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A COMPREHENSIVE METHODOLOGY TO IDENTIFY COMPETENCE GAPS IN PRODUCT AND DESIGN ENGINEERING CURRICULA

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ABSTRACT

This study investigates competence gaps in engineering education related to the development of wearable devices, specifically those used in rehabilitation. Using a qualitative research approach, we conducted focus groups with educators from three European countries as part of a three-stage methodology. Through thematic analysis, we identified five main themes: project methodology, pre-requisites, course structure, opportunities/outcomes, and competence gaps. Our findings reveal significant deficiencies in specific technical skills, including practical application of industry-standard software, systems integration knowledge, and computational abilities. Additionally, we observed substantial gaps in interdisciplinary collaboration and interprofessional knowledge transfer capabilities among engineering students. These results highlight the disconnect between current engineering curricula and industry requirements, particularly in preparing students for the complex, multidisciplinary challenges of designing customisable wearable medical devices. This research provides valuable insights for curriculum development in product and design engineering education, emphasising the need for enhanced practical experience and cross-disciplinary collaboration opportunities. Ultimately, this research advocates for a paradigm shift in engineering education towards more inclusive and human-centred approaches. By addressing competence gaps and fostering interprofessional collaboration, educational institutions can better prepare students to develop products that meet technical specifications and prioritise user experience and accessibility.

Keywords: Smart wearable devices, rehabilitation devices, interprofessional education, human-centred design, assistive technology

1 INTRODUCTION

The increasing demand for human-centred design in engineering and product development has highlighted the need for educational systems to adapt and equip students with the necessary skills to create inclusive and user-focused products [1]. This is particularly relevant in the context of designing smart wearable rehabilitation devices, which require a deep understanding of both technological innovation and user-specific needs [2]. To develop such knowledge, there is a need to address the competence gaps in product and design engineering curricula by focusing on the development of smart wearable rehabilitation devices.

These devices are designed to cater to the unique requirements of individuals, particularly those with disabilities or specific challenges who require rehabilitation. The ethos of bespoke design is central to this approach, emphasising the importance of tailoring products to meet diverse user needs and thereby enhancing overall performance and accessibility. To achieve this, the study proposes a comprehensive methodology that identifies gaps in current engineering education, specifically related to the development of wearable rehabilitation devices.

2 BACKGROUNDS

Studies of collaborations between engineering students and healthcare professionals in rehabilitation technology design projects are limited. For example, previous studies covered various educational settings, including university courses and research centres, using approaches such as clinical innovation teams and problem-based learning programmes [1]. Furthermore, successful collaboration required several key skills: the ability to integrate technical and clinical knowledge, effective interprofessional communication, project management capabilities, and an understanding of user-centred design principles. While the educational approaches typically involved hands-on projects and real-world problems, the studies used different methods to implement these elements [1]. The background literature shows limited agreement in assessing these competences, with few studies providing quantitative measurements of skill development [3]. These findings point to several gaps in current research, particularly the need for ways to measure interdisciplinary competences and evaluate long-term professional outcomes.

The rapidly evolving field of wearable rehabilitation technology has created a distinct need for engineers who can navigate both technical/technological complexity and clinical requirements. A review highlights the need for more interdisciplinary collaboration and research in this area [4]. Despite the recognition of this gap, engineering programmes have been slow to implement systematic approaches to develop the specific interdisciplinary competencies required for rehabilitation technology design [5]. Various educational initiatives have attempted to close this preparation gap, but result evaluation is limited. For example, undergraduate engineering and occupational therapy students working together on rehabilitation technology design projects for community-referred children with disabilities has been successful [6]. These inconsistent results show that there is no structured framework for identifying, developing, and assessing rehabilitation technology innovation competencies. Without a systematic approach, educational institutions will struggle to implement effective interdisciplinary programmes that prepare engineers for the complex challenges of developing wearable rehabilitation technologies with healthcare professionals. Therefore, this study aims to propose a comprehensive methodology for identifying gaps in current engineering education related to the development of wearable rehabilitation devices and to apply the initial stage of this methodology.

3 PROPOSED METHODOLOGIES

3.1 Stages

The methodology employs qualitative research methods across three stages (Figure 1). Initially, focus groups involving educators from the University of Malta, the University of Pisa, and the University of Oulu are conducted to gather insights into existing educational practices and identify potential areas for improvement, which is this study's focus (Stage 1). The findings from these discussions in focus groups inform the subsequent stage 2. Based on the results of Stage 1, comprehensive questions for group interviews with students and professionals from the same regions will be developed (Stage 2). In the final Stage 3, comprehensive data analysis and gap identification will be performed. This approach ensures a holistic understanding of the educational landscape from both teaching and learning perspectives. The data collected through these stages will be meticulously analysed to pinpoint specific competence gaps within product and design engineering curricula.

