BRIDGING HUMAN-CENTRED DESIGN AND ENGINEERING EDUCATION: A CASE STUDY OF PHARMACEUTICAL PACKAGING FOR THE ELDERLY

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ABSTRACT
The integration of real-world case studies into engineering design education enhances students' ability to develop innovative, human-centred solutions for complex challenges. This paper explores a mechanical engineering undergraduate final year project as a case study for fostering human-centred thinking in engineering and product design curricula. The project focused on designing pharmaceutical packaging tailored to the needs of elderly users, addressing barriers such as limited dexterity, vision impairments, and safety concerns. By employing a rigorous human-centred design process that included user research, prototyping, and iterative testing, the study delivered a packaging solution that balances usability and safety. The importance of designing for diverse user groups, particularly vulnerable populations such as the elderly, has been emphasised, along with meeting regulatory and practical constraints. Using this case study, educators can introduce students to the challenges of developing human-centred products that evoke a positive user experience in a healthcare context, stressing empathy and ethical considerations. This paper highlights how such projects effectively bridge the gap between theoretical concepts and real-world applications, fostering a mindset of empathy and inclusivity in future engineers. Ultimately, this approach can aid in preparing students when creating meaningful innovations that improve the quality of life for diverse populations.

Keywords: Human-centred design, user experience, engineering education, product design, pharmaceutical packaging

1 INTRODUCTION
At the University of Malta, the undergraduate engineering degree is a four-year course that balances core technical training with emerging topics such as sustainability. Within this curriculum, engineering design plays a vital role, requiring dedicated focus to tackle real-world challenges, and its significance cannot be disparaged.

This paper aims to discuss how integrating real-world case studies into engineering education enhances a student's ability to create innovative, human-centred solutions for complex design challenges. The case study presented focusses on pharmaceutical packaging for older people and emphasises inclusive design, user feedback and interdisciplinary collaboration. This paper outlines the teaching approach and human-centred design methods used to guide students from concept to prototype by reviewing the design tools employed during the case study project.

1.1 Human-Centred Design and User Experience in Engineering Design
Human-centred design (HCD) should be an aspect of design that is introduced to students throughout their engineering education. User experience (UX) works together with HCD and is as important to implement when designing products for a particular target market.

According to ISO 9241-220:2019 [1], the international standard for the ergonomics of human-system interactions, HCD refers to the "*approach to system design and development that aims to make interactive systems more usable by focusing on the use of the system; applying human factors, ergonomics and usability knowledge and techniques*". Similarly, the same standard defines UX as being "*user's perceptions and responses that result from the use and/or anticipated use of a system, product or service*." The development of skills necessary to implement HCD and UX are greatly beneficial when designing for people, to provide positive and meaningful experiences [2]. An engineer must be empathetic when designing a product to relate, to a certain extent, to the end-user. This can be accomplished by identifying what and why some experiences are meaningful to the consumer, what characteristics of a product must be implemented, and what makes a product easy, comfortable and satisfying to use [3]. Integrating UX with HCD enhances a product's design by developing an emotional engagement between the product and its user, ensuring a more enjoyable and satisfying experience [2].

1.2 Challenges and Advancements in Engineering Design

With ever-evolving technology comes the complexity of new problems, shaped by modern society and lifestyles. Engineers are now expected to not only design for functionality and efficiency, but also for sustainability, recyclability and ethical responsibility. Contemporary users and markets greatly value products that align with sustainable and socially responsible practices [4]. Important questions can be raised on how sustainability can be meaningfully integrated into HCD processes without compromising usability or accessibility. There is also a need for structured methods that guide idea generation and method selection within constrained design environments. While this paper discusses the application of established HCD and UX practices, future research could explore emerging approaches such as the Beyond-Human Persona [5] which broadens design focus to include environmental and systematic impacts.

The integration of UX within HCD can provide valuable guidance and key strategies to improve the overall product design process. However, designing for diverse user groups, including individuals with physical or cognitive impairments, remains a significant challenge [6]. Balancing and aligning a user-centred approach with business objectives can be a difficult task as priorities may be conflicting [7]. In areas such as the pharmaceutical packaging industry, the issues of inclusive and accessible design are compounded. Designing a product that is accessible to all users, including those with cognitive or physical impairments, requires specialised knowledge and resources, but is an aspect that has become a necessity for products to ensure equal opportunities for all [8].

