I4.0/5.0 MR training: Investigating MR tools to enhance learning experiences

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Abstract. As the manufacturing industry continues its shift towards highly complex Industry 4.0 production environments, there is an expected exponential increase and change in the demanded skills and qualifications among employees. However, traditional teaching methods may pose challenges when it comes to applying learned skills in real-life engineering situations, given the complexity of these environments. Recent advancements in technologies enabling virtual co-existence have opened up new opportunities for personalised and immersive services in pedagogy. While Mixed Reality (MR) and, more significantly, Metaverse infrastructure are still in their early stages, researchers and educators have the opportunity to lead the exploration of new avenues for reskilling educators and enhancing student learning experiences. This paper presents research conducted at the University of Malta, focusing on exploring the potential transformative pedagogical effects of MR in specialised Industry 4.0/5.0 engineering training. The paper proposes a framework for developing a Virtual Learning Factory (VLF) using MR technology, grounded in established and effective learning methodologies. The envisioned VLF aims to create an immersive experiential learning environment where engineering students can better adapt to the evolving industrial landscape, preparing them to excel in the dynamic era of advanced manufacturing. Additionally, the research delves into the potential impacts of MR-based training on enhancing training precision and efficiency.

1 Introduction

In today's fast-paced and competitive engineering environment, companies require fresh graduates who can quickly adapt, hit the ground running, and effectively manage complex real-life engineering systems [1]. However, finding such candidates has become more challenging due to the heightened complexity introduced by the Industry 4.0 paradigm. Companies now place greater emphasis on engineering skills such as design capabilities, performance assessment, and innovation, which are becoming increasingly vital for success in the field [1] . Nevertheless, reality presents a contradictory situation as new engineers often lack the necessary skills to navigate both traditional complex manufacturing methods and modern technological complexities. Graduate engineers may exhibit weaknesses in areas such as creativity, critical thinking, self-confidence, and problem-solving skills [2], all of

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which are essential skills needed to overcome engineering challenges, particularly those related to Industry 4.0, which are characterised by increased complexity. One of the primary reasons for this skills gap is attributed to traditional teaching methods and the lack of practical applications within the present education system. This gap contributes to the scarcity of thoughtful engineers and the disconnect between academia and industry.

Since the onset of the first industrial revolution, the educational system has continuously evolved and adjusted to align with the changing needs and priorities of industry [3]. As we navigate the landscape of Industry 4.0, there is a parallel movement towards what can be termed as Education 4.0, where students are positioned as proactive participants in the learning journey [4] . This shift aims to empower students to engage in interactive learning experiences tailored to their individual educational requirements [5]. One effective way to enhance and modernise the teaching process is by immersing students in Virtual Learning Factories (VLFs) using Mixed Reality (MR) technology. By simulating real-life manufacturing environments, students can explore how various manufacturing principles are interconnected and how they influence one another, providing a more comprehensive and practical understanding of engineering concepts [6]. Although there have been numerous previous studies that focus on innovative teaching techniques, the use of VLF is still in its infancy and there exists a wide area of research that needs to be explored on its potential benefits for engineers of the future.

The motivation behind this study is to present a hypothesis for the transformative positive potential of MR technologies in specialised Industry 4.0/5.0 engineering training. The study also explores a possible framework for developing a VLF using MR technology, which is built on established and effective learning methodologies.

2 Literature Review

2.1 Current Pd Current Engineering Teaching Methods

Education institutions delivering undergraduate courses related to STEM subjects have traditionally relied on teacher-focused strategies, primarily employing a lecture-lab model [7]. However, this traditional approach has revealed shortcomings in engineering fundamentals. These fundamentals include providing increased hands-on experience in real-world engineering design, fostering improved teamwork skills, and nurturing problem-solving abilities and critical thinking [8].

The current engineering education system's shortcomings worsen the skills gap and disconnect between academic teachings and industry needs. This issue stems from factors such as excessive reliance on traditional lectures and exams, hindering students from realising their full engineering potential [7]. Research suggests that student attention diminishes after 10-15 minutes of a lecture, yet many institutions still heavily depend on this method due to various logistical constraints [9]. Edgar Dale's cone of experience [7] and Kolb's experiential learning theory [10] highlight the ineffectiveness of passive lecture-based instruction, emphasising the importance of hands-on learning for students to comprehend and retain knowledge.

