dot represents a style or style variation. The traditional range plan (left) is based on a singular proportional sizing system in which variation is primarily created through style differentiation, while body diversity is addressed solely through grading. This reflects a conventional inside-out approach centred on lean production and standardisation. In contrast, the body-inclusive range plan (right) integrates multiple body variants into the product portfolio structure. Rather than relying on one dominant fit standard, the collection is strategically distributed across identified body variation clusters, enabling a more targeted and inclusive range plan without increasing product volume. The model illustrates a shift from singular standardisation toward managing embodied diversity through micro-standards within fashion management systems.

At the conclusion of the workshop, students analysed a traditional range plan and discussed which variations were necessary to accommodate different body variants. They recognised that each product category posed distinct fit and design challenges and that variation could not be distributed evenly across the portfolio. Drawing on professional knowledge, students evaluated which body variants could share designs and where additional variations were required. The exercise demonstrated that a significantly larger proportion of customers could be accommodated through strategic redistribution of body-shape variation. Students reframed inclusion not as product expansion, but as strategic reorganisation of the existing product portfolio. This shift expanded the discussion from isolated fit adjustments toward

systemic consideration of how variation can be embedded within fashion management and collection planning systems, expanding students' understanding of their professional role.

4 CONCLUSIONS

This study has demonstrated that inclusive product development can be approached as a systemic capability rather than as an additive adjustment to standardised collection structures. By integrating empirically informed vignettes with a systemic learning model, the framework enables students to move between empathic insight, technical evaluation and organisational reasoning. Learning is structured as recursive engagement across interpretive, analytical and strategic domains.

The workshop findings indicate that implementing inclusive range planning increases organisational complexity, as it requires coordination of multiple body standards rather than reliance on a single normative model. However, this complexity does not necessitate increased product volume. Instead, it requires strategic redistribution of variation across existing product portfolio structures, enabling a significantly larger proportion of customers to be accommodated without increasing the number of styles brought to market. Importantly, the workshop shifted student discussions from isolated product solutions toward systemic decision-making. Although the curriculum predominantly centres on product design, students demonstrated strong engagement with systemic and empathic reasoning, particularly when reflecting on how product portfolio structures, production frameworks and strategic planning shape the feasibility of inclusive design. The findings suggest that inclusive design competence extends beyond aesthetic sensitivity and technical adjustment to encompass the ability to embed variation within fashion management systems.

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BEYOND MY SIGHT: DESIGNING INCLUSIVE TOOLS AND REDESIGNING GAMIFIED VR ACTIVITIES FOR VISUAL IMPAIRMENT

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ABSTRACT

This research presents the findings of an empirical case study evaluating an international academic collaboration focused on the inclusion of higher education students with visual impairments (specifically low or no vision) in project evaluation and engineering management courses. In quantitative disciplines, traditional learning environments rely heavily on "visual-centric" methodologies, creating steep sensory barriers for visually impaired students. To address this systemic inequity, a multidisciplinary team designed, manufactured, and implemented a suite of reproducible, technology-based pedagogical tools in the classroom. These interventions encompass the development of adaptive physical laboratories, specialised computing tools such as a tactile slide rule embossed with Braille scales, and the strategic adaptation of gamified Virtual Reality (VR) simulations optimised for project and financial evaluation. Moving away from traditional digital screen readers—which process data in a strictly serial fashion and generate significant cognitive bottlenecks—these haptic-first, analogue-tactile interfaces leverage physical manipulation to build essential spatial intuition regarding mathematical proportionality, financial magnitudes, and exponential curves. By synthesising institutional comparative frameworks and practical pedagogical testing, this investigation provides an actionable roadmap for educators and instructional designers. Ultimately, this framework champions conceptual translation over passive content conversion, fostering independent operational autonomy, mitigating the professional skills gap, and ensuring competitive workplace readiness for graduates with visual impairments.

Keywords: Higher education, educational innovative, impaired vision, gamification, VR

1 INTRODUCTION

In traditional higher education classroom settings, engineering educators frequently overlook the specific pedagogical needs of students with significant visual impairments (VI). While institutional efforts in Educational Innovation often design cutting-edge techniques for complex quantitative theories, inclusive universal design is routinely omitted from initial planning stages. This systemic omission creates a "sensory barrier" in fields such as Industrial Engineering and Management Education, where complex data analysis, financial modelling, and project evaluation are heavily mediated through digital screens, visual metaphors, and graphical interfaces. For nearly a decade, our research group has sought to address this gap, developing methodologies to effectively teach core competencies in Project Management and Evaluation—such as calculating Return on Investment (ROI), Net Present Value (NPV), and master scheduling via PERT/CPM methods—to diverse student bodies.

To properly address academic accessibility in quantitative fields, it is clinically and pedagogically essential to establish the boundary between mild visual anomalies, severe visual impairments, and total blindness. In the context of this study, Low Vision is formally defined according to the World Health Organisation (WHO) and clinical standards as a chronic visual acuity of less than 6/18 (20/60) up to 3/60 (20/400), or a visual field loss of less than 20 degrees in the better-seeing eye, even after the best possible conventional medical, surgical, or refractive correction.

Crucially, this condition must not be confused with standard refractive errors (such as myopia, astigmatism, or presbyopia) that can be fully mitigated or neutralised through standard prescription glasses or contact lenses. Conversely, low-vision students retain functional residual vision that can be

strategically leveraged, distinguishing them from individuals with total blindness who lack light perception entirely. In countries like Mexico and Spain, the prevalence of low vision in university classrooms has risen sharply due to both accelerated device-driven eye strain post-COVID-19 lockdowns and growing metabolic comorbidities, such as diabetic retinopathy resulting from elevated blood sugar levels[1,2,3,4,5] Because many students choose not to formally disclose their visual health status, faculty members remain largely unaware, inadvertently compounding the fragmentation of visual information delivered through traditional screen readers or whiteboard lectures.

While digital accessibility tools like Optical Character Recognition (OCR) and text-to-speech screen readers exist, they process numerical data in a strictly serial, sequential fashion. This creates a severe cognitive bottleneck for VI students who must grasp the multi-step spatial and proportional logic required for engineering calculations. Therefore, the path toward true academic equity requires a shift from "passive assistance"—where a sighted peer or machine merely describes a visual element—to "active agency," where the student can independently manage data structures.

Building upon the "Beyond My Sight" research paradigm, this paper frames a specific inquiry into how physical, tactile artifacts and inclusive virtual environments can bypass digital serialisation to foster robust mental models of proportionality [7]. Specifically, this case study examines the design, deployment, and pedagogical impact of a disruptive, low-cost Braille Tactile Calculation Rule engineered to restore mathematical intuition and instrumental autonomy for low-vision students in fast-paced engineering curricula.

2 INSTITUTIONAL COMPARATIVE ANALYSIS

Table 1. Institutional comparative analysis

Strategy Dimension	Mondragón University	Tecnologico de Monterrey (Beyond My Sight)
Primary Framework	Cooperative Learning & UDL	Haptic Innovation & Individual Autonomy
Support System	Peer-mentorship and team-based tasks	Specialised tactile artifacts and physical tools
Technological Focus	Digital accessibility (Screen readers/OCR)	Analog-Tactile interfaces for mental mapping

2.1 Mondragón University’s Cooperative Approach

Mondragón University leverages its "Cooperativismo" roots to create inclusive classrooms. Their strength lies in **Collaborative Inclusion**, where the learning environment is adjusted so that the VI student is a core member of a functional team. However, this can sometimes lead to reliance on sighted peers for interpreting complex quantitative data.

2.2 The "Beyond My Sight" Paradigm

As detailed in the provided research, Tecnologico de Monterrey identifies a gap in existing assistive technology: digital screen readers often fail to provide the "spatial intuition" required for mathematics. The project advocates for **Tactile Learning Materials (TLM)** that allow the student to "see through their fingers," fostering a deeper cognitive connection to numerical proportions.

3 THE INNOVATION: THE BRAILLE TACTILE CALCULATION RULE

To complement the virtual environment upgrades, a high-fidelity physical computing and analog-tactile artifact was co-designed through a strategic collaboration between the School of Architecture, Art and

Design, and the School of Engineering and Sciences within the R&EIT framework. This specialised device adapts the manual sliding and mechanical positioning logic of a traditional mathematical slide rule to provide students with visual impairments (VI) and low vision with an autonomous method to construct, analyse, and solve Cash Flow Diagrams (CFD). Instead of navigating abstract or sequential rows of data via traditional digital text-to-speech screen readers, this physical instrument externalises financial datasets into tactile spatial constraints. The hardware assembly consists of three core interactive components: The Linear Track Base (Temporal Axis): A rigid, high-contrast horizontal frame machined with linear guide rails and embossed with tactical Braille intervals. This component physically maps the project's timeline (n periods/years), establishing a tangible spatial reference for the passage of time. Perpendicular Sliding Vectors (Cash Flow Pins): A series of mechanical sliders mounted vertically on the linear track. These sliders can be independently locked and moved along the temporal axis. Students manually extend the pins upward to physically represent positive cash inflows (revenues, benefits) or push them downward to signify negative cash outflows (capital expenditures, operating costs). The physical height or depth of the pin establishes a tactile scale of financial magnitude.

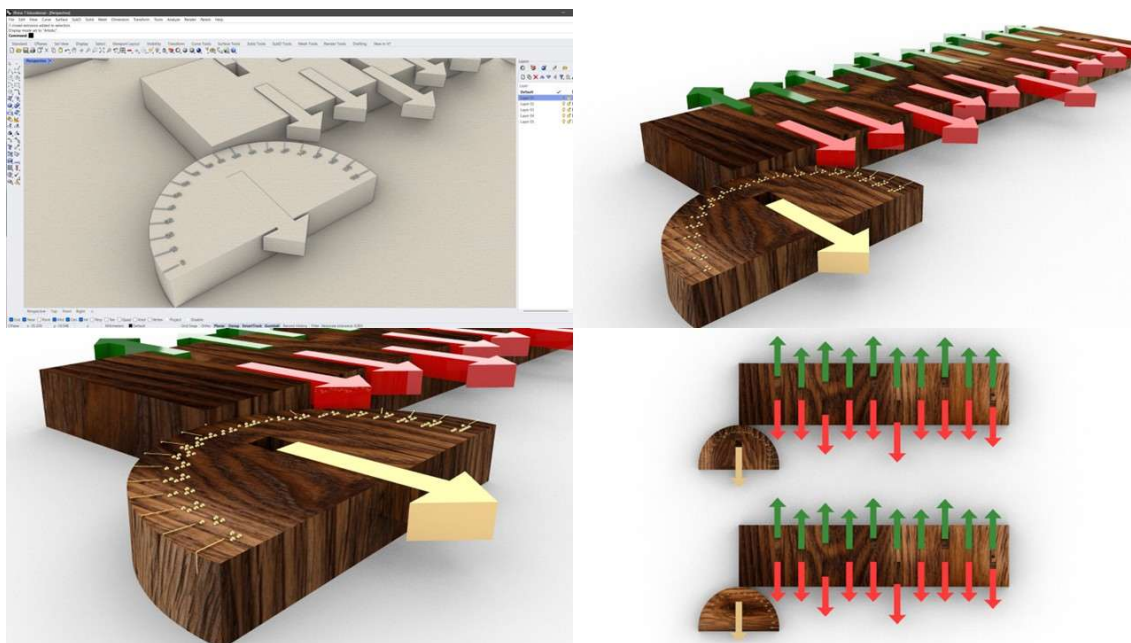


Figure 1. Tactile Calculation Rule for project evaluation, developed by R&EIT

The Rotatable Angular Protractor (Interest Rate Calibration): At the intersection of the coordinate axes, a mechanical circular cursor is integrated. This protractor is precisely graduated from 0% to 100%, featuring tactile notches and Braille labels along its circumference. By rotating this dial to match a project's Minimum Acceptable Rate of Return (MARR) or interest rate (i), the student alters the physical mechanical alignment of a guide bar. This physical angle represents the mathematical slope of continuous compounding or discounting factors (e.g., Present Value factors like $\$P/F\$$ or $\$P/A\$$), mapping financial equivalence across time through geometric tilt and mechanical leverage. By running their hands across the horizontal timeline, feeling the vertical displacement of the cash vectors, and engaging the angular protractor, students with low vision can process complex financial structures in parallel, achieving a structural cognitive mapping of Net Present Value (NPV) calculations that would otherwise be severely bottlenecked by auditory-only software assistance.

For an impaired student, the use of the Financial Calculator Rule is easy, just need the following steps.

1. Temporal Allocation: The student identifies the project duration (n) by counting the physical Braille intervals along the linear track.
2. Vector Mapping: The vertical sliders are unlocked and shifted to their respective temporal coordinates, then extended vertically (up or down) to represent the cash amounts.
3. Rate Adjustment: The angular protractor is turned to the designated interest rate percentage (0% to 100%), dynamically establishing the visual and tactile slope of equivalence.

4. Haptic Synthesis: The student sweeps their hand across the completed physical setup, instantly capturing the overall economic trend, balance, and feasibility of the investment project through spatial intuition.

4 RV, RA, AND SIMULATORS REDESIGN STRATEGIES

The transformation of high-fidelity simulators into inclusive educational artifacts entails a complex intersection of technical, economic, and social factors. Recent advancements in design education have explored synchronous communication through shared visual tracking systems, such as immersive gaze sharing in architectural critiques. However, as demonstrated by Kahlon, Maurya, and Fujii, such information-sharing platforms are inherently bounded by their exclusive reliance on the visual modality. To overcome this sensory barrier and include students with severe visual impairment (VI), educational simulators must transition toward multimodal, non-visual communication channels.

4.1 Technological Implications: From Visual to Haptic Rendering

The current software architecture of advanced simulators, such as our "Milking Parlor" and "Car Assembly Line" environments, is mathematically optimised for visual immersion. Transitioning these existing digital platforms into universally accessible spaces requires a complete architectural overhaul. To achieve this without compromising the core engine for sighted users, a Modular Accessibility Control Panel is integrated into the simulator's user interface. This allows VI and low-vision students to dynamically activate a comprehensive suite of optional accessibility features:

Sensorimotor Integration and Sonification: The software core must pivot from purely visual shaders to a rigid Haptic-First Architecture. This framework requires rewriting traditional collision detection algorithms to trigger distinct, varied tactile waveforms (haptics) alongside spatialised, directional audio cues (sonification). By doing so, mathematical proportionality and spatial volumes are rendered palpable, bypassing the need for sight.

Colour Blindness Adaptive Filters: For students whose low vision is compounded by colour vision deficiencies, the rendering pipeline introduces mathematical matrices that adjust the interactive colour palette in real time. The system allows users to select specific filters tailored to mitigate Deuteranopia, Protanopia, or Tritanopia, thereby ensuring critical operational cues within the project simulation remain highly visible and distinct.

High-Contrast Immersive Modality: When activated via the control panel, the engine strips complex, realistic environmental texturing and renders the interactive scene in a high-contrast visual mode. This modality forces interface frames and critical interactive objects in the environment to display highly differentiated colour values, significantly reducing visual ambiguity, glare, and spatial disorientation for low-vision users.

Dynamic Text Scalability: To resolve interface readability barriers, the layout UI uses a parametric typography system. Users can dynamically upscale the text size of all active interfaces, including simulation sub-menus, instructions, spatial labels, and integrated subtitles, ensuring font enlargement does not break UI boundaries or cause word clipping.

Focused Text-to-Speech (TTS) Synthesis: The simulator integrates an active voice synthesis engine that acts as a real-time auditory guide. Whenever a user selects, targets, or focuses on an interactive button, menu item, or environmental component, the TTS engine instantly reads out the corresponding content and instructional metadata, providing vital feedback that bypasses traditional visual processing bottlenecks.

Assistive Tool Synchronisation via IoT: To bridge the gap between virtual and analogue spaces, the physical Braille-based slide rule is integrated into the simulation cycle through Internet of Things (IoT) protocols or micro-computer vision tracking. This synchronisation ensures that real-time quantitative output from the virtual environment is instantly translated into physical coordinates on the tactile rule, enabling parallel data manipulation.

4.2 Economic Implications: Scalability and Cost-Benefit Analysis

The long-term viability and widespread adoption of inclusive learning tools, particularly those involving specialised technology like Virtual Reality (VR) and tactile prototypes, are fundamentally tied to their economic implications, specifically concerning scalability and the cost-benefit ratio.

Initial R&D Investment: Developing accessible VR environments and gamification platforms demands a high level of expertise in inclusive design principles, accessibility standards (e.g., WCAG, Section 508), and specialised programming for diverse input methods—including haptic feedback integration, real-time shader adjustment, and screen-reader compatibility. This highly technical development necessitates senior-level software engineers, resulting in elevated initial labour costs.

Physical Manufacturing of Tactile Prototypes: The physical manufacturing of learning aids requires specialised polymers, continuous 3D printing operation, and iterative design-testing cycles. Each prototype iteration—moving from initial concept to a robust, classroom-ready tool—involves substantial expenditures for raw materials, machine maintenance, and expert consultations with occupational therapists and educators for clinical validation. This structural complexity contributes to a high initial capital investment compared to purely software-based, mass-distributed solutions.

Long-term Efficiency and Shared ROI: However, a collaborative strategy between international institutions drastically reduces the "duplication of effort". By sharing open-source, inclusive codebases—such as the modular accessibility control panel architecture—and parametric 3D printing files, participating universities can exponentially decrease the marginal cost per inclusive student. Furthermore, these multi-sensory tools have been shown to enhance cognitive retention for sighted students as well, thereby increasing the overall return on investment (ROI) of the deployed educational technology.

4.3 Social Implications and Functional Autonomy

The joint project "Beyond My Sight" has profound social implications, explicitly focused on fostering independent agency and promoting professional parity for individuals who are blind or have low vision [6].

Fostering Active Agency: Our pedagogical strategy deliberately shifts VI students from passive recipients of information to active participants in quantitative engineering tasks. By providing synchronised, accessible tools (haptic feedback, custom UI filters, dynamic TTS, and tactile slide rules), the framework systematically reduces an individual's dependence on sighted peers. Mastery over advanced, cutting-edge technologies like VR and interactive gamification serves as a direct showcase of technical competence.

Promoting Professional Parity: True inclusion is achieved when graduates enter an equitable job market with competitive parity. The integration of physical-tactile calculation rules and adaptive virtual simulation bridges the critical skills gap by providing accessible methodologies for learning high-demand technical fields that traditionally rely on visual data interpretation. Simulating complex, real-world professional scenarios ensure workplace readiness and actively challenges deep-seated societal biases and employer misconceptions regarding the analytical capabilities of visually impaired professionals.

Through this multi-layered redesign, the paradigm pivots away from "passive assistance"—where a sighted classmate merely describes a graphical interface or reading screen—to "active agency," where the student with low vision independently manages, calculates, and executes complex project evaluation tasks with the same speed and rigor as their peers.

5 CONCLUSIONS

The "Beyond My Sight" project at Tecnológico de Monterrey demonstrates that the most effective tool for inclusion is often one that restores the student's ability to interact directly with the logic of the subject matter. While the cooperative models of Mondragón University provide an essential social framework, the **Tactile Calculation Rule** provides the technical independence necessary for success in financial and project evaluation fields. True inclusion of students with visual impairments is achieved when the student no longer requires an intermediary to interpret the world of data.