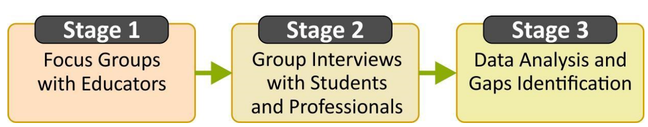

Figure 1. Situating this study at Stage 1 of the overall three-stage methodology

3.2 Focus groups with educators

The focus group's objective is to identify gaps in competences required for engineering education in wearable device development. To provide background for the group, initially, a brief case study of a smart wearable device designed to be used during rehabilitation therapy, primarily by children, is provided [2]. Following that, based on a common protocol, the case study was presented by a facilitator who prompted discussion between participants empowering them to ask questions. The initial segment of focus group was relatively unstructured, followed by a semi structured phase. The group is prompted by the questions of participants' opinions of the competence gaps when it comes to the manufacturing of customisable wearable devices and participants' thinking about the curriculum needs to include with regards to developing customisable medical devices for rehabilitation. A set of probing questions are provided to facilitate further discussion, covering topics of challenges, principles, requirements and opinions. For example, "What do you think should be the principles upon which smart wearable rehabilitation devices are successfully designed, fabricated and tested?" and "Can you identify the requirements of smart wearable rehabilitation devices?". At the end, the activity is concluded with the group identifying key gaps.

3.3 Participants

The recruitment of participants for the focus group is guided by the principles of diverse expertise and the inclusion of all participating partners (Table 1). In terms of expertise, efforts are made to cover all possible aspects of design, manufacturing, and practical application of a customisable wearable device.

Table 1. Characteristics of the three focus group meetings

Place (Participants, meeting mode)	Participants' expertise
University of Malta (9, in person)	Orthotics and Prosthetics, Occupational Therapy, Assistive Technology, Hand Therapy, Electrical & Mechanical Engineering, and Interprofessional Education
University of Pisa (9, online)	Mechanical Engineering, Physiotherapy, Industrial Design
University of Oulu (10, hybrid)	Design Science, Design Education, Electronics Engineering, HCI, Software Development, Digital Fabrication, Digital Healthcare, Nursing Education

3.4 Thematic analysis

Thematic analysis (TA) as a widely used qualitative data analysis method for identifying, analysing, and interpreting patterns of meaning within data [7], is used to analyse the focus group data. It offers flexibility in approaching research patterns and can be applied across various theoretical frameworks and research paradigms. In this study, we employ TA to report the results of the focus groups comprehensively.

4 RESULTS

The thematic analysis finds five main categories. These are project methodology, pre-requisites, course, opportunities/outcomes, gaps, and a tool (Figure 2). The **first** theme concerns general project methodology targeting development of a course on wearables for rehabilitation. It further emphasises the structured and methodological approach of the project. Moreover, the practice of data collection from several geographical locations, institutions, professions and work cultures can enhance the credibility of outcomes. While such a diversification of data collection and analysis enhances results' credibility it also requires streamlining of terminologies used in different professions (such as healthcare and engineering) and in different cultural contexts. The **second** theme includes pre-requisites and addresses the foundational knowledge, skills, and attitudes students need before engaging with advanced engineering coursework. This includes technical fundamentals, mathematical proficiency, spatial reasoning abilities, use-related knowledge and baseline digital literacy that form the essential building blocks for successful engineering education. Moreover, some fundamental aseptic knowledge is required including hygiene standards related to the use of wearable devices, considering skin conditions and sensitivity of the individual using the device while selecting the material for the device development. Hence foundational knowledge of basic material properties used in several manufacturing technologies is required. The **third** theme focuses on the course and examines the actual educational content and delivery methods, encompassing curriculum structure, teaching approaches, assessment strategies, and the balance between theoretical knowledge and practical application in engineering programmes. Learning-by-doing, using open-ended prototyping approach, Interprofessional Education (IPE), and case-study methods were suggested by the experts as a teaching methodology for the curriculum. This is due to the multidisciplinary nature of the course content. Furthermore, some other practice approaches such as joint supervision and clinical observation were also suggested by the experts as part of the teaching plan in such a curriculum as shown in Figure 2. The **fourth** theme outlines opportunities and outcomes and focuses on the potential benefits and results of engineering education, including career pathways, professional development possibilities, and the broader impacts that well-designed curricula can have on students' future success and industry readiness. However, some associated challenges were also highlighted, such as cost-effectiveness of the wearable device development, aesthetic aspects of the device, assessment of the wearable device at the development stage, and consideration of sensitivity of individuals using the device. Such challenges can be addressed on a case-by-case basis and by including general guidelines to the curriculum. The **fifth and** final theme points out the gaps and identifies the disconnects between current educational opportunities and industry requirements, highlighting areas where engineering curricula fall short in preparing students for professional practice. This includes missing technical competences, underdeveloped soft skills, limited exposure to emerging technologies, and insufficient integration of interdisciplinary perspectives. Apart from the competence gaps mentioned above, other gaps related to the design of smart wearable devices were also identified, such as information security, human-centric design and one's experience of the wearable devices. Information security includes issues related to data management collected through the device, where the accuracy, reliability and anonymity of the data can also be issues to be considered in curriculum development. The competence gap regarding human centric design and user experience is related to developing user guidelines of the devices to be provided to the users, ultimately leading to enhance user experience. During the design of the device the comfort and algorithmic requirements and preferences of the user need to be kept in mind. Considering such factors in the curriculum design can provide a well-rounded experience for the students.