In the next section, a case study shall be discussed related to the implementation of HCD and UX principles when designing a product for the pharmaceutical industry, and what such a process entailed.

2 PHARMACEUTICAL PACKAGING FOR ELDERLY USERS: A CASE STUDY

Designing products for any industry has its own challenges. Taking the pharmaceutical packaging industry as a case study, the main challenges that a design engineer faces include medication integrity and stability which can be adversely affected by environmental conditions, including light exposure and fluctuating humidity and/or temperature levels. Packaging tampering and counterfeit products are also severe issues which could be harmful to consumers [9]. Pharmaceutical packaging must be easily usable by their target market and be compliant with regulations and standards. Distinct target consumers face different challenges when using the same product. Taking the elderly as an example, such users tend to face difficulties when using medicine packaging due to factors such as limited hand function and mobility as well as visual and cognitive impairments. There is still a present need for user-centred solutions for medicine packaging design to target comfort and ease of use for the elderly whilst maintaining a safety aspect [10].

An undergraduate engineering final year project is taken as a case study on how the implementation of HCD and UX in engineering design is being taught at the University of Malta to shape young engineers to use engineering tools and methods to design good products, usable by their target market.

2.1 Case Study Project Overview and Engineering Tools Implemented

The undergraduate project under discussion aimed to design a novel medicine packaging solution that is easy to use by the elderly whilst simultaneously being child resistant [11]. The basic design cycle, as established by Roozenburg and Eekels [12], was followed by adopting an iterative approach to design via four main activities: Problem Analysis, Synthesis, Simulation and Evaluation. Various engineering design tools were used within each of the four activities which provide an indication of the extent to which engineering design has been taught at the University of Malta. The design cycle implemented, and the tools used during each activity, have been presented in Figure 1.

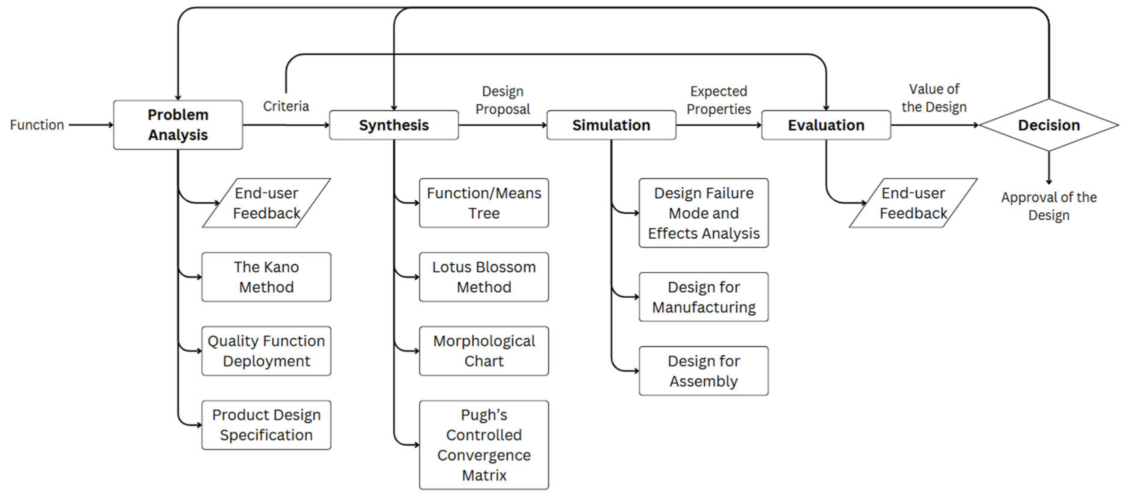

Figure 1. Design tools employed during each design activity, as adapted from Roozenburg and Eekels [12]