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AM I MY BROTHER'S KEEPER? WHAT THE WORLD'S MAJOR RELIGIONS TEACH US ABOUT INCLUSIVE DESIGN

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ABSTRACT

Inclusive design seeks to ensure that products, services, and educational environments serve diverse populations equitably. In engineering and design curricula, inclusion is often taught through technical standards (e.g., ISO 9241-210 [1]) and accessibility checklists (e.g., ADA guidelines). While these methods improve usability, they can reduce inclusive practice to compliance and risk-avoidance. This paper argues that the ethical teachings of major world religions (specifically Christianity, Islam, Hinduism, and Buddhism) provide rich moral vocabularies that can deepen designers' sense of responsibility. Drawing on inclusive design literature [2], engineering ethics scholarship [3], and design justice theory [4], alongside selected scripture passages [5], [6], [7], [8], we identify convergent themes such as relational responsibility, justice, duty, compassion, and non-harm. These religious motifs are interpreted as pedagogical heuristics. For example, "Am I my brother's keeper?" (Genesis 4:9 [5]) frames users as neighbours to care for, while Qur'an 4:135 [6] urges standing firmly for justice even at personal cost. We then outline how these themes translate into learning outcomes and assessment strategies (e.g., broader stakeholder mapping, equity audits) for design courses. Drawing on inclusive and participatory design and design justice principles [9], [4], the paper sketches a preliminary evaluative framework (reflective coding rubrics, co-design portfolios) for classroom implementation. In emphasising religion as a cultural ethical resource (not doctrinal dogma), we propose it as one path toward intercultural moral engagement. This approach reframes inclusion as an ongoing ethical reflection and aligns with calls to embed diversity and global perspectives in engineering education [4], [10].

Keywords: Inclusive design, religious ethics, design education, moral responsibility, equity, co-design, intercultural pedagogy

1 INTRODUCTION

Inclusive design is now central to engineering and product design education, reflecting broader commitments to equity and diversity. Standards such as ISO 9241-210 and accessibility legislation (e.g., ADA, AODA) institutionalise human-centred design and disability access [1], [2]. Professional guidance urges that accessibility be treated like any other engineering consideration, and UNESCO's SDG 4 emphasises respect for diversity in educational practice [10]. There is broad agreement that inclusion matters.

Yet instruction often remains procedural. Inclusive design can become checklist compliance rather than an ethical orientation. Students may learn to meet WCAG criteria without examining who remains excluded. Engineering ethics scholarship warns that rule-based training alone does not cultivate moral imagination or sustained commitment [15], [17]. Tokenistic inclusion can satisfy standards while failing marginalised users. Holmes and others argue that inclusive design must interrogate who is served and excluded by prevailing systems [11], [4]. The challenge is not awareness of standards, but depth of ethical engagement.

This paper proposes that the moral vocabularies of major religious traditions (e.g., Christianity, Islam, Hinduism, and Buddhism) can enrich inclusive design pedagogy. Globally, most people identify with a religious tradition [12], and religious narratives continue to shape moral intuition. These traditions articulate enduring ideals—justice, duty, compassion, stewardship, non-harm—that resonate strongly with inclusive aims. The Bible's Genesis 4:9 asks, "Am I my brother's keeper?" [5]; Qur'an 4:135

commands standing firmly for justice even at personal cost [6]; the Hindu scripture, Bhagavad Gita (2.47) calls for dutiful action without selfish attachment [7]; the teachings of Buddha, captured in the Dhammapada (verse 5), instruct that hatred is overcome only by non-hatred [8]. Such motifs provide culturally resonant frames for ethical reflection.

Our guiding question is: How might ethical principles from these traditions inform inclusive design pedagogy without proselytising? We treat religion as a cultural and narrative resource (not doctrinal authority) capable of expanding ethical imagination in plural classrooms. This approach complements secular frameworks such as care ethics [13] and value-sensitive design [3] rather than replacing them.

2 WHAT RELIGION ADDS PEDAGOGICALLY

Secular design ethics already offer robust tools. Religious ethics contribute distinct pedagogical strengths.

First, they are embedded in lived moral communities. Religious ethics are transmitted through story, ritual, and shared identity. Engaging these narratives acknowledges that students' moral reasoning is often shaped outside academic philosophy [13]. Connecting design dilemmas to familiar moral worlds can deepen engagement.

Second, religious narratives possess symbolic power. A verse such as "love thy neighbour as thyself" (Matthew 22:39) [5] evokes relational obligation more vividly than abstract directives. Stories cultivate empathy and emotional reasoning [13], [14]. Framing exclusion as a modern Good Samaritan scenario, for example, can render design consequences morally tangible.

Third, religious traditions have a global reach. The four traditions addressed here encompass a majority of the world's population [12]. Identifying convergent ethical themes—reciprocity, justice, compassion—supports intercultural dialogue and demonstrates that inclusion is not uniquely Western or secular [17].

These strengths require caution. Religious traditions are internally diverse and historically entangled with exclusionary systems. Our approach is selective and critical; foregrounding motifs aligned with inclusion while encouraging scrutiny of tensions and abuses. The aim is dialogical expansion, not moral harmonisation.

3 METHOD AND LIMITATIONS

This conceptual study synthesises inclusive design scholarship, engineering and information ethics, and selected primary religious texts. Using thematic coding, we identified recurring ethical motifs: human dignity, responsibility, justice, duty, non-harm, and compassion. We then mapped these motifs to inclusive design principles.

This study examines four religious traditions, selected in descending order of global population [12]. Each tradition encompasses substantial internal diversity; accordingly, our analysis focuses on widely recognised themes rather than offering a comprehensive account of doctrine. Future research should expand this scope to include smaller and Indigenous traditions.

We offer theoretical framing rather than empirical results. Proposed learning outcomes and assessment tools are exploratory and intended to guide future classroom research.

4 ETHICAL CONVERGENCE AND DESIGN IMPLICATIONS

Across traditions, five recurring themes align closely with inclusive design:

4.1 Christianity: Relational Responsibility

Christian ethics emphasise neighbour-love and stewardship. Cain's question, "Am I my brother's keeper?" [5], implicitly affirms mutual responsibility. Jesus' command to love one's neighbour as oneself and the *Parable of the Good Samaritan* [5] depict moral action as concrete care for the vulnerable.

Design implication: Inclusive design becomes relational stewardship. Users are neighbours whose dignity warrants equal consideration. Assignments may require students to narrate designs from marginalised perspectives or evaluate projects through care-ethics criteria [13]. The emphasis shifts from compliance to responsibility for real persons.

4.2 Islam: Justice and Structural Equity

Islamic ethics foreground justice and accountability. Qur'an 4:135 calls upon believers to uphold justice even at personal cost [6]. The protection of the vulnerable and the obligation of almsgiving (zakat) reinforce communal responsibility.

Design implication: Inclusion requires structural analysis [17]. Students assess distributional impacts: Who benefits? Who bears costs [17]? Projects incorporate equity audits and power mapping consistent with design justice principles [4]. Justice becomes a systemic lens rather than an afterthought.

4.3 Hinduism: Duty and Non-Harm

The Bhagavad Gita (2.47) teaches disciplined action according to duty (dharma) without attachment to reward [7]. The broader principle of ahimsa emphasises minimising harm to living beings.

Design implication: Inclusion is a professional obligation. Designers treat accessibility and equity as intrinsic duties rather than optional enhancements. Harm (whether physical, psychological, or social) is ethically unacceptable. Reflection exercises may contrast duty-centred reasoning with market-driven incentives.

4.4 Buddhism: Compassion and Interdependence

The Dhammapada teaches that hatred is overcome by non-hatred [8]. Buddhist ethics center on compassion (karuṇā), non-harm, and interdependence. All actions ripple through networks of relation.

Design implication: Participatory practice is an ethical necessity. Co-design, stakeholder collaboration, and mindfulness of unintended consequences embody interdependence [3], [4]. Students document how community input meaningfully reshapes design outcomes.

4.5 Cross-Tradition Convergence

Despite doctrinal differences, the traditions converge on principles central to inclusion:

- Human dignity: Every person possesses inherent worth.
- Responsibility: We are accountable for the impact of our actions on others.
- Justice: Fair distribution and procedural integrity matter.
- Non-harm: Preventing suffering is a moral priority.
- Compassion: Empathy guides ethical action.

These themes parallel secular care ethics and value sensitive design [3] while grounding them in globally resonant narratives. Importantly, compassion must extend beyond sentiment to structural transformation. Design Justice scholarship reminds us that exclusion is embedded in sociotechnical systems [4]. Religious motifs intensify rather than soften this critique by framing inequity as moral failure.

5 PEDAGOGICAL APPLICATIONS

5.1 Learning Outcomes

Students exposed to these frameworks should demonstrate:

- Broadened stakeholder identification, extending concern to marginalised communities.
- Explicit ethical reasoning in design justifications (e.g., duty, justice, care).
- Structural analysis of inequities affecting user experience.
- Reflection on long-term societal impact and unintended harm.

These outcomes move beyond checklist compliance toward moral reflexivity.

5.2 Assessment Strategies

Possible evaluative tools include:

- Pre/post reflective coding of ethical language and empathy depth.
- Stakeholder mapping rubrics assessing inclusion breadth and power awareness.
- Equity audits applied to case studies.
- Review of co-design documentation demonstrating shared decision-making.

Rubrics integrate ethical reasoning alongside technical criteria, signalling that inclusion is a core competence.

5.3 Illustrative Classroom Application

In a design studio, students first apply standard accessibility guidelines. They then revisit prototypes using four framing questions: Who is my neighbour? Where is injustice embedded? What is my duty? Who may be harmed? Teams document how these lenses alter priorities and stakeholder engagement. Comparative analysis can measure shifts from compliance language to justice-oriented reasoning.

6 SAFEGUARDS IN SECULAR CONTEXTS

To preserve pluralism, participation should remain voluntary and analytical rather than devotional in nature. Religious texts can be presented as cultural case studies, similar to philosophical sources, allowing them to be examined critically rather than treated as doctrine. Juxtaposing multiple traditions helps prevent privileging any single narrative, while encouraging critical reflection on historical exclusions within religions fosters a more honest and inclusive discussion. Collaboration with humanities experts further supports accurate and responsible representation. Together, these safeguards ensure that religious ethics function as interpretive resources rather than as prescriptive authority.

7 DISCUSSIONS

Technology embeds values [15]. Making ethical commitments explicit counters technocratic neutrality. Religious narratives can reinforce participatory and justice-oriented design movements, offering culturally diverse rationales for similar goals. Their inclusion broadens moral vocabulary in global classrooms.

Empirical research is needed. Comparative studies could evaluate whether religion-informed modules increase stakeholder breadth, justice awareness, or participatory rigor relative to standard inclusion training. Such inquiry could clarify the pedagogical value of narrative-based ethical framing.

8 CONCLUSIONS

Engaging major religious ethics as cultural resources can deepen inclusive design education. Without replacing secular theory, these traditions enrich ethical imagination through stories of responsibility, justice, duty, compassion, and non-harm. When applied critically and pluralistically, they transform inclusion from a procedural requirement into a sustained moral stance. Inclusive design thus becomes not only a technical practice but an ethical dialogue attentive to human dignity across cultural boundaries.

9 EXTENDED ANALYSIS: STRUCTURE, POWER, & MORAL IMAGINATION

While the convergences identified above are conceptually compelling, their pedagogical force depends on how they are translated into sustained structural critique. Inclusive design frequently falters not because designers lack goodwill, but because institutional norms, market pressures, and inherited infrastructures channel attention toward dominant users. Religious ethical narratives can disrupt this narrowing of concern by reframing exclusion as a violation of shared moral identity.

Relational responsibility, for example, can be extended beyond interpersonal empathy to institutional accountability. If the “neighbour” includes communities historically marginalised by race, disability, gender, or language, then ignoring structural barriers becomes ethically untenable. Students can consider and analyse how procurement policies, platform monetisation models, or data collection practices advantage some groups over others. In this sense, the brother-keeper question becomes systemic: not only “Did I design well?” but “Does the system I am participating in exclude others?”

Similarly, Islamic traditions of justice underscore impartiality and courage in confronting power. In classroom dialogue, this may translate into examining how design teams themselves reproduce inequity—whose voices are heard in brainstorming sessions, whose labour is credited, and whose expertise is discounted. Justice becomes reflexive: students analyse their own positionality within collaborative work. This internal dimension complements external equity audits and aligns with calls to interrogate sociotechnical bias in algorithms and infrastructures [3], [4], [16].

Hindu notions of duty can also be reframed structurally. Rather than limiting dharma to individual obligation, educators may highlight its social dimension: professional roles carry responsibilities toward collective flourishing. Engineering codes of ethics similarly articulate duties to public welfare. Students might compare dharma with contemporary professional standards, asking whether current incentives

adequately reward inclusive labour. Such comparisons invite critical reflection on how institutional reward systems sometimes discourage inclusive practice.

Buddhist interdependence provides a powerful counter to individualistic design paradigms. Dependent origination suggests that harms propagate through networks; a seemingly minor exclusion may compound across time and space. Classroom exercises could map cascading effects of design decisions (e.g., how inaccessible transit affects employment, healthcare access, or educational attainment). Visualising these interconnections helps students perceive inclusion as preventative justice rather than reactive accommodation.

10 INTEGRATIONS WITH EXISTING DESIGN FRAMEWORKS

Religion-informed framing should not stand apart from established design methodologies but interweave with them. Human-centred design, participatory design, and Design Justice already emphasise empathy, stakeholder voice, and equity [4], [9]. Religious narratives can function as entry points that motivate rigorous methodological application.

For instance, stakeholder mapping exercises grounded in justice can be paired with ISO human-centred design processes [1], [4]. Value Sensitive Design's tripartite investigations—conceptual, empirical, technical—can incorporate questions of duty and non-harm [3]. Co-design workshops may open with narrative prompts that humanise technical constraints. Rather than adding separate modules, religious ethics can serve as interpretive overlays, enriching familiar practices.

Importantly, this integration must avoid superficial symbolism. Simply quoting scripture without altering the design process risks trivialisation. The measure of success is methodological change: broader stakeholder recruitment, more transparent decision-making, documented iteration in response to marginalised feedback, and explicit articulation of trade-offs affecting vulnerable communities.

11 INTERCULTURAL DIALOGUE AND GLOBAL CLASSROOMS

Design and engineering education increasingly occurs in transnational settings. Students collaborate across continents and cultural contexts. Invoking multiple religious traditions can signal respect for diverse moral heritages and decentre exclusively Western ethical paradigms. In multicultural classrooms, comparative discussion of justice, compassion, and duty may foster mutual recognition and intellectual humility.

Such dialogue can also surface disagreement productively. Students may interpret justice or duty differently based on their cultural background. Structured debate, grounded in respect, encourages critical thinking and prevents homogenisation of ethical language. The classroom thus becomes a microcosm of global design practice, where intercultural negotiation is routine.

This approach aligns with educational movements promoting global citizenship and intercultural competence [10]. Inclusive design, framed through shared yet diverse moral vocabularies, prepares for professional practice in plural societies.

12 LIMITATIONS & FUTURE RESEARCH

Several limitations merit acknowledgement. First, textual selection inevitably simplifies complex traditions. More nuanced engagement would require collaboration with scholars of religion and area studies. Second, student reception may vary; some may welcome narrative framing, while others prefer strictly secular analysis. Mixed-method empirical research (including surveys, focus groups, and artifact analysis) should evaluate learning outcomes.

Third, care must be taken to avoid reinforcing majoritarian dominance by focusing only on large traditions. Future work should incorporate Sikh, Jewish, Indigenous, and humanist perspectives to broaden representation. Finally, measurable indicators of ethical growth remain contested. Developing reliable rubrics for empathy, justice awareness, and structural reasoning is an ongoing challenge.

Despite these limitations, the proposed framework offers a promising direction. It situates inclusive design within moral traditions that many students recognise, while preserving secular academic integrity. By linking narrative meaning with methodological rigor, educators can cultivate designers who see inclusion not merely as a requirement but as an ethical calling.

13 TOWARD A REFLEXIVE ETHIC OF INCLUSIVE DESIGN

Ultimately, the value of engaging religious ethics lies not in citation but in cultivating reflexivity. Designers routinely navigate tensions among cost, feasibility, aesthetics, and timelines. Ethical reflexivity requires asking how those constraints are distributed across populations. Who absorbs inconvenience? Who bears risk? Who is rendered invisible? Religious narratives often dramatise precisely such moral crossroads: moments when comfort or loyalty conflicts with justice or compassion. Bringing these stories into design critique underscores that exclusion is rarely accidental; it is frequently the outcome of unexamined priorities.

Embedding reflexivity in studio culture can involve recurring ethical checkpoints. At major project milestones, teams might articulate which stakeholders have gained voice since the previous review and which remain peripheral. They may document decisions where efficiency was balanced against equity and justify those trade-offs publicly. Over time, such practices normalise ethical transparency alongside technical documentation.

Moreover, positioning inclusive design as a moral dialogue can counter professional burnout. When inclusion is framed solely as compliance, it may feel burdensome. When understood as participation in a broader human commitment to dignity and justice, it can become motivating. Religious traditions sustain moral communities through shared narratives of purpose. Similarly, design education can cultivate communities of practice oriented toward equity.

The framework advanced here, therefore, seeks to widen, not narrow, ethical imagination. By drawing from multiple traditions, it affirms that the aspiration toward justice, compassion, duty, and non-harm transcends single worldviews. Inclusive design education, enriched by these narratives and anchored in rigorous methodology, prepares engineers and designers to act responsibly, courageously, and imaginatively within diverse and deeply interconnected societies.

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THE IMPACT OF STAGE TRADITION DERIVED ROLE-PLAY ON DESIGN THINKING PEDAGOGY

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ABSTRACT

Design education often employs embodied approaches such as role-playing to foster inclusivity and empathy. However, achieving psychologically and physically embodied empathy remains challenging. This study explores how role-playing in interdisciplinary design education can benefit from long-established stage traditions. We review previous role-play practices in design and apply a theatre-based method through a comparative case study. A two-day intensive Design Thinking course was delivered to two interdisciplinary university cohorts (2024: n=22; 2025: n=18). In 2024, conventional design skits were used for final presentations. In 2025, the programme was co-taught by a theatre-trained facilitator, adapting Konstantin Stanislavski's psychological character analysis to design pedagogy. This method integrates user needs with psychological motivations to embed narrative depth in service interactions. Surveys assessed interests, team contributions, learning gains, project outcomes, and free comments. Results indicate that the 2025 cohort emphasised embodied emotional understanding and relational designs more strongly than the task-focused cohort of 2024. Project themes shifted from infrastructural solutions to equity, diversity, inclusivity, and well-being (e.g., recharge zones, nature immersion, disability support). The findings suggest that integrating stage-based design can significantly influence the student output and learning outcomes. Future research should examine integration within a broader design curriculum.

Keywords: Inclusivity, empathy, stage, theatre, design education

1 INTRODUCTION

1.1 Inception of Psychological Theatre + Lack of Clarity in Role Plays of DT

Today, design education increasingly addresses equity, diversity, and inclusion; with that, pedagogical approaches must also move beyond procedural tool instruction toward deeper psychological and relational understanding.

Design Thinking (DT) is understood as an iterative approach to design education that looks for the needs of the end-user via multiple methods, and ideas are generated, tested, and revised based on user feedback (Carroll et al., 2010) [1]. In this study, Design Thinking also refers to the title of the two-day intensive course examined. In design education, theatre-inspired methods often are used in the form of role-play, and it appears as a common method in design-resource toolkit repositories. Facilitators may also use improvisation, costumes, props and warm-up activities (designkit.org, Simsarian, 2003) [2]. The pedagogical merit of role-play remains unclear.

In the 20th century, Konstantin Stanislavski created a method of character analysis based on psychology - *perezhivanie* or “experiencing in performance”. In this method, the actor aligns their psyche with an imagined one of a character and sustains a continuous inner life. This approach has been discussed as a way to build creative understandings of users in design research (Postma et al., 2010) [3].