5 DISCUSSIONS

5.1 Lacunae in specific technical skills

The discussion relates to the themes identified through the thematic analysis. The analysis suggests several lacunae in technical skills across engineering education and curriculum. Within the gaps in the engineering curriculum theme, notable shortcomings are identified in students' practical application abilities, particularly in using industry-standard software tools and platforms. Students lack sufficient experience with CAD software, simulation tools, and manufacturing technologies that are commonly used in professional settings. Several of these categories might be relevant to other engineering disciplines. Notably, the analysis also points to deficiencies on a meta-level, for example, in systems integration knowledge, where students struggle to connect theoretical concepts with practical implementation. This includes limitations in understanding how different components and subsystems interact within complex engineering projects in a rehabilitation context. Additionally, there are gaps in specialised technical areas such as design for manufacturing, materials selection, and advanced prototyping techniques that are essential for product development. This supports the observation that transdisciplinary approaches to assistive technologies can lead to innovative and transformative solutions by integrating different knowledge and methods [8]. A hands-on, transdisciplinary approach [6] aligns with the observation that integrating diverse knowledge and methods can lead to innovative solutions in assistive technology development. Another significant technical gap concerns data analysis and computational skills. These themes suggested that students often graduate with inadequate abilities in programming, algorithm development, and applying computational methods to solve engineering problems. The themes suggest that while theoretical knowledge may be present, the practical technical competences needed to execute projects effectively in real-world contexts are often underdeveloped, creating a disconnect between academic preparation and industry requirements.

5.2 Interdisciplinary collaboration and interprofessional knowledge transfer

Overall, there is also a significant need for interprofessional knowledge transfer. The analysis reveals a significant gap in students' ability to work effectively across disciplinary boundaries. Engineering students need more structured opportunities to collaborate with peers from other fields, such as business, design, and health/social sciences, to develop a holistic understanding of product development challenges. There is also a need for improved communication skills specifically tailored to interdisciplinary collaboration contexts, where technical concepts must be translated for non-technical stakeholders. Similar translation requirements are valid for concepts of different domains.

Figure 2. Identified themes in the thematic analysis

Previously, a cross-domain translation of concepts has been required for such courses, with engineers explaining technical modifications to non-technical audiences and therapy students teaching engineers to contextualise designs within rehabilitation frameworks [3]. This aligns closely with the identified need. These observations highlight the importance of integrating interdisciplinary learning experiences into engineering education, enabling students to collaborate effectively across different fields and apply diverse perspectives in their design processes.

6 CONCLUSIONS

This research presents a novel approach to addressing competence gaps in product and design engineering curricula, focusing on the development of smart wearable rehabilitation devices. It is the first stage of a study which employs a three-stage qualitative methodology to identify educational gaps and emphasises the importance of integrating interprofessional knowledge transfer and human-centred design principles into engineering education. The implications concern educational structure in terms of course content and modules, technical competence development and focus, requirements for interdisciplinary knowledge and common "language", focus on user-centred design, ethical issues for vulnerable populations, and overall regulatory considerations.

The research highlights the need for a more interdisciplinary approach combining technical and health sciences-related expertise with understanding user needs. The expected outcomes shall provide holistic insights into how to equip educators, students, industry professionals, medical experts, and end-users with the knowledge to develop more effective, empathetic, and innovative rehabilitation solutions. As we move towards a future where personalised and adaptive technologies become increasingly prevalent, equipping students with these skills will be crucial in driving innovation and ensuring that engineering solutions are truly centred around human needs.

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