During the Problem Analysis activity, the problem statement was expressed and factors such as the target market, what the problem itself was and what could be causing it were included. A quantitative approach was opted for to better understand the product to be designed, its characteristics and what factors were most important to incorporate. A study was conducted with elderly users to determine these critical characteristics. The Kano Method was used to analyse a few of the questions asked during the study and the results led to the compilation of a Quality Function Deployment (QFD) and Product Design Specification (PDS). The Kano Method was used to analyse customer satisfaction elicited by several potential features on the product to extract additional customer requirements for the QFD. The QFD was compiled to determine the product's engineering requirements, based on customer requirements, and their order of importance. The PDS was consequently built to define each product requirement including, for instance, the maximum cost of the product. An aspect that was highlighted by the PDS was the want to enforce sustainable disposal of the product following fabrication; the product needed to be designed using materials that could be reused and recycled, and which would pose minimum risk to humans and the environment when disposed of. This was established to ensure that the final product abided by sustainability goals and green engineering principles. The Problem Analysis activity resulted in the identification of main product requirements, namely its ease of handling and grip-ability as well as its ease of use by elderly users whilst being child-resistant. Financial considerations were also addressed to ensure the product's economic viability and market appeal.

The Synthesis activity included the generation of new conceptual ideas by concatenating separate ones, accomplished via design tools and brainstorming activities. Three brainstorming design tools were employed; a Function/Means Tree (used to identify and break down the major functions [means] that make up the primary function of the product into sub-functions [13]), the Lotus Blossom method (focus is put on the core problem from which additional sub-themes and ideas are inter-connected resulting in new patterns being generated [14]), and a Morphological Chart (an analytical and systematic tool used to establish product functions by deconstructing its design problems [15]). Additionally, upon initial concept generation, Pugh's Controlled Convergence Matrix (PuCC) method was implemented as an iterative decision matrix. The PuCC method was used to converge to the best concept that had the most potential to out-perform other market leaders, and to allow the designer to merge concepts together to create new ideas [16]. The tools employed during the Synthesis activity resulted in the generation of a final provisional design of the product.

Following this, the Simulation activity consisted of formulating the conceptual idea/s into digital and physical models. Digital modelling was accomplished via computer aided design (CAD) packages and physical prototypes were fabricated via 3D printing. A Design Failure Mode and Effects Analysis was used to identify all possible failures that may occur, and any high-risk failure modes were amended. Design for X methods, namely Design for Manufacturing and Design for Assembly, were also employed to optimise the design prior to fabrication. The Simulation activity resulted in the development of the final product design.

Finally, the Evaluation activity included testing the physical prototype/s to determine where the product was strong and where it could be improved. It was then decided if the design process was complete or if an additional iteration back to the Analysis or Synthesis activities was necessary [12]. The design was prototyped and tested via a study with elderly users and children, to see if the design was a success. The design's primary objective of providing an easy-to-use and comfortable to handle product for the elderly was successful whilst the secondary objective for the product to be child-resistant was deemed to be acceptable but required further testing and improvement to fully eliminate the potential risk of child accessibility on accident. It must be underlined that the final design of the pharmaceutical packaging has not been presented within this paper to safeguard Intellectual Property.

2.2 Challenges and Setbacks

From a technical perspective, the biggest challenge faced was the need to design a product targeted for elderly users who have issues with their upper limb mobility, strength and dexterity, and have the product be potentially usable one-handed [17]. Additionally, the product simultaneously needed to be child resistant to avoid the risk of medication ending up in a child's hands. This brought about design challenges that required multiple design iterations and feedback from potential end users to establish a finalised product. Understanding what would bring about a positive UX and attempting to integrate HCD throughout the project was also a challenge [2]. Studies with potential end-users aided in mitigating this and their feedback was critical in understanding what would elicit a positive UX. Feedback during the Evaluation activity was crucial as participants were able to hold and use the prototyped final design, so physical and real-time opinions and critiques were gathered.