1.2 Current Methods to Cultivate Empathy

In previous research, the skills of developing empathy for users and capturing their needs in a human-centred way require learning over time. It is reflected as a process of cultivation within and outside the theatre's scope. In past studies theatre methods were explored for cultivation of empathy in design contexts. For example, Saito et al. (2022) [4] used storytelling and Forum Theatre as a way of encouraging reflection on emotions and wicked problems in DT-inspired workshops. Liu et al. (2024) [5] used empathy-focused experiential learning as part of design education through the 4E framework (Experience, Empathy, Exploration, and Evaluation) over a 10-week implementation through 2-hour

weekly sessions. However, intensive DT courses often lack the extended implementation periods used in previous studies, raising the question of whether shorter empathy-oriented interventions could also be effective.

1.3 Stanislavski's Character Analysis for Design Pedagogy

Stanislavski supported the idea by dividing the role creation into smaller units or “bits”, during which a specific task stemming from a character’s inner necessity is performed (example: “I want to... in order to...” (Hobgood, 1973 pp.150-151) [6]. His character analysis has been suggested as a method for architectural design by systemising imagination and creativity across disciplines (Öztek and Erkılıç, 2026) [7]. Authors introduced the concept of *vitalness*, which underscored two Stanislavskian exercises for character analysis: *given circumstances* and *magic if*. Vitalness is explained by Oztek & Erkilic as a common ground between architecture and theatre’s ability to create a multi-layered milieu of dynamic life. Research on the comparative effects of Stanislavski-inspired role-play on DT workshop participants remains scarce, however. This study examines whether Stanislavski-inspired role-play affects beginner university students’ engagement with empathy and user understanding within a two-day DT course. We surveyed participants with open-ended questions to investigate their outlooks after the workshop. Through analysis of qualitative data and visuals, the study asks the following question: Does Stanislavski-inspired role analysis increase: (a) specificity of user characterisation (b) specificity of product/service features, and (c) expressed empathic reasoning?

1.4 Comparison of Existing Role Play Precedents and Stanislavskian Theatre Use

Prior work has identified the usefulness of role-play for visualisation and systemisation; however, the participants remained more presentation-oriented rather than psychologically engaged with the users (Boess, 2006) [8]. Stanislavski-derived character analysis may lead to a more exploratory way of role-play via the emphasis on user motivation and embodied perspectives. Therefore, this study asks whether Stanislavski-inspired facilitation can deepen empathic reasoning of early DT course learners.

2 METHODS

2.1 Study Design

A comparative design case study was conducted on two consecutive two-day intensive Design Thinking (DT) courses (2024: n=22; 2025:18). The course was offered as part of curriculum in interdisciplinary science and innovation field at the undergraduate level.

Participants were primarily third-year undergraduate students at (institution Z) taking an interdisciplinary innovation and science curriculum. Approximately three-quarters of participants were Japanese, while the remaining participants were international students, primarily from China and Taiwan, with an approximately equal gender distribution.

Both cohorts were exposed to the same team-based syllabus and learning objectives. The schedule followed a Double Diamond structure, with Day 1 focusing on problem space and Day 2 on solution development.

The main difference between the cohorts was the pedagogical treatment of role-play.

In 2024, participants used a conventional skit form to present design. In 2025, the course was co-taught by the Author 1, a formally trained theatre director, who introduced Stanislavski’s character psychology analysis into the DT process.

It was examined whether the intervention influenced:

- (a) specificity of user characterisation
- (b) specificity of product/service features
- (c) expressed empathic reasoning

These three dimensions were retained as interpretive lenses for organising results, rather than being operationalised as a full score rubric.

2.2 Pedagogical Conditions

Role-play in 2024 was primarily used as a presentation, in which students presented user scenarios with solution propositions in short skits without specific acting guidance. They were encouraged to express user needs, show how the proposed solution addressed those needs, use props or prototypes, and involve all team members. The interviewed user did not have to be represented by the same student in the skit. While examples of design and non-design skits were shown, no specific acting guidance was provided.

In 2025, two Stanislavski-inspired modules were introduced by author 1. The intent was to shift the participants' understanding of role-play from presentation to exploration. The modules stem from user interviews with a focus on imagining the user's lived experience. Before showing the modules, we explained that a user (or any other character performed) **always** has a series of *psychological* needs that motivate their actions. The needs were framed via action-based verbs. The two modules that we implemented after the explanation were as follows:

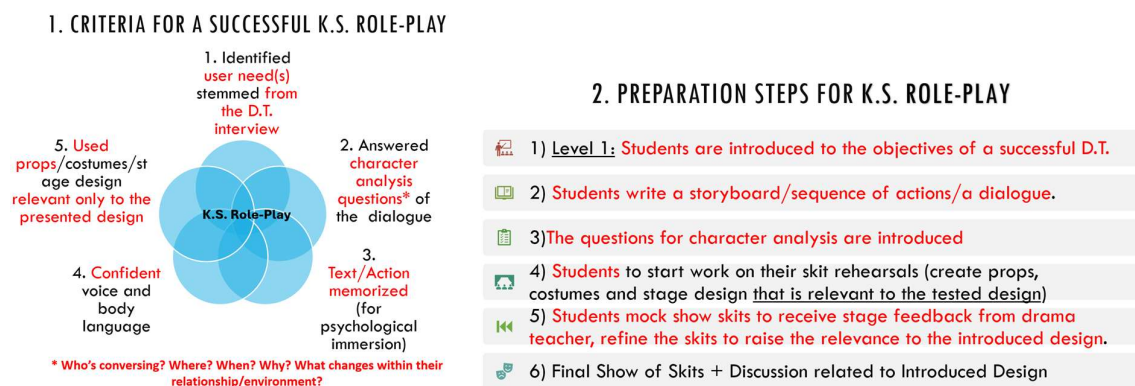


Figure 1. Stanislavski System Inspired Modules Taught by Author 1

2.3 Data Collection

Data was collected primarily via post-course surveys, documentation of final project outputs, and video materials of the workshop process. The surveys included multiple open-ended questions, such as the presented idea content (Q5), points of interest (Q6), roles in the team (Q7), gains from class (Q8), and optional comments (Q12). The time of reflection was automatically measured. Cross-item descriptive coding across Q5-Q8 and Q-12 was used to analyse the responses. Three interpretive lenses were used to analyse the code: user characterisation specificity, product/service specificity, and empathic reasoning. Indicators such as— role-play as presentation vs. exploration; emphasis on DT tools vs. process salience; interview vs. fieldwork salience and self-reflection/value shift language were counted across cohorts.

Percentages reported in the results indicate the proportion of responses in each cohort that contained each coded indicator at least once. Project outputs were categorised by dominant orientation, such as infrastructural or relational/EDI-focused solutions.

Table 1. Coding framework used for qualitative analysis

Lens	Main indicators	Survey items
User characterisation specificity	Constrained-persona framing; interview/fieldwork salience	Q5, Q6
Product/service specificity	DT tool/process salience; product or feature detail	Q6, Q8
Empathic reasoning	Embodied/affective empathy; role-play as understanding; self-reflection/value-shift	Q6, Q8, Q12

2.3.1 Data Screening

A predefined codebook aligned with the RQs was applied consistently across cohorts to reduce interpretive drift. As the study is cohort-based and exploratory, differences between the cases will be interpreted as pedagogical associations rather than causal claims.

3 RESULTS

The 2025 intervention with Stanislavski-inspired facilitation, showed an increase in user-character specificity and embodied empathic reasoning when compared to the 2024 cohort, whereas the 2024 cohort showed stronger focus on DT course tools and process language.

Table 2. Comparison of coded indicators across cohorts

Indicator (code)	2024 (n=22)	2025 (n=18)	Lens / note
Constrained-persona framing in idea statement (Q5)	27.3% (6/22)	88.9% (16/18)	A – User specificity. 2025 much more often embeds a psychologically/conditionally specified user in the problem statement.
Role-play mentioned as part of learning (Q6)	18.2% (4/22)	50.0% (9/18)	Role-play is more salient in 2025 reflections.
Role-play framed as empathic understanding (Q6)	4.5% (~1/22)	22.2% (~4/18)	C – Empathic reasoning. 2025 more often treats role-play as a way to “be in their shoes”.
Embodied/affective empathy language (Q6–Q8)	9.1% (2/22)	44.4% (8/18)	C. Marked increase in references to bodily and emotional understanding in 2025.
Interview/fieldwork named as key element (Q6)	40.9% (9/22)	27.8% (5/18)	A + C. 2024 leans more on interview-driven, cognitive access; 2025 more often claims interviews are insufficient without embodiment.
DT tool/process salience (Q6)	45.5% (10/22)	38.9% (7/18)	B – Process/feature specificity. DT mechanics are foregrounded more consistently in 2024.
Self-reflection/value-shift language (Q6)	13.6% (3/22)	27.8% (5/18)	C + meta-learning. 2025 more often reports shifts in mindset, blind-spot awareness, or ambiguity tolerance.

Cross-item descriptive coding (Q5–Q8, Q12) showed a shift from process-centred reflection in 2024 toward constrained-persona framing and embodied empathic reasoning in 2025 (Table 2).

Constrained-persona framing in design outputs rose from 27.3% (6/22) to 88.9% (16/18) in 2025, with the latter cohort mentioning disability, injury, low-energy thresholds, mental drainage, and recharging needs. This output-level difference suggests substantially higher user framing specificity in 2025.

Second, role-play references increased from 18.2% (4/22) to 50.0% (9/18). Importantly, role-play was more frequently defined as a method for empathic understanding in 2025 (22.2%, 4/18), than in 2024 (4.5%, 1/22). Consistent with this, embodied/affective empathy language rose from 9.1% (2/22) in 2024 to 44.4% (8/18) in 2025, indicating a stronger orientation toward experiential perspective-taking.

In contrast, interview/fieldwork salience (Q6) remained more present in 2024. In 2024, interviews and the “5 Whys” were more frequently emphasised as the main mechanisms of learning, whereas the 2025 cohort responses more often mentioned embodied enactment and user motivation.

Finally, self-reflection/value-shift language increased from 13.6% (3/22) in 2024 to 27.8% (5/18) in 2025. Overall, the findings suggest a cohort-level shift from procedural articulation toward psychologically grounded user understanding and embodied empathic reasoning in 2025.

4 DISCUSSIONS

Findings suggest that Stanislavski-informed role-play can shift participants from skit performances for presentation use to a more exploratory engagement with user psychology. Compared to the cohort of 2024, the participants of 2025 reflected greater focus on constrained user perspective, empathic embodied reasoning, and language reflecting user understanding.

A possible explanation is that the Stanislavski-informed exercises motivated the participants to consider internal objectives and interpersonal situations rather than leaping to solutions. Role-play functioned not only as a device for communication, but also as a method for inquiry. Instead of resolving the problems of the users instantly via design ideas, the participants seemed to invest time in reflecting on ambiguity, misunderstanding and emotional perspectives.

Meanwhile, the 2024 cohort showed stronger understanding of DT course tools and process-related language, suggesting that theatre-inspired facilitation can shift attention from procedural aspects to psychological analysis. Instead of viewing these aspects as opposing, the findings indicate that both can have a synergistic pedagogical value in design education.

Limitations of the study include a small sample size and a comparatively short intervention of only 2 days. Furthermore, there might have been a potential instructor effect, as author 1 is a theatre director, and lastly, a coding interpretation bias is also possible.

Future research should potentially explore how psychological theatre inspired role-play could be integrated in a long-term design education curriculum – whether the effects repeat in different student populations and how can embodied empathy-oriented methods structurally interact with technical design instruction.

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DESIGN THINKING IN PRACTICE: AN INTERNATIONAL CROSS-CASE EDUCATION COMPARISON OF PEDAGOGICAL PATHWAYS

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ABSTRACT

This paper presents a comparative educational case study examining how two differently framed design education projects contributed to student learning and innovation-oriented outcomes within the context of sustainable agricultural technology. The study compares two parallel university courses conducted in the UK and Sweden in collaboration with the agricultural technology company DeLaval. Rather than claiming broad pedagogical generalisations, the paper focuses specifically on how differences in project structure, technological framing, user access, and collaboration influenced student learning processes and design outcomes. The first case involved 11 individual projects completed by Advanced Design Management students at Aston University, where students developed user-centred product-service concepts informed by field visits, interviews, and market analysis. The second case involved five engineering design students at Mälardalen University who developed a virtual reality (VR) assembly-training prototype for the DeLaval VMS V300 milking robot. A cross-case qualitative analysis was conducted using design thinking framework dimensions including scope definition, degree of user engagement, working structure, contextual familiarity, and iteration practices. Findings indicate that open-ended projects encouraged broader conceptual exploration but created challenges in contextual understanding, while technology-constrained projects supported technical depth but limited conceptual diversity. Across both cohorts, limited access to users and unfamiliarity with agricultural contexts affected iteration quality and confidence in decision-making. The findings support a more cautious conclusion that international thematic alignment can enrich reflection and expose students to complementary design approaches when supported through structured interaction and contextual access. The study contributes practical insights for educators designing cross-institutional sustainability-focused design projects.

Keywords: design education, design thinking, design process, agriculture, virtual reality, service design

1 INTRODUCTION

The agriculture industry offers a highly important area where even small innovations can have significant impact. As the largest source of food globally, agriculture has undergone substantial development throughout history, more recently, has experienced increasingly severe labour shortages. With the world's population expected to increase by two billion people by 2050, continuous innovation is essential, creating new educational opportunities that support further advancement. This paper examines two independent international design education projects situated within the broader context of sustainable agricultural innovation, recognising that agricultural practices and challenges are inherently shaped by geographic and cultural contexts. Sweden and the UK are significant contexts in the dairy industry as they represent complementary environments for agricultural innovation. Sweden is strongly associated with advanced, sustainability-driven dairy technology and a high level of automation, driven by innovation-led companies. In contrast, the UK exhibits more diverse farming practices, which shape technology adoption in response to varying farm sizes, labour constraints, and the feasibility of integrating new solutions [1]. In recent years the use and integration of emerging technologies in engineering and design education settings have set a new tone, where integration challenges present complex learning experiences for students, educators, and organisations alike. A user-centred approach

is increasingly important in this context, ensuring that user needs and expectations are systematically integrated throughout the development process.

Prototyping remains a foundational activity in advancing design efforts towards functional and purposeful outcomes. However, it now operates within an increasingly iterative and digitally enabled product development landscape [2]. In recent years, virtual simulations and digital twins have emerged as cost-effective and scalable means of evaluating and refining design concepts prior to physical realisation. In parallel, Extended Reality (XR) technologies, encompassing immersive and interactive digital environments, are reshaping established design practices and challenging conventional prototyping paradigms [3]. When teaching the development of products that incorporate emerging technologies, it is critical to ensure that user needs and expectations are systematically integrated throughout the development process. It is also important to raise awareness of the importance of user-centred approaches as they increase the likelihood that resulting tools are not only technically robust, but also useful, usable and accepted [4,5]. At the same time, there remains sustained interest in understanding how learning processes unfold within complex, multidisciplinary product development projects, particularly in relation to building a shared knowledge base among diverse stakeholders [6]. This study aims to propose the use of a broader educational ecosystem [7], connecting international partners and different approaches for diversity and comparisons linked to design thinking phases [7,8,9], and contextual challenges within the agricultural sector. Thus, this design education initiative showcases how international student cohorts pursuing different user-driven perspectives, can engage through pedagogical and thematically aligned pathways. It further illustrates how opportunities emerged as potential outcomes rather than guaranteed results, and how the degree of facilitation and preparatory setup can influence the extent to which students were able to engage in dynamic, cross-border design processes.

2 METHODOLOGY

This explorative comparative study draws on two independently conducted project-based university courses linked through a shared agricultural innovation theme. To allow for analytical transparency, the comparison was structured using four predefined analytical dimensions: (1) scope definition, (2) user engagement, (3) working structure, and (4) contextual familiarity. Data sources included student reports, reflective documentation, presentations, prototype outcomes, interviews, survey feedback, and instructor observations collected throughout the duration of both courses. By study adopts a qualitative cross-case synthesis approach to identify recurring patterns, contrasts, and pedagogical implications emerging from the two educational settings. The analysis focused specifically on how project framing influenced student iteration practices, stakeholder engagement, and concept development. The study draws on two educational cases: 11 individual projects completed by final-year Product Design Management students at Aston University, and one collaborative XR-focused engineering design project conducted by five fifth-year students at Mälardalen University. Findings are based on project outputs, observations, reflections, presentations, interviews, surveys, and design documentation developed throughout the courses. The methodological approach combines exploratory qualitative inquiry with project-based learning and design research methods, emphasising iterative processes, user-centred design, prototyping, and reflective learning across both educational contexts.

At Aston University, the student project was developed to create innovative product service systems for DeLaval to enhance added value to their products and services in the Advanced Design Management module. The project was conducted over a 12-week period. Learning objectives were established to enhance student ability to apply design as a strategic tool for planning, developing and innovating products and services as part of key design management activities as well as to discuss and analyse design strategy and business elements. The module included lectures on service design, systems-thinking, user-centred design, and a guest lecture covering the dairy industry, dairy cows, milking systems and DeLaval all of which provided useful knowledge for students to carry out their products. It also contained individual activities and tutorial sessions in which students could apply what they learned during lectures and discussed with the tutor. Students were encouraged to apply design thinking, a user-centred approach and iterative design processes that enable continuous improvement [8]. A visit was made to a family-run dairy farm located in Staffordshire, UK in November 2024 to provide students with an opportunity to observe dairy cows, machinery and the environment and to have conversations with farmers. The module comprised two sets of tasks linked to formal assessments as follows: 1) generating creative reports presenting their understanding about product service systems, research

findings from both secondary and primary research and proposed design directions accompanied by client presentations; and 2) submitting creative reports demonstrating product and service prototypes developed from insights gained during the research, along with presentation boards. The first and the second tasks were completed in week 7 and week 12.

At Mälardalen University the student project was set to explore Extended Reality (XR) and how it could be made useful within the agricultural sector, more specifically by developing a Virtual Reality (VR) experience capable of supporting assembly training of the DeLaval VMS V300 milking robot. To enable an immersive learning experience, this eliminated the need to handle heavy parts and reduced the risk of injury and equipment damage. The 20 weeklong project experience involved three sprint review sessions, lectures such as typology optimisation and Virtual/Augmented Reality simulation that supported the project-based course setup. Throughout the project students explored different tools that could be used for the design of the VR environment like eDrawing (compatible with Solidworks), Unite (a game engine that requires C# expertise), and Godot (a free game engine enables users to design using fewer complex scripts). Godot was chosen for the development. The project made sustainability considerations where energy efficiency took consideration to the type head-mounted-display that would be preferable, also waste reduction concerning battery lifespan and minimising environmental impact of devices being used. Interviews and a survey were used to collect farmers' experiences and reveal potential constraints or insights for how XR could be of use in their work. The project was assessed based on a) Function verification, b) Material selection, c) Design validation, d) Simplified life-cycle analysis and sustainability analysis, e) Dimensioned construction drawings, f) Validated calculations, g) Oral presentation, and h) Technical report. In combination with the project a separate assignment was needed to complete the overall course. For this, a digital prototyping supporting tool [9], also known as ePST was prepared together with a prototyping reflection report. This assignment was provided for everyone to fill out, outlining the different types of prototyping experiences they each encountered throughout the given project. The ePST template was also assessed according to level of engagement, degree of meaningful content, and its depth and richness.

2.1 Pedagogical exchange

The two case studies were analysed through across four key aspects: scope, user engagement, working structure, and contextual familiarity through a systematic qualitative comparison of the two pedagogical settings. The comparisons are grounded in differences between constructivist, user-centred and experiential learning approaches at Aston and more structured, technology-mediated, system-focused and collaborative pedagogies at MDU. Data were observed from student project outputs, presentations, reflective reports, and also instructor observations as well as student feedback gathered throughout the courses. To support broader reflection and extend students' understanding of the shared thematic area, teachers encouraged informal knowledge exchange between the project groups. Rather than establishing formal collaboration, the initiative was designed as a pedagogical trigger to broaden perspectives through peer-to-peer sharing of experiences, design approaches, and contextual insights. An online workshop was organised in the early project phase, aligned with the empathy and define stages of the design process. During this session, students presented ongoing work, shared initial findings, and discussed conceptual directions and challenges. This enabled comparison of disciplinary approaches, research methods, and interpretations of agricultural contexts. Due to timetable constraints, further structured meetings could not be implemented. Instead, continued interaction was encouraged as a voluntary, student-driven activity beyond the formal course structure. The exchange aimed to strengthen situational awareness and support reflection on how differing farming practices, user contexts, and design methods can influence problem framing and concept development. Overall, the activity functioned as a means of expanding perspectives through interdisciplinary peer learning rather than formal collaboration.

3 FINDINGS

This section outlines the unique project experiences that characterised their respective outputs.

3.1 Aston University projects

In the first task, students demonstrated their understanding about product service systems through literature review, generated findings from secondary and primary research that informed the identification of problem areas and the ideation of products and services. They used various tools for

user research and market analysis, such as user personas, user journey map, service blueprint, SWOT analysis and benchmarking. Although students had limited access to people in the dairy sector, four students engaged participants from the dairy sector through interviews to identify user needs and explore potential design solutions. One student actively involved dairy farm owners during the design development, evaluation and iteration stages, while another included participant feedback as part of the design refinement process. A wide range of innovative design concepts and directions incorporating products and services were proposed. Key concepts include: Concept 1) a wearable blood monitor – product and service innovation to help dairy farmers rapidly diagnose and treat illness in cows, Concept 2) a product and service monitoring and preventing water pollution in dairy farms, Concept 3) a comprehensive digital platform tailored for South Asian entrepreneurs interested in scaling their dairy business through automated and efficient dairy farming and Concept 4) a hoof care product that helps maintain healthy hooves and prevent lameness. These initial concepts were further advanced in the second task. In the second task, students presented design outcomes developed based on the design concepts and directions suggested in the first task. Insights obtained from the farm visit and conversation with the farmers were reflected in their development processes. Improvements and refinements were made throughout the processes. Some of the students conducted more research to strengthen their solutions and determine details of their designs. The four concepts were suggested as seen below in

3.2 Mälardalen University project

To explore the possibilities of how XR can be used in agriculture the aim of promoting the assembly training of the DeLaval's VMS V300 milking robot presents the potential for visuals communicated in a safe manner. Figure 2 provides a simplified version of the milking robot, provides an overview for easy mounting process, addressing details and process steps. Based on interviews and survey feedback collected, the project group gained additional insights that informed the development of the VR-based assembly prototype. One of the primary challenges identified during the design process was the limited screen resolution, which affected the clarity and precision required for designing and assembling individual components within the virtual environment. To support operators during assembly, the prototype incorporated marked “snap zones” that allowed components to be picked up and attached sequentially. New elements were introduced only once the preceding component had been correctly positioned, thereby guiding users through the assembly process. While the implementation of realistic physics in VR proved challenging, iterative refinement led to improvements in the final prototype. In particular, earlier issues such as screws falling off the virtual work surface were resolved, allowing components to remain in place and ready for use. After user testing opportunities for further refinement added to improve the movement and manipulation of individual parts. One of these refinements focused on authentic handling, as this was highlighted by users as a critical aspect for the experience. In addition, feedback suggested that grasping and positioning components could be made more intuitive to better reflect real-world assembly tasks. Given the overall complexity of the system, users also indicated that stepwise instructional support could enhance usability. In more detail, suggestions included the integration of pictorial instructions and visual cues, such as highlighting or illuminating components to indicate which parts should be selected and connected at each stage. Despite the project constraints prevented the full implementation of all suggested features, the findings point to promising directions for future development and demonstrate the value of iterative user-informed refinement in VR-based design environments.

4 ANALYSIS

The presented design phase comparisons provide a structured basis for the subsequent discussion, where pedagogical framings, contextual access, and design constraints are examined. Table 1 presents the cross-case analysis that also highlights the two educational settings that have generated different forms of learning and design exploration rather than directly comparable outcomes. The Aston University projects demonstrated broader divergence in concept generation, largely due to the open-ended nature of the brief and the individual working structure. Students explored a wide range of product-service opportunities, but several projects remained conceptually broad because of limited access to domain-specific stakeholders and time constraints associated with iterative refinement. In contrast, the Mälardalen University project produced a narrower but technically deeper outcome through the development of a VR-based assembly-training prototype.

Table 1. Cross-case analysis

DESIGN THINKING PHASE	 Aston University (Advanced Design Management)	 Mälardalen University (Engineering Design Project)	COMPARATIVE PEDAGOGICAL INSIGHT	CONTEXTUAL CONTRIBUTION
Empathise	Market analysis, farm visits, stakeholder interviews; service-oriented context exploration	Surveys, interviews on assembly training; workflow analysis	Aston: human-centred exploration; MDU: technical-system focus	Context shapes early problem framing and user inquiry depth
Define	Open-ended opportunity framing from research insights	Constrained brief focused on VR training usability	Aston: broad reframing; MDU: scoped definition	Scope determines design autonomy vs analytical depth
Ideate	Broad concepts (health, pollution, digital services, hoof care)	VR tools, interaction design, training solutions	Aston: conceptual diversity; MDU: technical iteration	Framing influences innovation breadth and direction
Prototype	Conceptual service/product prototypes, presentation artefacts	Functional VR training prototype with interactive features	Aston: conceptual prototyping; MDU: operational system build	Prototyping reflects exploratory vs technical validation
Test	Limited feedback due to access constraints	Iterative user testing of technical design (interaction, guidance)	Aston: direct link to farm user input; MDU: low authentic user feedback loops	Iteration depends on user access and system tangibility
Reflection and Exchange	Online workshop on concepts and approaches	Cross-institutional sharing of VR development experiences	Mainly reflective peer learning	Structured reflection broadens disciplinary awareness
Pedagogical Orientation	Open, user-centred, exploratory design	Constrained, systems and engineering-focused	Complementary pedagogical models	Different framings produce distinct sustainability learning pathways

The constrained technological framing enabled students to focus on implementation challenges, usability refinements, and sequential interaction design within a specific system context. The findings do not provide sufficient evidence to claim that one pedagogical approach is superior to the other. Instead, the cases illustrate how different educational framings influence the balance between conceptual breadth, technical depth, and opportunities for user-centred iteration. Across both institutions, students experienced uncertainty when working within an unfamiliar agricultural context, particularly when attempting to translate user insights into actionable design decisions. The comparative findings therefore suggest that contextual immersion and structured stakeholder access play a significant role in supporting confidence, iteration quality, and design relevance within sustainability-oriented design education. Although the collaboration was not sufficiently extensive to evaluate measurable collaborative learning outcomes, the interaction enabled students to compare disciplinary perspectives, discuss contextual differences between Swedish and UK farming practices, and reflect on alternative design approaches. Consequently, the paper reframes a purpose-driven, international pedagogical exchange, as an exploratory mechanism capable of supporting reflection and perspective-sharing when appropriately facilitated. Despite these differences, both student groups experienced a common challenge in encountering unfamiliar contexts. Agriculture and dairy farming represented new terrain for most participants. While Aston students received introductory input on dairy systems through a guest lecture and a dairy farm visit, many still reported difficulty identifying novel product–service opportunities within an unfamiliar industry. Furthermore, identifying and engaging potential users and stakeholders within the dairy sector for primary research proved to be highly challenging. Similarly, MDU students experienced uncertainty due to limited contextual access, leading them to focus on controllable and well-defined elements, particularly existing technologies. This underscores the importance of contextual immersion and access to primary users, especially in specialised domains where tacit knowledge plays a central role in shaping meaningful design outcomes [2].

The educators at both institutions attempted to mitigate arising challenges by introducing collaborative sessions, shared project pitches, and joint reflective activities that resonates with research that emphasise structured interaction as a means to broaden perspectives and enhance engagement [3]. Although insight exchange occurred primarily at a conceptual level, early sharing proved valuable in stimulating alternative viewpoints and reinforcing user-centred thinking across both cohorts with Aston students reporting difficulties integrating service design principles, alongside the development of a physical product to

address the identified problem, reflecting their stronger background in physical product design. It is therefore questionable how service design literacy is scaffolded within product-focused curricula and whether additional methods or tools are required to support effective service prototyping [8]. While the collaborative “lifeline” between the two universities could have been strengthened through deeper data exchange and more structured interaction, the experience nevertheless demonstrated the value of purpose-driven international collaboration.

5 CONCLUSIONS

This paper presents a comparative and qualitative analysis of two thematically aligned educational projects focused on sustainable agricultural innovation. Rather than making broad claims regarding educational transformation or innovation impact, the findings demonstrate more specifically how differences in project framing, technological constraints, and stakeholder access shaped student learning experiences and design outcomes. Notably, the Aston University case encouraged broad conceptual exploration and service-oriented thinking, whereas in contrast, the Mälardalen University case supported focused technical development within a constrained XR environment. A key contribution of the study lies in identifying recurring challenges across both settings, particularly the difficulty students experienced when engaging with unfamiliar agricultural contexts and accessing relevant stakeholders for iterative feedback. In addition, both cases generated useful insights and concepts that could be of value to the company DeLaval, in relation to user-centred innovation and technology-led innovation. The study also suggests that thematic alignment can be an inspirational source for interaction and between different courses, providing a comparative reflection and exposure complementary design approaches. Given the limited empirical evidence, indications derived from the present cases should be interpreted cautiously due to the exploratory nature of the study, the limited cohort sizes, and the qualitative character of the analysis. In summary, clear agendas and focused objectives remain essential; yet openness to cross-border learning can significantly enrich student understanding and design outcomes when supported by a shared thematic focus and aligned pedagogical intent. Future work would benefit from more systematic longitudinal evaluation, comparative student reflections, stakeholder assessment metrics, and structured collaboration activities between institutions to strengthen the analytical basis for evaluating educational outcomes.

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HOW DO STUDENTS' PERSONAL AND CULTURAL BACKGROUNDS INFLUENCE THE DEVELOPMENT OF THEIR DESIGN IDENTITIES WITHIN UNDERGRADUATE PRODUCT DESIGN EDUCATION?

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ABSTRACT

Discussions of equality, diversity, and inclusion in design education often focus on institutional strategies or pedagogical interventions. Fewer accounts centre on students lived experiences of identity formation within diverse studio environments. This paper presents a structured reflective account authored by two final-year undergraduate Product Design students, developed through a facilitated dialogue guided by design lecturers and informed by the Describe–Interpret–Evaluate–Plan framework. The reflections explore how personal and cultural backgrounds shaped early assumptions about “good design,” particularly an emphasis on feasibility, efficiency, and outcome-driven resolution. Through sustained collaboration within a socially diverse studio cohort, peers challenged these assumptions by prioritising conceptual exploration, empathy, and speculative thinking. What initially appeared as differences in ability became recognisable as epistemic differences rooted in lived experience.

The paper suggests that diversity within design education operates not only demographically but cognitively, influencing how problems are framed and value is assigned. Structured reflective dialogue within the studio environment is shown to support the development of more adaptive and self-aware professional design identities.

Keywords: Design identity, reflective practice, cultural diversity, design education, student experience

1 INTRODUCTION

A designer's professional identity is not the sole product of the acquisition of technical skills. Rather, it develops through reflection, participation and interaction of communities of practice, where a gradual negotiation of values and ways of thinking is developed[1, 2]. Contemporary discussions of student-centred design education further emphasise professional identity as an evolving construct shaped through participation in studio culture and reflective engagement with practice[3]. Within design education, the studio serves as a formative environment where students can publicly test ideas, give and receive critique, and engage with peers who will likely hold different values about what good design is and how it should be achieved. It is for this reason that, in this context, it is important to know that a designer's identity is not fixed but evolving and is equally shaped by curriculum and lived experience. Increasingly, our class cohorts are becoming more diverse, bringing a mix of students with varied national, educational and cultural backgrounds. These differences allow briefs to be interpreted differently, change how critique is received, and alter how value can be assigned within work. On entry to a programme, a student's disposition is shaped by prior social and cultural experiences that frame early approaches to problem-solving as well as professional aspirations[4]. Learning is not simply a skill development for individuals, but socially mediated participation in shared and developing practice[5]. While discussions of equality, diversity and inclusion often focus on institutional strategies or different pedagogical interventions, fewer accounts centre on the lived experiences of students[6]. In this paper, “personal and cultural backgrounds” refers broadly to the constellation of lived experiences, educational pathways, familial influences, and socio-cultural contexts that shape individual value systems and approaches to design. With this framing, the authors begin to address this gap. The discussion is initiated voluntarily by two students in their final year of study and is developed through a facilitated reflective conversation guided by design lecturers. Within the text, the student authors explore how their personal

and cultural backgrounds shape their development as emerging designers within a diverse studio environment.

2 REFLECTIVE FRAMING

In design, identity often develops through implicit participation in studio practice. Assumptions and ideas about value, quality, authorship, and professional development may guide decisions without explicit articulation, shaping the interpretation and development of design output. Reflective practice offers a means of unearthing these tacit influences. Schön[1] posits that professional knowledge cannot be solely technical but must be reflective, and that practitioners need to examine the assumptions embedded in their actions to grow. In this regard, reflection is imperative to understanding professional identity, as it surfaces values and dispositions that shape practice and make them visible to the designer. The reflections presented here were formed from a voluntary, student-initiated dialogue prompted by the conference theme of *Exploring Diversity*. The conversation was facilitated by design lecturers familiar with reflective practice and structured using the Describe – Interpret – Evaluate – Plan (DIEP)[7] framework commonly employed within the programme to guide reflective practice.

This work is not empirical research but a reflective account from learners. Although supported by teaching staff, the interpretation and perspectives articulated remain those of the student authors. The aim is not to measure diversity but to convey how personal and cultural backgrounds have influenced their development as emerging designers in a shared studio environment. The reflections are primarily grounded in a facilitated dialogue between the student authors, informed by their cumulative studio experiences and supported by recollections of coursework, critiques, and informal reflective activities undertaken during the programme. While not based on systematically archived data, the dialogue enabled a structured articulation of lived experience rather than a retrospective reconstruction of events.

3 CONTEXTS

The student authors of this paper are emerging at the end of a four-year Bachelor of Science in Product Design programme. The degree, based in Ireland, is built around a platform of progressive development from foundational skills to independent practice, integrating a large number of studio-based design modules alongside technical and theoretical classes. Across the programme, there is a strong emphasis on iterative problem-based learning, research and problem framing, prototyping, physical making, and public presentation of outcomes. In the final year, students are expected to exercise much greater autonomy in defining and resolving design challenges within a capstone project, which accounts for more than 50% of their graduating grade.

Throughout the programme, much of the learning occurs within shared studio spaces characterised by regular formative critiques, peer discussions and public displays of work. The studio functions not only as a physical space but also as a cultural environment in which identity and belonging are negotiated [8]. Questioning and revisions are normalised as critical parts of the design process and are built around feedback shared by both lecturers and peers. Alongside independent projects, there are many collaborative projects that require students to negotiate ideas, roles, and interpretations within a group setting. This approach allows for informal learning to occur through proximity, observation and overheard dialogue.

The cohort includes students from varied national, educational, and socio-cultural backgrounds. Differences in prior exposure to design, familiarity with professional tools, assessment cultures, and attitudes toward critique contribute to a heterogeneous learning environment, a pattern also observed in work examining the influence of educational culture on undergraduate design practice[9]. Mixed gender representation and varied prior educational pathways further shape participation and expectations within the studio. These structural and interpersonal dynamics form the context within which individual design identities are developed and negotiated.

4 REFLECTIVE ANALYSES

4.1 How our journeys began, our assumptions towards design, the course and our expectations

The first design project immediately revealed that the programme was more challenging than anticipated. In response, a familiar sense of urgency has emerged within us and prompted us to tackle design projects literally and logically. Design constraints such as limited time and high expectations for

resolution reinforced this mindset, encouraging us to prioritise rapid progression towards a highly detailed, feasible design rather than exploratory divergence.

This approach was reinforced by the initial assumptions about what constituted good design, which we equated with primarily high polish and appeared effortless. These examples became our benchmark against which we measured ourselves. Due to the absence of skill in foundational areas in the early years of study, we often overcompensated by overdeveloping assigned tasks, prioritising finish and detail in other ways to assert competence with our internal value systems.

Throughout extensive group work, it became clear that our approach was not universally shared. Our primary concerns, such as how the product would function, how it would be manufactured or whether it was feasible, did not always align with the priorities of others. This misalignment generated frustration, as our emphasis on ‘Good Design’ appeared disconnected from peers who felt more attracted to abstract and speculative conceptualisation. At the time, these exploratory and conceptual strategies were seen as inefficient and detached from real-world constraints, reflecting our deeply embedded association between feasibility and value. These alternative design approaches challenged the logically wired, highly critical design decision-making that kept us in security throughout the early months of our design venture.

This outcome-driven mindset didn’t emerge in isolation; it can be traced to before entering higher education, where exploration was rarely pursued without a clear purpose or a predictable outcome. Within our home environments, which were shaped by risk aversion and efficiency, experimentation had to be preplanned or likely to succeed, to be considered viable or responsible. Failure was often strongly associated with incompetence, and external validation functioned as a source of security and acceptance. As a result, unstructured exploration felt not merely inefficient but misaligned with our internalised understanding of responsibility and productivity.

These values and assumptions carried into our early stages of design practice, greatly narrowing our tolerance for ambiguity and therefore limiting our creative potential by preventing us to pursue speculative or open-ended direction, where uncertainty translated to incompetence.

4.2 How diversity impacted our education – design attitudes and personalities, and what our approach was like to them at surface level

At the beginning of the Product Design course, the cohort entered the shared learning environment with a wide range of perspectives, backgrounds, and personalities. These differences quickly became visible in the ways students approached strategy, collaboration, and communication. Through the inexperienced lens of first-year students, such variations were often interpreted as differences in knowledge or skill.

However, as the course progressed and education deepened, technical knowledge and practical skills gradually levelled out. What remained were distinct design approaches. This shift helped students recognise that differing ideas, priorities, and working styles do not stem from unequal proficiency, but from the individual characteristics of each designer, shaped by personal experiences, values, and worldviews.

Each student's past has contributed to the formation of a unique design personality, guided by specific motivations that drive their work. From the examined course, the following generalised design personalities shown in **Figure 1** have been identified:



Figure 1. Emergent design personalities identified through reflective dialogue. These categories are reflective and interpretive in nature and are not intended to represent empirically validated or mutually exclusive typologies

The design personalities illustrated in Figure 1 are not intended as definitive classifications but as interpretive constructs emerging from the student authors' reflections on studio participation. While students often displayed traits associated with multiple orientations, one tendency frequently appeared more prominent in shaping individual approaches to design.