3 DISCUSSIONS

The rapid advancement in technology has brought about various opportunities and challenges for design engineers. New tools are being developed to aid engineers on their journey to product design that integrate these advancements. The digital age, for instance, has brought about CAD modelling and digital twins, an aspect of engineering that has helped reduce the time and resources needed to design a product and aids in stream-lining this process. Artificial intelligence (AI) is an advancement that is steadily becoming more popular for idea generation and generative design techniques, not just for concept generation and product synthesis, but also for structural optimisation and material design [18]. Through AI-enabled processes, one can navigate through the mass of data generated by customer reviews and feedback in an optimal and efficient manner [19]. This would make the task of eliciting customer requirements from reviews easier to fulfil, consequently aiding a designer when implementing UX and HCD. The development of smart packaging has also been on the rise. Such packaging is becoming increasingly popular in the pharmaceutical industry to improve patient safety and maintain product integrity. Smart pharmaceutical packaging is capable of monitoring essential environmental and handling conditions by incorporating sensors within the package [20]. For the next generation of engineers to adequately make use of these technologies, engineering education must be adapted to teach the foundations of this technology. When designing a product for a target market, the implementation of HCD and UX is of utmost importance, and the tools necessary to synthesise such products need to be taught at the early stages of one's engineering education. At present, traditional and hands-on methods are being taught at an undergraduate level and these help to shape one's mindset into thinking in an analytical and empathic way. Additionally, students should also learn how to apply modern technologies such as AI, digital twins and smart packaging, and integrate them into HCD and UX practices. These tools have the potential to enhance user modelling, simulate user interactions, and enable data driven personalisation [21, 22]. Future research should explore how such technologies can be systematically embedded into HCD processes to deepen insight and increase the responsiveness of novel design solutions.

In the case study discussed, HCD was applied through an iterative approach, allowing for continuous refinement of the product's design based on real-world testing and feedback from potential end-users. User feedback loops were integrated at multiple stages of the design process, ensuring that end-user needs and preferences shaped the development process. Interdisciplinary collaboration played an important role in bringing together engineering, healthcare, and design perspectives to develop a more holistic solution. Inclusive design principles were prioritised, ensuring that the product was accessible, safe, and effective to use by diverse user groups, including those with particular medical or physical needs, with the elderly being the primary target user. These approaches collectively reinforced a user-centred design process that enhanced both functionality and usability.

Using case studies such as the one discussed as a frame of reference for students can be greatly beneficial. Product design can be a challenging and overwhelming task for engineering students, especially when lacking prior experience. Having a guiding approach can assist students in managing the complexities of product design. The discussed case study highlights the value of integrating multiple design tools rather than relying on a single method, encouraging students to approach problem-solving with flexibility. It also draws attention to the critical role of customer feedback at various stages – from initial requirement gathering to final product evaluation – ensuring that designs remain user-centred. Incorporating case studies into engineering education bridges theory and practice, equipping students with the skills necessary to tackle real-world design challenges effectively.

Undergraduate projects play a crucial role in bridging the gap between theory and practice, offering engineering students the opportunity to apply diverse design tools and methodologies that may not be fully integrated into their standard curriculum. By engaging in hands-on projects, students can experiment with industry-relevant techniques, refine their problem-solving skills, and develop a deeper understanding of HCD. The case study discussed demonstrates how exposure to multiple design tools enhances a student's adaptability and innovation, preparing students to tackle real-world challenges with a holistic and user-focused approach.

4 CONCLUSIONS

Engineering design presents several challenges, including rapid technological changes and advancements. Continuous advancements brought about by the digital age such as CAD modelling and AI have optimised and improved the design process, and the innovation needed to create novel ideas and concepts. As presented via the case study discussed, at present, engineering education teaches its students to think analytically and holistically through traditional hands-on methods. Such tools aid in teaching students to be empathetic with their target market and employ HCD and UX when designing a product. Using such a case study to assist in teaching engineering students about the integration of HCD and UX into product design would be greatly beneficial for the student.

Engineering education must evolve to keep pace with rapid technological advancements and the emergence of Industry 5.0, which is expected to extend beyond profitability from the production of goods and services and will probably require different schools of thought [23]. To prepare future engineers for this shift, HCD must be integrated with emerging technologies such as AI, digital twins and smart packaging to develop innovative products and services. In the pharmaceutical industry, future engineers must go beyond the technical performance to prioritise patient accessibility, safety and adherence to regulatory requirements, particularly for vulnerable populations such as the elderly. Engineering education should incorporate generative design and regulatory compliance to ensure adequate usability and ethical responsibility. By embedding HCD principles into engineering curricula, students can develop smarter pharmaceutical packaging that enhance patient experience while meeting industrial and regulatory demands.

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