In turn, these design personalities naturally orient students toward one of three primary design approaches shown in **Figure 2**, which were identified within the course:

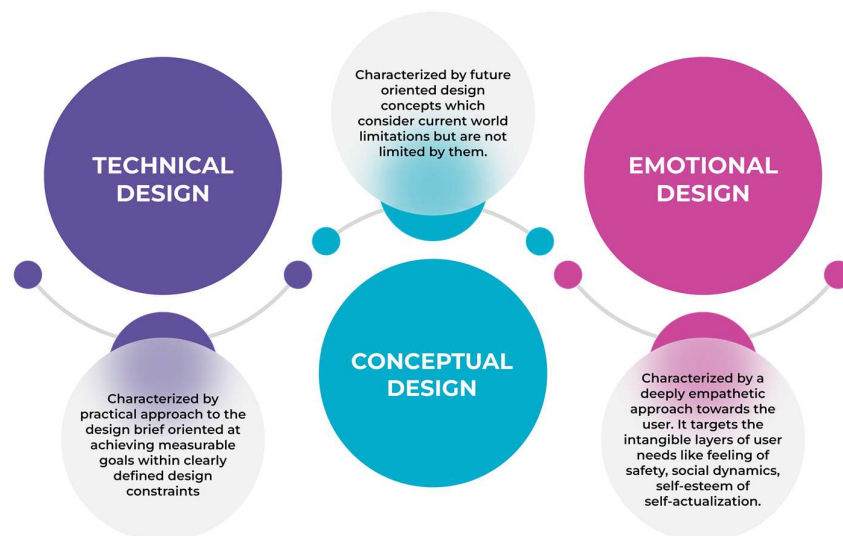


Figure 2. Dominant design approaches emerging from studio participation

Over years of individual and group projects in studios and classrooms, this diversity of personalities and approaches became increasingly evident. Throughout this process, each student gradually developed a distinct identity. Despite a shared curriculum, by the end of their educational journey, these identities proved even more varied than they had initially appeared.

4.3 How it shaped us to be better designers – more open to alternative approaches, which helped us define who we are and what we appreciate.

By the final year of the programme, perceived differences in technical proficiency appeared to diminish over time, yet our design approaches remained distinctly different. This contrast prompted a critical realisation: our outcome-driven mindset was not simply a strength, but also a limitation. While it enabled efficiency and feasibility, it often constrained exploration and emotional depth.

Working within a diverse studio environment challenged these assumptions. Exposure to peers who prioritised empathy, speculation, and conceptual divergence expanded our understanding of what constitutes good design. Their approaches revealed dimensions of meaning and user connection that our efficiency-oriented perspective had overlooked.

Without this diversity, our practice may have remained narrow and self-reinforcing. Instead, it encouraged reflection, adaptation, and growth. By engaging with alternative methodologies, we became more open and more self-aware. Ultimately, we've become more balanced designers who can navigate both practical constraints and human complexity.

5 DISCUSSIONS

The reflections of the student authors suggest that design identity develops as much through participation in a socially situated studio environment as through the curriculum. To that end, the undergraduate studio functions as more than a site of technical skill acquisition and is as important as a place of socio-cultural learning, providing a domain where assumptions, values and dispositions can be negotiated. This follows Vygotsky's [5] understanding of socially mediated learning, where identity formation occurs socially rather than in isolation.

Exposure to peers who prioritised conceptual speculation and emotional engagement disrupted the view that *feasibility* = *value*, and what initially appeared as differences in ability resolved into alternative ways of framing challenges and measuring success.

Within the context of a differentiated studio, diversity operates not as a demographic category but as a cognitive and interpretive one, providing variation, nuance, and growth. Learners bring different relationships to critique, failure, authorship and validation within the shared space. Rubin's [10] metaphor of creativity as a universal current filtered through lived experience provides a useful lens: each designer engages with creativity through a distinct personal-social history and set of values. When these co-exist in a collaborative space, they can generate tension as well as expansion.

It is important to note that the shift from frustration to appreciation was not automatic and required sustained collaboration and structured reflection. As with the facilitated dialogue underpinning this work, space to articulate previously implicit assumptions and internalised ideas of value and usefulness is a necessary pedagogical mechanism which allows differences to be examined and understood rather than just explored.

These reflections suggest that inclusive design education may depend less on aligning students to a single model of "good design" and more on recognising and engaging epistemic diversity. In this instance, it is this diversity which broadened tolerance for ambiguity and deepened appreciation for alternative methodologies, allowing for a more adaptive and adaptable design identity to emerge. While situated and personal, these insights indicate that structured reflective practice within the studio is imperative for the formation of robust, tolerant design professionals.

6 CONCLUSIONS

The reflections presented in this paper illustrate how professional design identity develops through sustained participation within a socially diverse studio environment. Over four years of shared education, differences in personal and cultural background shaped contrasting orientations toward feasibility, exploration, critique, and value. What initially appeared as misalignment between students gradually became recognisable as an epistemic difference rooted in lived experience.

Through collaboration and facilitated reflection, these differences were reframed from sources of frustration to sources of expansion. The early prioritisation of efficiency and outcome-driven resolution, while productive, was revealed as only one interpretation of “good design.” Exposure to alternative approaches broadened tolerance for ambiguity and deepened appreciation of conceptual and emotional dimensions of practice.

This case suggests that diversity within design education functions not only as demographic representation but as interpretive variation that shapes how problems are framed and resolved. When supported by structured reflective dialogue, such variation can contribute to more adaptive and self-aware professional identities. Although situated and non-generalisable, the account offered here indicates that inclusive studio environments benefit from mechanisms that surface and interrogate difference, allowing identity formation to evolve through engagement rather than assimilation.

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UNLOCKING SPATIAL FLUENCY: A SCAFFOLDED APPROACH TO VR VISUALISATION IN FOUNDATIONAL DESIGN EDUCATION

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ABSTRACT

This paper presents a scaffolded pedagogy for teaching Virtual reality (VR) sketching and modelling to engineering students for product design and development. The approach addresses a common barrier for non-design learners: difficulty using traditional freehand sketching to externalise ideas. The framework deliberately progresses from foundational analogue 2D exercises (line control, shape-to-form reasoning, and object deconstruction into geometric primitives) to immersive 3D ideation and surface development using Gravity Sketch as the sole VR platform. By enabling students to work at 1:1 scale and iterate through reversible actions, the VR environment reduces intimidation and supports the development of spatial awareness and controller fluency. Students learn to generate concepts, refine surfaces for product casings, and communicate curvature, proportion, and ergonomic intent directly in three dimensions, improving the speed and clarity of design discussions. Implemented over a 16-week semester with 50 engineering students, the course culminated in individual projects demonstrating that an analogue-to-VR progression can build practical spatial and visual reasoning skills essential for contemporary product development workflows.

Keywords: Visual thinking, VR sketching, spatial reasoning, virtual reality (VR), design education

1 INTRODUCTION

Engineering students increasingly operate in digital-first environments, yet many struggle to externalise early-stage ideas because conventional entry routes—freehand sketching and traditional CAD carry steep learning demands. Freehand sketching can be imprecise [1] for communicating three-dimensional form and typically requires years of practice to reach clarity, while CAD tools often impose a high cognitive load during ideation, shifting attention from exploration to command execution. As immersive technologies mature, VR sketching offers an alternative pathway that can reduce these barriers by enabling students to think and create directly in 3D [2]. This paper investigates spatial fluency as a key capability for bridging the analogue–digital gap in concept development. We define spatial fluency as the practical competence to interpret, manipulate, and communicate form natively in three dimensions, without relying on 2D translation [3]. Through an empirical, credit-bearing intervention with non-design engineering students, examines how a structured analogue-to-VR workflow, centred around Gravity Sketch for product-oriented sketching and modelling, supports ideation, spatial communication, and proof-of-concept visualisation [4]. The study contributes an actionable pedagogical structure and evidence of how immersive sketching can expand access to design capability within engineering education [5].

2 BACKGROUNDS

Virtual Reality (VR) is increasingly shaping how early-stage concepts are explored, evaluated, and communicated in product development. Immersive environments allow learners to work with form at varied scales, test proportions and ergonomics through embodied movement, and iterate in three dimensions with immediate feedback [6]. Prior work on immersive prototyping positions VR as a practical medium for advancing concepts earlier in the pipeline, particularly when physical prototyping is slow or resource-intensive [7] & [8]. Yet, educational adoption remains uneven, partly because commercial tools are typically introduced as software training rather than as structured learning experiences with explicit outcomes [9].

A strong motivation for VR-based instruction is the documented role of three-dimensional spatial visualisation in engineering and design performance [1]. Sorby emphasises the need to strengthen spatial ability among non-design learners, as it underpins the interpretation and manipulation of 3D form. VR sketching has been described as a bridge between ideation and prototyping because it enables learners to construct, assess geometry & volume within an immersive space [4]. Evidence from applied domains such as automotive concept design further suggests VR sketching can improve spatial fidelity and reduce iteration time [10]. In response, the course was delivered in a workshop-style format, emphasising guided demonstrations, short practice cycles, and iterative critique. Sessions progressively moved from foundational sketch habits to immersive form exploration, enabling students to build competence through repeated making, feedback, and refinement within a concept-oriented VR workflow.

3 METHODOLOGIES

This study employed an instructional intervention design to evaluate a scaffolded pedagogical approach for developing VR sketching capability and creative confidence [7] among students from non-design backgrounds. The intervention was structured as a short intensive course progressing from analogue sketching foundations to VR-based ideation, modelling, and final rendering, with instructional support gradually reduced as students gained competency. The study involved 50 undergraduate engineering students with no formal design background [7], divided into 10 batches of five students to enable close facilitation and iterative feedback. All participants completed the same sixteen-week instructional sequence. Each 45-minute session emphasised incremental skill development through repeated practice, guided exercises, and structured critique, enabling students to build confidence and spatial fluency before advancing to more complex tasks. The intervention followed a scaffolded learning strategy in which demonstrations, guided exercises, and instructor feedback were progressively replaced by independent exploration as learner competence increased [4]. Scaffolding was implemented through: (a) sequencing skills from basic drawing control to volumetric reasoning and digital production; (b) a structured transition from analogue sketching to immersive VR workflows involving VR sketching, 3D modelling, and texture application; and (c) continuous progress monitoring to support diverse learner entry points. This approach allowed students to engage directly with VR-based form development without prior VR sketching experience. To evaluate the intervention, an anonymous post-study survey was conducted using Google Forms. The survey captured participant feedback, learner experiences, and reflections on the course structure and VR workflow. The responses informed post-study analysis and contributed to refinements in the pedagogical framework. The pedagogical pipeline unfolded across seven sequential stages (Figure 8 below).

3.1 Analog Foundations (Paper-and-Pencil Sketching)

The course began with low-stakes analogue sketching to develop baseline visual confidence and hand-eye coordination. Learners practiced line control and contour drawing before advancing to shape-to-form development (e.g., transforming 2D shapes into 3D forms). Students also engaged in analogue deconstruction, in which complex real-world objects were observed and mentally decomposed into geometric primitives (e.g., cubes, spheres, cylinders, lamps, and organic shapes, etc.). The focus was on “seeing structure” rather than producing aesthetically refined sketches, thereby reducing performance pressure while strengthening volumetric understanding (See Figure 1 below).

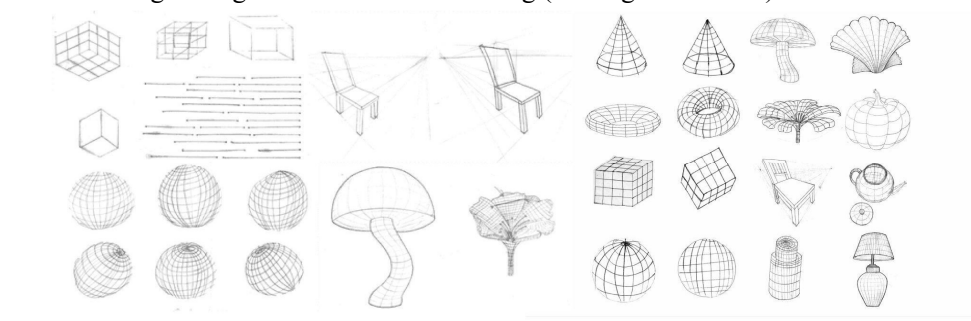


Figure 1. Example of visualising primitive geometry

3.2 VR Tool Familiarisation (2D-to-3D Transition)

After establishing basic volumetric reasoning, learners were introduced to a VR sketching platform (e.g., Gravity Sketch). Familiarisation followed a structured progression: students recreated contoured volumes and simple everyday objects in 3D space, practicing scale, placement, and orientation. This stage emphasised continuity with Stage 1 by transferring already-learned concepts (volume, proportion, primitives) into the immersive environment (see Figure 2 below).

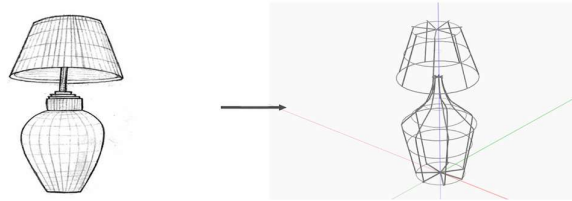


Figure 2. Analogue to 3d conversion

3.3 Concept Framing (Moodboard and Inspiration Board)

To anchor exploration and prevent tool-driven divergence, students developed a Moodboard/inspiration board aligned with a concept they wished to explore (See Figure 3 below). This activity was conducted through iterative discussion and critique, including feedback from senior faculty. Boards typically included references related to form language, style cues, contextual use, and material/texture inspirations [11].



Figure 3. Mood board with the setting of the Concept

3.4 VR Ideation and Volumetric Concept Sketching

Students then engaged in rapid ideation directly within VR. The emphasis was on generating multiple volumetric alternatives through quick exploratory sketching, iterating on shapes, proportions, and configurations, and progressively converging toward a selected form direction. Outputs from this phase included multiple candidate concepts and one refined concept for further development (See Figure 4 below).

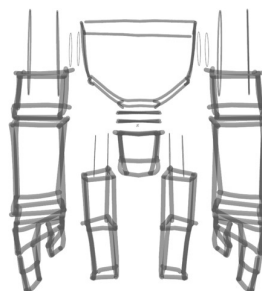


Figure 4. Example of VR Sketching

3.5 VR Modelling (Surface Development and Refinement)

Following concept selection, learners transitioned from sketching to VR-based modelling (See Figure 5 below). Instruction focused on constructing and refining surfaces, improving form coherence, and managing surface interactions (e.g., continuity and intersections). This stage aimed to convert exploratory sketches into more stable model-like representations suitable for subsequent detailing and export.

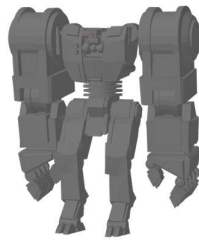


Figure 5. Example of VR Modelling

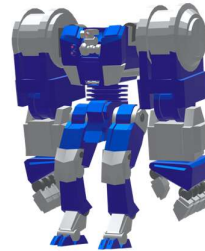


Figure 6. Texture preview with lighting

3.6 Detailing and Texturing

Once primary form decisions were finalised, students were introduced to detailing and texturing workflows (See Figure 6 above). Learners explored secondary features and surface qualities to improve visual clarity and communicative fidelity. Texturing was intentionally positioned after form stabilisation to ensure that surface qualities complemented, rather than substituted for, unresolved geometry [8].

3.7 Export and Rendering

In the final stage, students exported their VR-generated 3D files and used Blender to produce presentation-ready renders (See Figure 7 below). Instruction included file import, basic model preparation as needed, lighting and camera setup, and composition for final visualisation. This stage completed the pipeline from early ideation to shareable outputs.

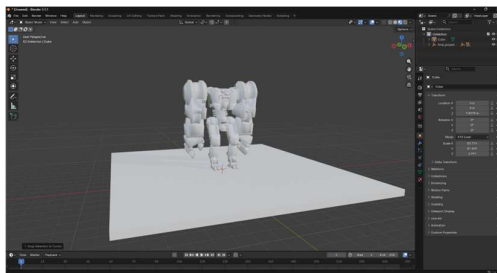


Figure 7. Finalisation of composition to render in Blender

Progress was tracked throughout the intervention to support mastery-based movement across stages. Early sessions involved higher instructional support (demonstrations, step-by-step guidance, corrective feedback), while later sessions emphasised learner independence and self-directed iteration. Batch-based delivery enabled facilitators to observe difficulties (e.g., spatial reasoning, tool control, or concept convergence) and provide targeted feedback. The pedagogical pipeline visualisation can be viewed in (See Figure 8 below).

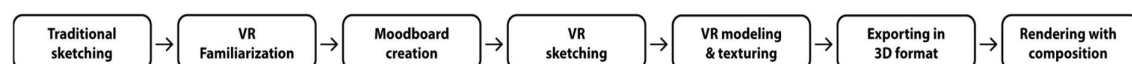


Figure 8. Finalisation of composition to render in Blender

4 RESULTS

Students' most significant learning gains were observed during the transition from unstable 2D sketching to immersive VR sketching, modelling, and final rendering. Gravity Sketch served as the

primary platform due to its support for spatial sketching and surface-oriented (NURBS) modelling, enabling students to create clean, editable geometries aligned with product-design workflows [3]. The learning process followed a progressive structure. Initially, students converted basic geometric forms into simple 3D models. From the second week onwards, they translated inorganic objects composed of basic shapes into VR-based 3D forms, strengthening their ability to convert orthographic sketches into perspective representations. From the third week onwards, students advanced to modelling organic forms, improving their understanding of surface flow, contours, and curvature. Sketching curved forms in VR required greater controller fluency and spatial coordination, enhancing embodied interaction with form generation. Pedagogically, this phase focused on developing controller fluency, including tool handling, stroke control, and navigation, alongside spatial awareness related to scale, depth, and volumetric judgment. Students demonstrated improved understanding of volume, proportion, and structural logic through continuous instructor observation. Increased confidence in line work, reduced sketch jitter, and improved contouring and proportional scaling prepared them for VR-based ideation tasks [12]. Building on these foundations, students developed exploratory conceptual briefs inspired by forms encountered in films, games, and popular media. Rough 2D sketches were imported into VR to establish three-dimensional bounding volumes, grounding concept exploration within explicit spatial constraints. Within Gravity Sketch, students explored concepts through 1:1-scale spatial sketching and refined them into higher-precision surfaces suitable for product casings [9]. Students who struggled with perspective sketching on paper benefited from embodied VR ideation, as they could rotate, scale, and evaluate forms directly in 3D space, enabling faster iteration and clearer visualisation. This was particularly valuable for engineering students, for whom three-dimensional form representation was not a natural part of prior training. Concepts were subsequently exported to Blender for texturing, lighting, and rendering, resulting in high-fidelity digital twins representing refined concept configurations rather than exploratory sketches. A comparative synthesis highlights the strengths of the VR-based workflow (See Figure 9 below). Conventional CAD-first instruction often prioritises precision and configuration while underemphasising experiential and aesthetic exploration. Conversely, purely VR-led approaches may encourage expressiveness without ensuring configurational feasibility. The proposed workflow balanced both approaches by combining immersive ideation with structured refinement. Features such as 1:1-scale feedback and low-risk iteration tools, including undo/redo functions, encouraged students to explore more complex configurations than they would typically attempt within conventional CAD workflows [4].

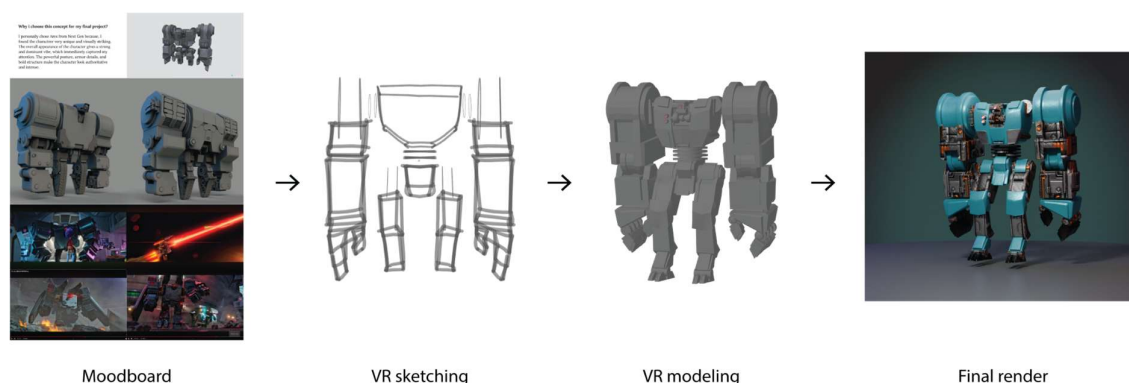


Figure 9. Full workflow from mood board to render

5 DISCUSSIONS & CONCLUSION

This research challenges the positivist assumption that design knowledge is primarily abstract or symbolic. Instead, it adopts a constructivist and embodied epistemological perspective in which knowledge develops through situated action and experiential engagement. By sketching and modelling in VR at a 1:1 scale, students engage with space beyond geometric representation, experiencing form through bodily movement, spatial awareness, and continuous interaction between the hand, tool, and design. This embodied interaction supports spatial fluency, understood as a practical “knowing-how” that enables learners to think and operate directly in three-dimensional space without relying on 2D translation methods [3]. In this context, VR functions not only as a tool but as a medium that reshapes learning by making spatial reasoning immediate, interactive, and embodied. Three major outcomes

emerged from the intervention. First, students demonstrated increased creative confidence. The intimidation associated with the blank page gradually diminished, and learners initially hesitant to sketch progressed toward generating complex VR-based forms through a scaffolded workflow moving from analog deconstruction to immersive refinement. Second, communication of spatial intent improved significantly. Instead of relying solely on ambiguous 2D drawings, students demonstrated curvature, thickness, ergonomics, and spatial relationships directly in 3D space, enabling clearer critique and faster iteration [4][2]. Third, the workflow enabled high-fidelity proof-of-concept outputs. Models exported to Blender for texturing, lighting, and rendering resulted in digital twins that met product-configuration expectations even among engineering students with limited design training. These findings suggest that immersive workflows can effectively bridge conceptual ideation and digital realisation. However, these benefits coexisted with practical and ergonomic constraints affecting broader adoption. Some students struggled with immersive navigation and initiating ideation directly in 3D space, reporting disorientation and unfamiliar motor demands. Others experienced eye strain, headset discomfort, and visual fatigue, particularly students with astigmatism, high-powered spectacles, or recurring headaches. Extended use also caused lens fogging for participants wearing glasses. Technical and infrastructural limitations further affected workflow efficiency. Tethered cable systems used for instructor monitoring and real-time feedback occasionally restricted movement and introduced risks of physical obstruction. Limited laboratory space also constrained freedom of movement within the immersive environment. Additional ergonomic concerns were observed among female students with long hair or hair accessories, as headset straps interfered with proper fitting and comfort. Maintaining hygiene standards required regular headset sanitisation using alcohol-based wipes and ensuring devices remained fully charged before each session. Furthermore, the 45-minute session duration limited prolonged exploration, controller fluency, and sustained immersion. Overall, the study highlights the potential of VR-based workflows in supporting design learning by enabling students to think, sketch, and develop ideas directly in three-dimensional space. While the approach demonstrated promising outcomes in creativity, spatial understanding, and digital visualisation, the findings also emphasise the need to improve accessibility, comfort, and practice duration to create a more inclusive and effective immersive learning environment.

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BREAKING BARRIERS, BUILDING BRIDGES: FOSTERING TRANSDISCIPLINARY LEARNING BY USING FACILITATIVE INTERVENTIONS

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ABSTRACT

Society faces grand sustainability challenges such as climate change and energy scarcity. These wicked problems are intertwined between disciplines, making boundary-crossing collaboration essential. Packaging design is an area strongly linked to sustainability, yet current development processes often operate in silos, failing to address the intrinsic complexity of sustainable packaging. To stimulate cross-boundary collaboration in this field, the learning community ‘Packalicious’ was launched in 2020 by the University of Twente, in collaboration with the Netherlands Institute for Sustainable Packaging (KIDV) and four Dutch universities of applied sciences. Packalicious has since evolved into a symbiotic, transdisciplinary ecosystem of learning, connecting over 12 educational institutions, 27 industry partners, and governmental stakeholders to address intricate packaging challenges. Across four years of multidisciplinary Packalicious sessions, several recurring challenges emerged: communication issues caused by disciplinary jargon, varying impact horizons of stakeholders, and the intangibility of the subject, which can hinder concrete decision-making. While collaborative tools and group dynamics exercises have been widely applied, these often risk ‘beating around the bush’, emphasising sustainability concerns without progressing toward concrete actions. During the scale-up of the learning community the critical value of facilitative interventions became apparent as a means to enhance transdisciplinary learning. This paper highlights the potential of such tangible entities to supplement abstract collaborative tools and accelerate cross-boundary collaboration. Tangible objects, artifacts, and designerly learning approaches can anchor discussions, foster shared understanding, and support the development of intrinsically sustainable product-packaging combinations.

Keywords: Transdisciplinary collaboration, boundary objects, learning community, sustainability, packaging development

1 INTRODUCTION

In industrial development processes, legislative interventions, and the public opinion, the focus on sustainability-related issues and considerations is becoming increasingly critical. For the field of packaging development, this materialises in intensified views on the two-fold role of packaging as a facilitator of functions throughout supply chains [1-3], and as a motivator in discussions on material use and waste. Through this, packaging is the ultimate enabler of diverse purchase, use, and disposal scenarios. Often, packaging is being regarded as superfluous and wasteful immediately after the completion of its role in protecting and delivering products. Operationalising the diverse and complex aspects of sustainability in the development of product-packaging combinations in a well-founded manner is the domain of design and development teams, in which different stakeholders shape multidisciplinary collaborations [1]. To nurture and secure these collaborations for future development processes, connecting and educating ‘designers of the future’ (addressing research, industry, education, and society) is essential. They must be able to navigate the boundaries of the disciplines involved and must be able to frame the problem at a systemic level [4], allowing new strategies and solution directions to emerge. The complexity of such educational endeavours is the outset of this research, for which the University of Twente started a learning community on packaging sustainability, together with the Netherlands Institute for Sustainable Packaging (KIDV, now renamed to Verpact) and four Dutch universities of applied sciences, in October 2020. This learning community was named ‘Packalicious’, and aims to empower education, governmental bodies, research institutes, and the packaging industry

in accelerating developments towards intrinsically sustainable product-packaging combinations, and the definition thereof, by means of transdisciplinary ways of collaboration. This must result in a symbiotic, sustainable ecosystem in which stakeholders from different disciplines bring together knowledge and learn *with* each other, rather than 'just' learn *from* each other [5].

Drawing from three years of experimental experience, this paper aims to distil lessons learned in (1) transdisciplinary collaboration resulting from the development and scale-up of Packalicious, and (2) its function as a learning ecosystem bridging cross-disciplinary gaps. This paper highlights the value of facilitative interventions (e.g., boundary objects and dedicated connectors) to further accelerate cross-boundary collaboration with a shared objective of fostering intrinsically sustainable product-packaging combinations, through answering the research question 'How can facilitative interventions provide value and facilitate boundary-crossing collaboration in transdisciplinary learning ecosystems?'.

2 VALUATING FACILITATIVE INTERVENTIONS

The effectiveness of transdisciplinary approaches in tackling the world's most urgent problems remains complex [8]. Stakeholders do understand the complexity and interrelatedness of the themes and see the need to act on these issues – however, steering towards transitions appears to be quite a different endeavour. The Packalicious learning community demonstrates that for a successful understanding of the complexity of impactful societal challenges (such as the acceleration of intrinsic sustainability in packaging) it is critical for stakeholders to look beyond each other's expertise boundaries. Boundary-crossing activities require collaboration, learning, and co-creation across disciplinary, cultural, and professional practice [9, 10]. To build bridges between the activities and learnings of the development and scale-up of Packalicious, and the added value of facilitative interventions and boundary-crossing activities, this research centralises the four learning mechanisms as proposed by Akkerman and Bakker [9]: identification, coordination, reflection, and transformation, which serve to enhance collaboration and boundary-crossing efforts.

2.1 Boundary objects and dedicated connectors

Crossing boundaries can be simplified when using boundary objects [9] in the co-creation process by different disciplines. Boundary objects refer to “an object, artifact or concept that serves as a point of interaction and coordination between different social groups or communities, particularly in situations where those groups have distinct, often incompatible, understandings or ways of working” [11]. They facilitate (1) effective communication, (2) knowledge exchange, (3) common ground sharing, (4) collaboration promotion, and (5) innovation and creative problem solving [9, 12, 13]. Most importantly, they drive transitions by bridging conflicting logic without constraining their diversity [14]. Boundary objects' main goals are supporting the transfer, translation, and transformation of knowledge [15]. Transferring knowledge is simply processing information, while translation focuses more on creating a common ground, and transformation refers to the conversion of knowledge into action [16]. These three levels are crucial to address complex, interdisciplinary issues and to jointly develop new insights and solutions. Figure 1 visualises different types of boundary objects, categorised in a matrix inspired by the Packalicious learnings. These axes were derived from observations across the Packalicious sessions, where different boundary objects served distinct roles in bridging disciplinary gaps. The horizontal axis distinguishes between digital, two-dimensional representations and physical, three-dimensional objects, while the vertical axis separates conceptual, domain-reflecting models from process-based models embedded in active making. Together, the four quadrants reflect how boundary objects can range from collaborative physical prototypes - such as LEGO models that symbolically represent reality - to conceptual mapping approaches such as gigamapping, which create structure and overview within complex problems. Rather than implying a hierarchy, the matrix acknowledges that different interventions serve different collaborative needs, and that the most effective learning within Packalicious often emerged when boundary objects from multiple quadrants were combined.

3 SCALING UP A LEARNING COMMUNITY

Launching Packalicious as a learning ecosystem proved to be successful [5, 6]. However, as the community expanded, specific challenges arose. In this paragraph the development of Packalicious is discussed, zooming in on the different iterations in the community's development and scale-up, and the effect facilitative interventions had on this.

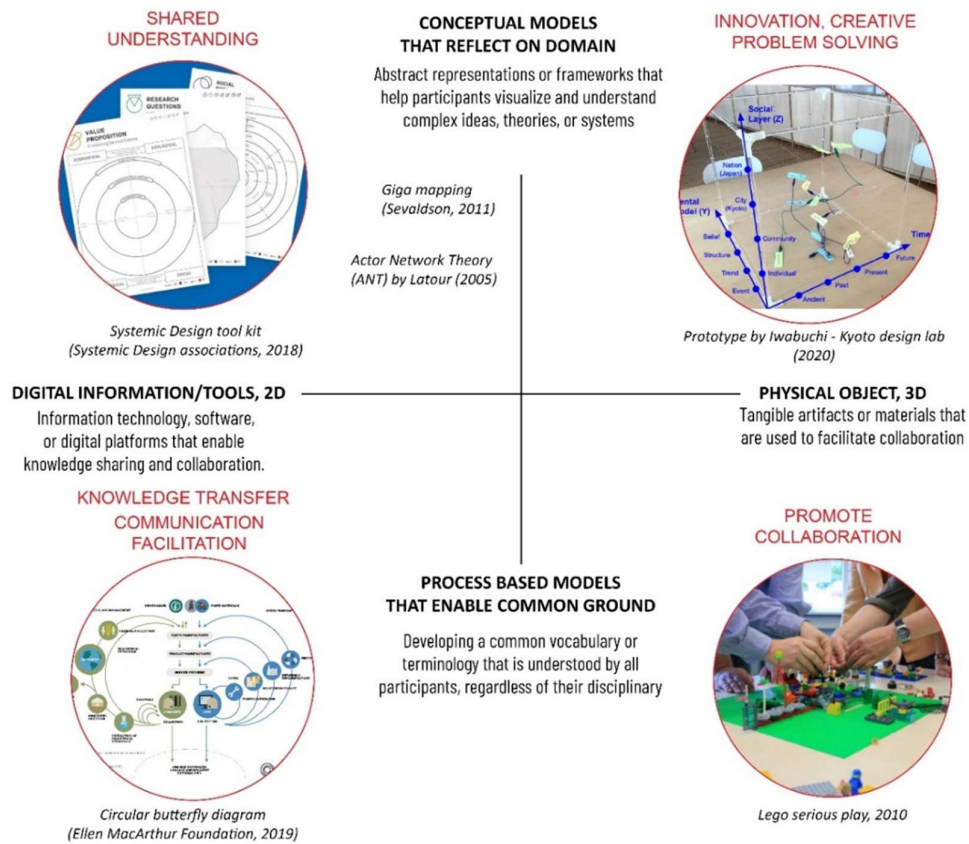


Figure 1. Overview of different types of boundary objects

3.1 Packalicious 1.0

The initial steps of the learning community development journey primarily focused on fundamental community building and the creation of a shared community vision by a core team consisting of students, lecturers, researchers, a packaging expert, and a packaging industry representative. Following, the learning community was launched during a live event. Two real-life industry cases were selected: ‘portion packaging’ and ‘reusable packaging’ (Figure 2), for which the challenges and solution space were explored in separate interactive sessions.

3.2 Packalicious 2.0

After the initial launch of Packalicious, its impact, value, and efficacy were evaluated through semi-structured interviews with packaging industry representatives, lecturers, and students [5]. The primary objective of this evaluation was probing the various stakeholders’ perception of the usefulness of the learning community.

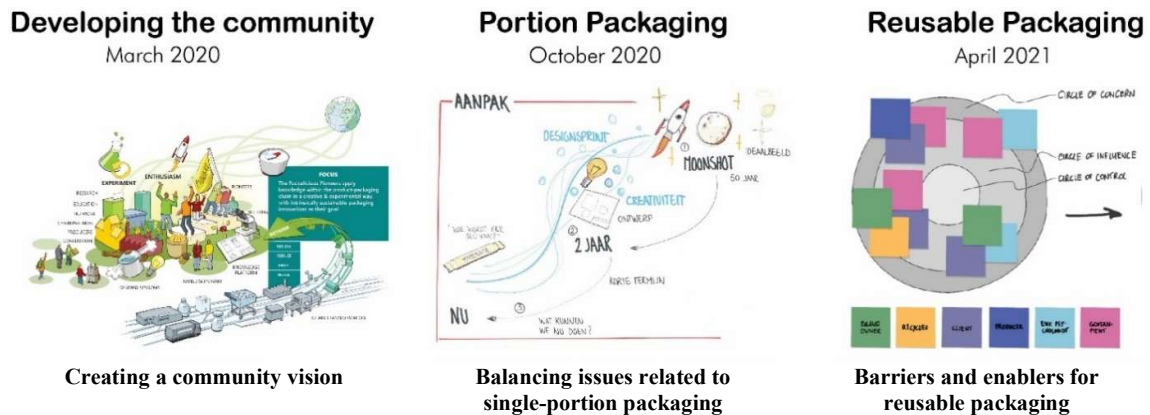


Figure 2. Chronological phases (interactive sessions) of Packalicious 1.0

After establishing that the results represent a successful and positive evaluation of Packalicious as a learning community, it was scaled up and further developed under the banner of Verpact. With this, the initial value of the learning ecosystem was extended to a more in-depth definition of intrinsic sustainability and a broader, more multidisciplinary stakeholder team. In combination, this fuelled the development of a strategy and research agenda on addressing the complexity of packaging sustainability, by means of various live interactive brainstorming and concept development sessions (Figure 3), with a broad and multidisciplinary representation of stakeholders.

Scaling up the learning community resulted in a substantial increase in the number of participants, which enriched discussions yet complicated collaboration. Boundary-crossing challenges such as communication issues (different disciplines speak different professional languages), stakeholders' varying impact horizons (short-term versus long-term solutions) and subject intangibility ('what are we working towards?') arose. These collaborative challenges complicate solving wicked societal problems [7], such as intrinsic sustainability - which Packalicious aimed to explore through shared case studies and interactive sessions. While developing the learning ecosystem as a platform, it was found that the strictly scoped case studies from the initial projects offered more guidance than the attempt to formulate overarching themes ('grand challenges') during Packalicious 2.0. Facilitating collaboration across disciplines in this endeavour proved to be a complex process, particularly when it came to aligning all expectations. During the scale-up of the learning ecosystem, the critical value of facilitative interventions (like boundary objects and dedicated connectors) as a potential medium to facilitate cross-boundary collaboration became apparent. In the next sections these facilitative interventions will be elaborated upon. The most recent iteration of Packalicious centred on the tension between standardisation and differentiation in sustainable packaging, bringing together stakeholders from supermarkets, brand owners, and knowledge institutes, alongside students from multiple backgrounds. Students acted as dedicated connectors, while industry and academic partners contributed practical examples - collectively mapping insights through shared boundary objects. This approach fostered shared ownership and engagement beyond individual curricula.

The Packalicious interactive sessions demonstrated the power of facilitative interventions which shed light on the connection between different disciplines, and which resulted in the definition of a shared vision. Examples such as in-process sketches by a visual notetaker and the Circles of Influence [17] functioned as boundary objects, framing the topic and aligning the participants' perspective variety. The scale-up of Packalicious indicated that (tangible) boundary objects provide a tangible perspective and a means to grasp the complexity of the design process. Figure 4 offers an overview of the boundary objects used in the Packalicious sessions. Two-dimensional visual sketches supported a shared understanding of how a complex problem could be approached in a practical way, the back-casting method bridged conceptual framing with collaborative action, and physical tools such as the Rethink Card Game fostered a deeper sense of connection with the subject matter, supporting both shared understanding and personal investment in the challenge. In-depth interviews with industry stakeholders and students showed that students started out uncertain in their facilitative role but became noticeably more engaged when working with boundary objects, picking up these tools more readily than professional participants did. The various Packalicious sessions demonstrated the central and directing roles the involved design students (the packaging designers of the future) adopted.

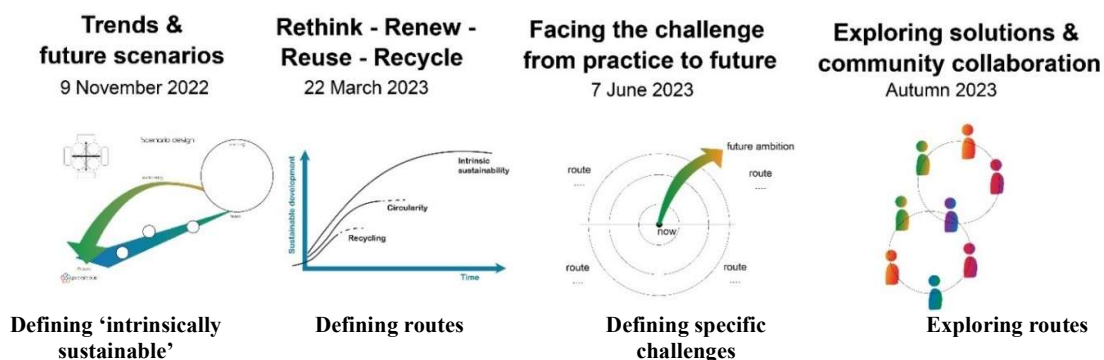


Figure 3. Chronological phases (interactive sessions) of Packalicious 2.0

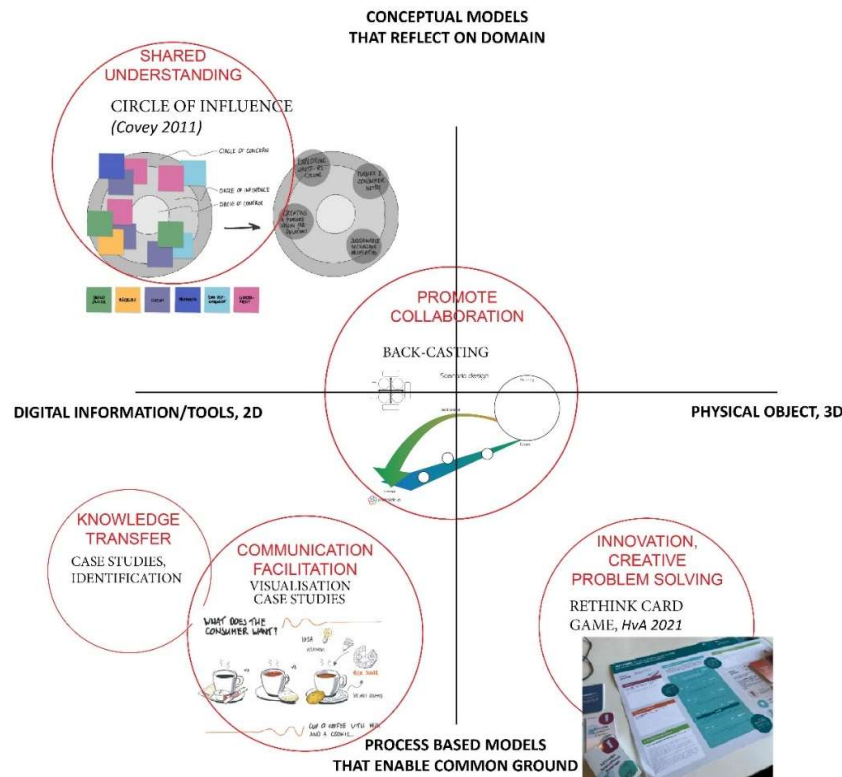


Figure 4. Overview of different types of boundary objects used in the Packalicious context

Often, they used boundary objects to steer discussions (echoing findings by Valk et al. [18]), and to ensure that the other stakeholders came to a shared vision and solution space. The students participating in the Packalicious sessions can be identified as dedicated facilitators, mediators, or connectors, in addition to their training as ‘traditional’ designers [19].

4 DISCUSSION AND CONCLUSIONS

With the description of the development and scale-up of Packalicious and the role of facilitative interventions in this, this research addresses the collaborative challenges that exist between disciplines. These stakeholders each have their own discipline, work methods, and specific professional language, constructing a diverse and therefore complex ecosystem. Aligning expectations among these diverse disciplines is not always straightforward, especially in the transformative phase [9], where the actual transition needs to be initiated. This paper argues that a solution can be found in effectively using facilitative interventions, such as boundary objects and dedicated connectors, as a learning means.

Designers (represented by design students in the context of Packalicious) can play a connecting role in this matter, by using these boundary objects to bridge cross-disciplinary gaps. They take on the roles of facilitators and mediators in transdisciplinary collaborations to ensure that the right connections are made. Their mode of problem-solving is more solution-focused by exploring several possibilities to find the optimal match. The development and scale-up of Packalicious demonstrate similarities to the initial two stages of the learning mechanisms. However, as was the case for the further acceleration of Packalicious, collaborations are often not successful in making steps in the transformative stage, to arrive at actions rather than just agreeing that something needs to be changed. For Packalicious, this hurdle which limits transformation can be identified as the result of the complexity of the challenge at hand, coupled with stakeholders' uncertainty about their role in the process. Stakeholders grasp the intricacy and interconnected nature of the themes and recognise the necessity to act on these matters, yet navigating the path toward transitions shows to be challenging.

This research argues that the combination of effectively using boundary objects and employing dedicated connectors adds significant value to cross-boundary collaboration and learning, answering the research question. It is the combination of the right balance of facilitative interventions (boundary objects, dedicated connectors, solid group dynamics) that leads to successful collaboration with the potential to look beyond boundaries and come up with innovative solutions. This paper aims to clarify

the designerly value of such interventions, for the application within the scope of Packalicious, and potentially beyond. This acts both as an answer to the research question, and as an invitation to the academic design research community at large to further discuss this and join in researching the transitional and educational value and application of facilitative interventions.

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BRIDGING DISCIPLINES THROUGH MAKING: COMPETENCY DEVELOPMENT IN INTERDISCIPLINARY WEARABLE REHABILITATION TECHNOLOGY EDUCATION

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ABSTRACT

Interdisciplinary collaboration is essential in engineering and product design education, yet educators struggle to identify and develop the competencies it requires. This paper presents findings from an intensive workshop in which 21 students from engineering, design, and occupational therapy across four universities collaboratively developed wearable rehabilitation devices. A progressive four-session structure covered the full development cycle: 3D scanning, CAD modelling, electronics integration, and performance testing. Evaluation exposed critical gaps in traditional engineering education. Students flagged regulatory and clinical requirements as the most significant missing competency, followed by electronics and programming skills. Most consistently, participants lacked understanding of clinical rehabilitation contexts, such as patient needs, human anatomy, and real-world device usage, highlighting that contextual knowledge is as essential as technical skill in healthcare technology design. This research provides practical curricula frameworks for developing both technical and collaborative competencies. The findings confirm that hands-on, interdisciplinary learning bridges educational divides but requires deliberate integration of clinical context and cross-disciplinary exchange, further offering actionable guidance for educators in engineering and product design.

Keywords: Smart wearable devices, rehabilitation devices, interprofessional education, human-centred design, assistive technology

1 INTRODUCTION

The development of wearable rehabilitation devices requires technical expertise spanning multiple engineering and healthcare disciplines, along with a deep understanding of contexts and patient needs [1], [2]. However, traditional engineering and product design education typically operates within disciplinary limits, leaving graduates unprepared for the collaborative, context-related challenges of healthcare technology innovation [3]. While interdisciplinary collaboration is recognised as essential, educators lack clear approaches for identifying and developing the competencies needed for such cross-disciplinary teamwork in this domain [1], [3].

This study presents findings from an intensive hands-on workshop that brought together 21 students from engineering, design, and occupational therapy backgrounds across four European universities to collaboratively develop wearable rehabilitation devices. With a two-day four-session structure the workshop provided a complete device development cycle experience in an advanced makerspace environment (a collaborative workspace where people work together to create, invent, and build things using a set of tools and equipment). Part of a larger effort to develop an online course, this study

evaluates how this pedagogical approach promotes both technical competencies and collaborative teamwork while revealing gaps in students' preparedness for healthcare technology development. Grounded in constructivist and experiential learning theory, and building on existing competency frameworks for wearable technologies, this study moves beyond descriptive pedagogy to analytically examine why clinical knowledge represents the critical gap in interdisciplinary wearable education, positioning healthcare context integration, not technical skill alone, as the central and novel contribution of cross-disciplinary collaboration in this domain.

2 BACKGROUNDS

2.1 The case of smart wearable technology

A **smart wearable** is an electronic device designed to be worn on the human body that collects, processes, and transmits data in real time, often connecting to other devices or cloud services. Such wearables can target rehabilitation context. For example, DigiClap is a smart wearable device designed to support rehabilitation in children with cerebral palsy (CP) through gamified occupational therapy [2]. Using a user-centred design approach, the device is worn on the hand and captures finger and hand movements to interact with a serious game on a tablet. The device is additively manufactured using a 3D printer, combining rigid material for structural housing and flexible material for the finger rings, ensuring comfort and a personalised fit. Its modular architecture allows finger modules to be added or removed based on each child's therapeutic goals. Onboard Inertial Measurement Units (IMUs) capture real-time motion data, processed via an algorithm and transmitted wirelessly to a cloud platform, enabling occupational therapists to monitor progress remotely. Clinical evaluations confirmed that the smart wearable motivated hand movement and was positively received by both caregivers and occupational therapists [2].

2.2 Learning and competency for designing, fabricating and testing smart wearables

Effective learning for smart wearables design requires multidisciplinary, hands-on approaches combining theoretical knowledge with practical fabrication and prototyping skills, supported by competency frameworks across novice to expert levels. Previous study describes an innovative syllabus covering theoretical knowledge (materials and design), practical “learning by doing” (coding and manufacturing), and industry-involved product design. Further reports [4] reveal successful multidisciplinary teaching, integrating jewellery design, programming, and electronics with user involvement and prototyping. On the framework side, a previous study proposes a three-level competency framework (novice/advanced beginner, competent/proficient, advanced/expert) for sensor and wearable technologies in clinical contexts [5]. Moreover, competency modelling was demonstrated through interactive learning environments with gamification feedback [6]. However, previous studies do not advance beyond example pedagogical approaches.

3 METHOD

The design brief targeted an adjustable motion-tracking ring for AR/VR-based upper-limb rehabilitation—specifically, a customisable wearable ring for phalangeal motion tracking. Background included clarification: Wearable devices that track finger joint movements can provide critical input for interactive VR/AR therapy sessions. However, commercial solutions are often rigid, bulky, or lack modularity. The design brief assigned to the group concerned the development of a simple, adjustable, and lightweight ring capable of tracking motion at individual phalanges, which can later integrate with sensor modules to support real-time data acquisition.

The activities spanned over two days and covered (i) 3D scan of the participant's fingers for average sizing, (ii) a parametric 3D CAD design of the adjustable ring, (iii) first iteration of 3D-printed prototype, (iv) sensor integration, (v) development of working principles of a typical test jig/test procedure/plan, (vi) ergonomic testing, (vii) short iteration cycle based on feedback, (viii) final prototype presentation at closure session with challenges encountered and lessons learnt. The participants worked in multidisciplinary teams of five, including mechanical engineering, design, computer science, and occupational therapy backgrounds. They were in their first or second year of master's studies or in doctoral studies in their respective majors. All participants provided informed consent prior to participation. Data was anonymised and handled in accordance with the EU General Data Protection Regulation (GDPR) and the ethical guidelines of the University of Oulu.

This study employed three complementary methods to evaluate competencies in wearable rehabilitation device development: (1) Hands-on and observation workshop (Figure 1a): Four progressive practical sessions covering the complete device development cycle (3D scanning (Figure 1b), CAD modelling and 3D printing, electronics and programming (Figure 1c), and testing, (2) Post-workshop survey (mixed-methods questionnaire administered to all participants to capture feedback, measure learning outcomes, and assess competency gaps), and (3) A qualitative feedback from educators. A total of 21 students participated. The majority (62%) were in the 20-24 age group, followed by 24% in the 25-29 range, while 14% were 35 or older. Participation was well-distributed across the four partner institutions. The University of Oulu was best represented, at (38%, n=8), followed by the University of Pisa (29%, n=6), the University of Malta (19%, n=4), and the University of Strathclyde (14%, n=3). Figure 1 shows the work in two workshop sessions.

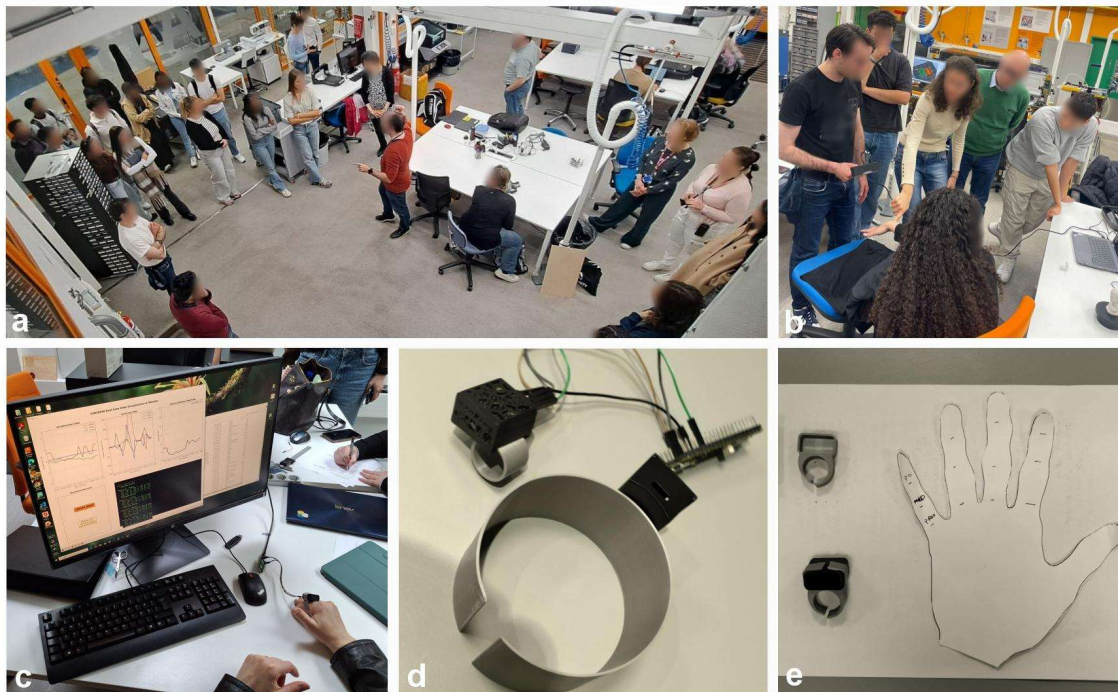


Figure 1. Super Fab Lab Oulu environment during the introductory (a), 3D scanning (b), electronics and programming (c) sessions, and example developed solutions (d, e)

3.1 Workshop

The workshop sessions are outlined in Figure 1a-e: **3D Scanning:** Students were introduced to 3D scanning technology and practiced capturing objects as digital 3D models. While few had prior experience, the activity sparked strong interest and highlighted both potential applications and challenges in handling complex anatomies. **CAD Modelling and 3D Printing:** Engineering and occupational therapy (OT) students collaborated to design a finger module for a wearable rehabilitation device (see example in section 2.1). Using CAD tools, clinical insights were translated into prototypes, which were then fabricated with 3D printing for further testing. **Electronics and Programming:** Participants integrated Raspberry Pi Pico boards and IMU sensors into the 3D-printed devices. After a brief introduction to circuitry and real-time monitoring, they assembled and programmed the system to capture and visualise motion data. **Testing Wearable Devices:** The workshop concluded with assembly and testing of the devices. Students evaluated performance, sensor outputs, and discussed feedback with OTs, reflecting on limitations and improvement opportunities.

3.2 Survey

To complement observations during the workshop, independent educators took notes, and the post-workshop survey was administered. The survey was completed by all 21 participants, representing engineering, design, and occupational therapy students. The survey design combined Likert-scale ratings, multiple-choice items, and open-ended questions. This allowed for both quantitative assessment

of key aspects and qualitative feedback, providing deeper insights into the student experience. The survey covered five main areas: (1) student profile – age and university affiliation, (2) organisation of activities – perceptions of the schedule, balance between theory and practice, and pacing of sessions, (3) logistics – availability and suitability of machines, facilities, and other resources, (4) sessions – ratings of whether each session was complete, enjoyable, useful, and relevant to learning goals, and (5) session-specific comments – space for participants to provide positive observations, highlight challenges, and suggest improvements for each session.

4 RESULTS AND DISCUSSION

4.1 Quantitative results

Participants expressed high satisfaction with workshop organisation, with over three-quarters providing positive ratings (57.1% rating it as excellent and 19% as good). Only 23.8% rated it as satisfactory, with no negative ratings, indicating effective planning and execution. The high satisfaction possibly meant that the results around content balance and gaps were more valuable. Specifically, the **balance between theoretical content and hands-on practice** received mixed but generally positive feedback. Equal proportions of participants (33.3% each) rated this aspect as good or excellent, while 23.8% found it satisfactory and 9.5% provided lower ratings, suggesting room for improvement in content balance. All four workshop sessions (3D Scanning, CAD Modelling and 3D Printing, Electronics and Programming, and Testing Wearables) were rated highly for being both engaging and comprehensive (Figure 2a). Participants found all sessions highly applicable to their learning objectives, with predominantly high ratings for usefulness and relevance (Figure 2b). Furthermore, the workshop successfully met or partially met expectations for all participants, with 90% fully satisfied and 10% partially satisfied. Figure 2c shows what students identified as areas of further development. Students identified regulatory and clinical requirements as the primary area needing development (n=15), followed equally by electronics/embedded systems and programming/software integration (n=14 each).

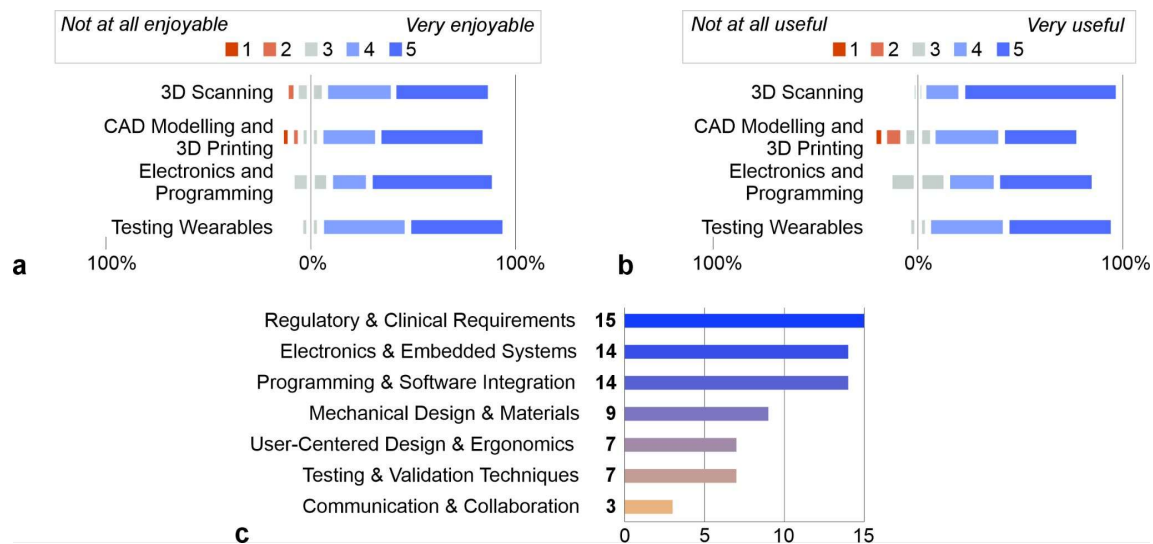


Figure 2. Enjoyability (a) and usefulness (b) of the workshop sessions; (c) areas of further development identified by the students

4.2 Qualitative results from student observations

To capture detailed feedback, students were asked to reflect on each of the four sessions in terms of what they found positive, useful, challenging, and what could be improved. Students found the workshop engaging and highly valuable, particularly praising the hands-on learning approach that allowed them to apply all sessions directly. Interdisciplinary collaboration emerged as a key strength, with participants noting that working across different backgrounds helped bridge knowledge gaps and enriched the learning process. However, a number of challenges surfaced consistently. Time constraints limited opportunities for iteration and refinement, while steep learning curves in electronics and CAD sessions created disparities between beginners and experienced students. Technical difficulties, from scanner stability and CAD precision to sensor calibration and data consistency, also hindered progress. Overall,

students appreciated the balance between theory and practice, expressing interest in broader applications to healthcare contexts. They recommended clearer clinical integration, more structured interdisciplinary exchange time, and extended practice opportunities to strengthen future implementations.

4.3 Qualitative results from educator observations

Educators provided complementary perspectives on the workshop. Their observations focused on both the potential of the technology and the practical challenges encountered during its use. Key points noted by educators included: Challenges in identifying suitable procedures for 3D scanning in context; Limited participation from OT students/teachers in some cases; Recognised the relevance and potential of 3D scanning technology; Strong interest in exploring and testing new methods for scanning; Emphasised the need for more hands-on practice to develop problem-solving skills, particularly when scanning complex anatomies; Despite enthusiasm, the integration of scanning results into subsequent phases (CAD design, electronics integration) was limited or partial.

4.4 Differences and missing topics

While several similarities were observed across the sessions, the survey also highlighted notable differences in how students experienced each activity. These differences related to the perceived strengths of the sessions, the main challenges encountered, unique aspects that stood out, and the diversity of prior experience among participants (Table 1).

In addition to evaluating the sessions, students were asked to reflect on areas where they felt further knowledge or skills would have enhanced their learning experience. Their responses pointed to gaps in both technical and contextual competencies, ranging from a stronger rehabilitative and biopsychosocial perspective to more practical knowledge about materials and fabrication (Table 2).

Table 1. Major differences in sessions

Aspect	3D Scanning	3D Modelling	Electronics	Testing
Biggest positive	The theory was clear and made the hands-on activities easier.	Creative process of turning ideas into objects	Seeing complex electronics explained clearly	Real-world insight: spotting design flaws and iterating
Biggest challenge	Multitasking: keeping the scanner steady, covering all angles	Learning a new CAD tool vs known tools; tolerances	Beginners struggled with coding & sensor calibration	Short time made re-testing and fixes tough
Unique aspect	Opened students' eyes to new applications in various sectors	Highlighted the link between design choices & real printing outcomes	Students enjoyed seeing how changing code affected sensor data in real time	Introduced structured frameworks like VVT for testing methodology
Learner diversity	Many total beginners	Mixed: some with strong CAD experience	Divide: some with coding experience, others none	Some already knew basic testing concepts

Table 2. Missing topics and skills from the student perspective

Missing competence	Description
Clinical / Rehabilitation Context	Many students felt they lacked a solid understanding of how the device would be realistically used by patients and therapists. They wanted more insight into human anatomy, clinical needs, and usability in real scenarios.
Creative Process & Concept Ideation	Several students felt the ideation phase was too rushed, which limited their ability to generate and refine creative concepts. They suggested including techniques for concept development and exploration before jumping into the design.
Technical Skills	Some students identified technical gaps, mainly related to using unfamiliar CAD software or lacking experience in modelling and scanning the body accurately.
Cross-Disciplinary Awareness	Students highlighted the importance of bridging the gap between different academic backgrounds. They felt more basic cross-field knowledge would help engineers, designers, and health science understand each other's perspectives.
Time & Group Dynamics	Many didn't think topics were missing but pointed out that time was a major issue. More time would have allowed them to refine designs, test more iterations, and better connect within their groups.

The workshop findings recommend five key improvements for interdisciplinary wearable rehabilitation education. First, extend practical sessions across multiple days with open lab hours and buffer time for iteration. Second, integrate clinical context through therapist-led presentations, patient case studies, and rehabilitation setting observations at the start of each session. Third, structure interdisciplinary exchange through mixed engineering-health teams, knowledge translation exercises, and reflection sessions. Fourth, strengthen materials understanding via property libraries, hands-on testing, and manufacturing demonstrations. Fifth, implement progressive skill building across four sessions assessed on technical competency, clinical integration, collaboration quality, and regulatory awareness.

5 CONCLUSION, IMPLICATIONS AND FUTURE WORK

The study illuminates how diversity in educational backgrounds (spanning engineering, design, and health sciences) enriches the learning process while simultaneously creating pedagogical challenges in wearable rehabilitation technology education. Drawing on students' experiences, they particularly value interdisciplinary collaboration for bridging knowledge gaps, yet steep learning curves create disparities between participants with different prior experiences. These findings directly inform strategies for accommodating diversity in multidisciplinary student projects in design education. Based on comprehensive feedback from student participants, the study proposes evidence-based recommendations for interdisciplinary design education. The five evidence-based recommendations proposed address practical, clinical, and collaborative dimensions of future course design. A follow-up clinical study is planned, in which students will complete a design brief drawing on knowledge from the e-learning course, with outputs evaluated by an expert panel. The modular session structure of the workshop is designed to be adaptable for distributed or online delivery but also can be scaled up to traditional course structure. This structure is forming the foundation of a forthcoming e-learning course that will allow broader cohorts across institutions and disciplines to engage with the same interdisciplinary competency development framework.

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ENGINEERING GROUP SUCCESS THROUGH ACTIVE INTERVENTIONS AND COMMUNITY BUILDING

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ABSTRACT

Teamwork is an essential part of engineering projects, and it is well established that diverse teams deliver better outcomes: the open-ended nature of engineering challenges requires a variety of viewpoints to develop creative solutions, which leads to more robust, well-rounded results. However, diversity can also introduce challenges, such as communication barriers and bias, potentially leading to misunderstanding and conflict. This is particularly true in educational settings where the main (perceived) outcome is a grade rather than a real-world engineering solution and where students' prior experiences have often been quite homogeneous, e.g. in single-sex schools. This dynamic can result in minoritised team members feeling their contributions are less highly valued and not being listened to by the team. Educator's responses to this issue range from passive acceptance, i.e. arguing that such experiences prepare students for future workplace realities, to active interventions. Examples of the latter include the mandated rotation of administrative roles, assignment of roles based on self-identified skills and areas for growth and avoiding having a lone minoritised student in a further homogeneous team. These interventions, amongst others, have been incorporated into the Design, Make, Test module at the Mechanical Engineering undergraduate programme at Imperial College London. Arguably the most significant contributor to student wellbeing has been the co-creation, with student representatives, of dedicated active communities that organise informal sessions where students share experiences, realising they are not alone. Therefore, planned future developments include extending this approach to other underrepresented groups in the cohort whilst also raising awareness among majority-group students about any undesired behaviours and encouraging them to adapt their actions.

Keywords: Engineering projects, co-creation, inclusivity and diversity

1 INTRODUCTION

Most engineering degrees comprise one or more modules where a major project is delivered by the students as part of a team. The reasoning behind such modules is well documented: firstly, employees expect engineering graduates to be competent not only in their main technical disciplines but also in transferrable skills including communication, collaboration, project management, problem-solving under uncertainty, and critical self-reflection **Error! Reference source not found., Error! Reference source not found..** Secondly, it has been long-established that it is not domain-specific knowledge that graduates most regularly draw upon in their daily professional practice, instead, they consistently identify interpersonal skills, engineering reasoning, and the ability to work effectively within a team as the competencies that matter most in early careers **Error! Reference source not found., Error! Reference source not found..** Thirdly, the Washington accord **Error! Reference source not found., Error! Reference source not found.** which defines a range of attributes of graduates, stipulates that engineering degrees teach and assess students' ability to collaborate in teams. These transferable skills are typically developed as part of a design-focussed project in which students are tasked to collectively deliver an engineering solution within specific constraints. Such design projects require students to mirror the realities of professional engineering practice, i.e. negotiate roles, manage conflict, coordinate effort across individuals with different strengths and weaknesses, and communicate their decisions to a range of stakeholders. A student's experience of delivering their group project has implications for module-level learning and assessment outcomes, as well as for students' broader confidence, sense of belonging, and educational outcomes. In 2023, EngineeringUK **Error! Reference source not found.** reported a significant ethnicity awarding gap in engineering, with 28.1% of Black students receiving a first-class honours degree, compared to an overall average of 44.8% for all students. Yet groups with diverse backgrounds

consistently outperform homogeneous groups of like-minded individuals, even when the like-minded teams are composed of members with higher grades in other modules **Error! Reference source not found., Error! Reference source not found.** Tian **Error! Reference source not found.** argues that gender balance within a team correlates with stronger performance on novelty and impact, whilst the 4th edition of the UK Engineering Council's Accreditation of Higher Education Programmes explicitly places a strong emphasis on inclusive design as well as equality and diversity as graduate learning outcomes **Error! Reference source not found.**, reflecting a broader acknowledgement that diverse teams deliver better-rounded engineering solutions. Group work has the potential to reduce awarding gaps **Error! Reference source not found.**, although it is well-established that peer assessment can increase it **Error! Reference source not found.**, meaning that careful management and support of diversity in teams is essential for equity. It needs to be noted that the students entering engineering programmes typically have relatively uniform prior educational backgrounds, see e.g. **Error! Reference source not found., Error! Reference source not found.** In addition, the makeup of the student-body is far from diverse; mechanical engineering as a discipline sits at approximately 20% female participation and engineering in general has a broadly 70% white ethnicity **Error! Reference source not found.** whilst for most degree programmes the number of students with a non-binary or specific disability status is too small to make any statistically relevant statements. The design project may represent a student's first sustained experience of working alongside peers from different backgrounds and with markedly different experiences. This has implications for how students communicate, how they interpret the contributions of their peers, and how well-equipped they are to recognise and respond constructively to the dynamics that diversity can introduce into a team. In this paper, we describe a series of active interventions in a third-year engineering group design module and reflect on their observed impact on the student experience.

2 BACKGROUND AND MOTIVATION

Team diversity does not automatically translate into better outcomes. Assumptions about competences or roles based on demographic characteristics may result in the contributions of minoritised members being systematically undervalued **Error! Reference source not found., Error! Reference source not found.** whilst also reinforcing existing biases. This undermines social integration and may even result in perceived or actual situations of conflict **Error! Reference source not found., Error! Reference source not found.** Unconscious bias has been shown to negatively affect the contributions and experiences of minoritised team members **Error! Reference source not found., Error! Reference source not found.** A compounding factor in educational contexts is the effect of demographic isolation within a team: it has been shown that female students in STEM group work express less comfort, show reduced verbal participation, and experience greater anxiety when they are the sole representative of their demographic group **Error! Reference source not found., Error! Reference source not found.** This so-called token dynamic, in which a minoritised member is numerically isolated within an otherwise homogeneous team, has been shown to increase performance pressure and reduce the likelihood that the individual's contributions will be equitably recognised or acted upon **Error! Reference source not found., Error! Reference source not found.** Where teams default to a division of labour based on perceived rather than demonstrated competence, minoritised members are frequently assigned peripheral or administrative roles, regardless of their technical ability, with the consequence that they derive less learning value from the experience than their majority-group peers **Error! Reference source not found.** The cumulative effect is that students who are most exposed to bias within the group project experience are also those most likely to disengage from engineering as a discipline. For example, female students in engineering have reported that male peers gave their ideas less credit and excluded them from technical work in group projects **Error! Reference source not found.**, a dynamic that both affects individual wellbeing and creates structurally unequal learning opportunities within the team. The Design, Make, Test (DMT) module is a compulsory third-year module taken by the entire cohort of approximately 180 undergraduate students in Mechanical Engineering at Imperial College London. With a time commitment of 500 hours per student, the module serves as the capstone project for the engineering design-focused learning within the degree, building on individual and small-group design work undertaken in the first and second years. The formal learning outcomes span the full engineering design cycle, from the derivation of customer requirements through manufacture, testing, and project management, with the explicit aim of exposing students to a realistic project structure **Error! Reference source not found.** The module is organised around a so-called

superproject format, with a superproject comprising three teams of four students that collaborate to deliver a functioning prototype as part of a larger, integrated engineering system. Across the cohort, fifteen distinct super projects are defined each year, each with a unique technical brief ranging from a rocket engine to the propulsion system of a robotic turtle. Compared to traditional small-group projects, this nested structure enhances the authenticity of the educational design project experience, allowing more complex problems to be tackled whilst requiring students to develop the communication, collaboration, and interpersonal skills that characterise real-world engineering practice. Each subassembly team is supported by a dedicated supervisor acting as a technical specialist, whilst an overarching project director takes the role of client and coordinates integration across the three subassemblies. A systems engineering team, comprising representatives from each subassembly, meets fortnightly with the project director to maintain alignment with the overall project brief and to manage interfaces between the three subassemblies. Further pastoral and professional support are provided by a team comprising the module leader, a senior Teaching Fellow being responsible for student wellbeing, the Departmental wellbeing advisor, and EDI coordinator, who offer confidential guidance to students throughout the project without involvement in assessment **Error! Reference source not found..** Staff to provide this supervision and support structure amounts to approximately 2 full-time equivalents on an annual basis, and includes academics, teaching fellows, laboratory and workshop technicians as well as administrative staff. Evidence for the significance of diversity and inclusion dynamics in group design projects were found in the feedback received through the National Student Survey (NSS) over the period 2022-2025. Analysis of open-text responses across this period identified a consistent pattern: whilst feedback on personal projects and general module experiences was predominantly positive, negative comments associated with group design projects related specifically to diversity and inclusion. Students described experiences in which disability within a team was not supported amongst other group members and called for greater EDI awareness and training among staff, as well as highlighting a desire for more structured attention to diversity within the group project experience. This pattern was consistent over multiple years, suggesting that EDI (equality, diversity and inclusion) related difficulties in group work are a persistent feature of the student experience. The reported negative consequences of teamwork risk undermining the wide range of positive outcomes that working in a team of peers is actually intended to support and provide a clear evidence base for the need for intervention.

3 INTERVENTIONS

In response to the notion that student experience in group design projects can be improved through addressing diversity and inclusion dynamics, a series of active interventions and informal support have been incorporated into the DMT module. These interventions operate at three levels: the composition of teams, the structure of roles and responsibilities within them, and support with team structures.

3.1 Team composition

At the level of team composition, care is taken to avoid placing a single marginalised student within an otherwise homogeneous group. As a trial, this has been introduced for gender: gender-based isolation within a team significantly increases the pressure on the female team member and reduces the likelihood that their contributions will be equitably valued **Error! Reference source not found., Error! Reference source not found..** By ensuring that female students are not alone in their team of four students, the intervention seeks to create a team environment in which female students are less exposed to the performance pressures and marginalisation associated with token status. Structuring teams to prevent this dynamic may be seen as a reasonable protective measure within an educational context. However, it raises a legitimate pedagogical concern: in most professional engineering environments, female engineers cannot rely on such structural protection, and a female student who has only ever worked in carefully balanced educational settings may be poorly equipped for the realities of workplace culture. This tension is not easily resolved and arguably should not be resolved by simply accepting isolation as a necessary hardship on the grounds that it reflects industry norms. Accepting that exposure to marginalisation constitutes preparation for it implicitly places the burden of adaptation on minoritised students rather than on the wider team and institutional culture. To our knowledge, there is no evidence that students having experience being a minority in a project develop greater professional resilience as a result. In contrast, Hu **Error! Reference source not found.** and Isaac **Error! Reference source not found.**, argue that such experiences increase the likelihood of disengagement and attrition.

3.2 Team roles

Within teams, two complementary approaches to role assignment have been introduced. The first is a mandated rotation of administrative roles such as chairing meetings, keeping meeting minutes and maintaining project documentation. This ensures that no single team member, by default or by informal consensus, is expected to fill this position for the duration of the project. Whilst some people may see these roles as essential and highly influential in any team process, in most educational settings they are seen as a tedious, administrative burden that may be assigned to a noncomplaining team member. Guiding meetings, keeping minutes and documenting are, however, essential transferrable skills for any engineer. The second approach to role assignment is a skills-based assignment process, in which students self-identify their areas of strength and areas in which they wish to develop, with roles allocated accordingly. This approach serves a dual purpose: it identifies, values and draws upon the diversity of skills and perspectives within the team more deliberately, and it provides a structured basis for role allocation that is grounded in individual agency rather than unexamined assumptions about competence. It is, however, in direct conflict with the general desire to work efficiently and aim for the highest possible mark in the minimum amount of time. At present, the self-identified skills-based assessment is implemented through a non-regulated informal process during the initial stages of the project, with the outcomes reported as part of the groups project plan. A more formalised assessment, e.g. performed whilst the supervisor is in attendance, could be considered to ensure the process gets appropriate consideration and attention whilst all students can contribute equally.

3.3 External Support

Informal networking sessions for marginalised students are run once or twice per term. Similarly to the approach piloted for team formation, this initiative was first trialled for gender, with students who identify as women, or nonbinary, being invited to participate. Sessions are hosted by the module leader and supported by the Head of Student Experience and the Department's EDI Coordinator and are scheduled outside of regular lecture hours - food is provided. The core format is a lightly facilitated discussion centred on the student experience: this normalises the difficulties and challenges certain students are facing, lowering the barrier to addressing them whilst providing an opportunity for both staff and peers to share advice and strategies for addressing those challenges. The sessions also function as a feedback mechanism, giving staff direct insight into the minoritised student experience.

4 OUTCOMES, DISCUSSION AND CONCLUSION

The design of the module has been amended over several iterations to address EDI related issues. This development has taken place using a co-creation approach with students and has resulted in a self-sustaining feedback and co-creation cycle via the generation of the informal community support sessions. Attendance at these sessions has grown year on year, with increasingly tangible outcomes, such as newly introduced questions assessing group dynamics that have been incorporated into the peer assessment exercise. Student feedback gathered during these sessions, as well as in student experience focus groups and the Departmental EDI survey evidences a change in culture within the undergraduate cohort where our marginalised students are happier in their group work and more confident in raising concerns on their projects, enabling faster resolution. In that sense, feedback received from specific focus groups e.g. on gender is used help to make the experience more inclusive for all students. On team composition specifically, a typical response from a student in the National Student Survey (NSS) directly attributed to the DMT module is: *"I don't know how I would cope without [being put in pairs]."* On team roles, the number of complaints from students about being *"stuck in an admin role"* have decreased noticeably. From these experiences and from literature it is clear that team composition strategies in educational settings serve a developmental purpose that is distinct from professional practice. By ensuring that minoritised students are able to participate equitably during the period in which core engineering competencies and professional identities are being formed, interventions seek to establish a foundation of confidence and experience from which students are better placed to navigate less equitable environments in their subsequent careers. The goal is not to shield students from difficulty indefinitely, but to avoid allowing structural disadvantage to interfere with the formation of the very capabilities they will need when that protection is no longer available, or to impact their academic outcomes. As such, future steps to be taken will include considering other marginalised groups as part of team composition, using a community-led approach, whilst taking care to not further marginalise groups or make anyone feel othered. One notable example is a study into the student experience in

collaborative projects led by two East Asian students, following a pilot elsewhere in the University. Whilst the project has aimed to take an asset-based approach through co-creation, empowerment and structural change, limitations still exist, predominantly in the form of majority-group behaviours. Some measures have been put in place to address these through whole cohort awareness and skill training sessions throughout the curriculum, such as Allyship, Unconscious Bias and Active Bystander as well as Professional EDI skills and inclusive teamworking. However, these sessions are not always well-attended, and their learnings not always implemented, so further work is needed. In the longer-term, awareness-raising activities will have to be introduced within the module, aimed at majority-group students, with the objective of encouraging reflection on team behaviours and dynamics that may, often inadvertently, disadvantage minoritised members. This initiative aims to foster a cohort of graduates with inclusive teamworking skills and recognise that structural change is required when addressing the interpersonal behaviours that undermine inclusion.

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Exploring Diversity in Engineering & Product Design Education

Inclusive design asks designers and engineers to empathise and understand the diverse people they are designing products and services for, but what if that diversity was mirrored in the wider engineering, design and product development industry? A diverse design team offers opportunities to provide appropriate solutions and understand psychological and physiological needs as well as cultural or social nuances, which ethnographic research and design tools may not be able to fully capture. The E&PDE 2026 conference is dedicated to acknowledging and changing the visible lack of diversity within Engineering and Product Design Education



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