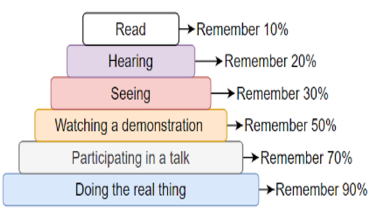

Fig.1. Edgar Dale's Cone of Experience

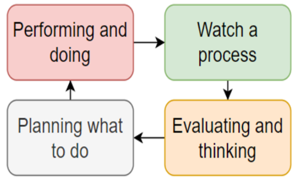

Fig.2. Kolb's Learning Cycle

The use of modular courses in education exacerbates the challenge by offering only specific aspects of engineering problems, potentially leading to a fragmented learning experience and hindering students from grasping the intricate complexities of real-world engineering scenarios [4]. Moreover, the limitations imposed by cost considerations prevent educational institutions from investing in real-life manufacturing equipment to demonstrate various manufacturing processes. As a result, students may graduate without the hands-on experience necessary to navigate the complexities of industrial systems effectively [11]. Furthermore, according to Foley et.al. [12] the fear of failure culture that still exists within students is a major impediment to thinking creatively. This leaves students unwilling to explore creative problem-solving ideas, with their fear of failure [12]. To address these pressing issues, it is imperative to reimagine manufacturing education and bridge the gap between academic knowledge and industry requirements. By revamping engineering curricula to incorporate hands-on experiences and practical applications, educational institutions can better equip aspiring engineers with the skills and competencies needed to leverage emerging technologies and spearhead innovative solutions in the ever-changing engineering landscape [13].

2.2 Bridging the gap with technologies

Efforts to bridge the gap between education and industry are leveraging cutting-edge technologies like Mixed Reality (MR) and Virtual Learning Factories (VLF). Mixed Reality refers to a technology that can present a combination of real and virtual environments to humans. In a nutshell, MR is an umbrella term for VR and AR [14]. (Virtual Learning Factories (VLFs) create a simulated learning environment that mirrors real-life situations under supervision [14]. The metaverse enables interaction through MR in VLFs, revolutionising engineering education with immersive, hands-on experiences in virtual industrial settings [15]. This experiential learning approach enhances understanding of complex concepts and cultivates essential skills for real-world challenges, moving away from the limitations of modular courses. By embracing these innovative methodologies, students are equipped with practical knowledge and problem-solving abilities essential for excelling in the dynamic field of engineering [15].

Through the integration of MR technologies and VLF, educational institutions can provide an engaging learning experience that meets the evolving demands of the engineering workforce [1]. Gamification, incorporating game dynamics into learning, enhances student achievement and motivation in the classroom. It creates a safe environment for exploration and innovation, reducing the fear of failure and emphasising the learning process itself [16]. This shift in focus from the end result to the learning process itself is key [17]. In addition to reducing the fear of failure, a well-designed educational game allows for prompt feedback. Research by Kapp [16] emphasises that providing feedback is crucial, and the more precise and frequent the feedback given to learners, the more influential the learning process becomes [16]. By immersing students in virtual industrial environments and promoting collaborative learning, these technologies bridge the gap between theory and practice, empowering a new generation of skilled engineers ready to drive innovation in the digital age [1].

2.3 Gap Analysis

Undoubtedly, MR and VLFs offer significant promise for revolutionising higher-level engineering education. However, despite the well-documented theoretical advantages highlighted in the literature, implementing these technologies in educational settings is still in its early stages and has not been widely adopted by academic institutions. This research explores MR's potential transformative benefits in specialised Industry 4.0/5.0 engineering training, aiming to contribute to the broader conversation on innovative pedagogical methodologies. The goal is to present a framework that broadens the discussion about these technologies in education and assists others in effectively implementing a VLF using MR technology, based on established learning methodologies, to prepare a workforce that is well-equipped to thrive in the dynamic era of advanced manufacturing.

3 Methodology – Proposed Framework

This study aims to propose a methodology for developing a VLF that leverages the full potential of MR technology tools to maximise the transformative benefits in engineering higher education. To develop this tool, the study suggests following the Six Sigma process improvement cycle: Define, Measure, Analyse, Design, and Verify (DMADV). In this instance, the focus of improvement is the engineering education process. To effectively enhance the engineering education process, it is crucial to have a deep understanding of the current teaching methods. Therefore, during the define and measure phases of the DMADV cycle, conducting a comprehensive examination of the existing teaching methods is vital. Further to investigative literature reviews, it is recommended to perform a stakeholder analysis involving key participants in the knowledge transfer process, such as students and mentors. One effective approach to gathering extensive feedback while ensuring response quality is developing a questionnaire to collect input from students and mentors on any proposed new teaching methods. Moreover, for a more organised and efficient research approach, it is advisable for the questionnaire to be structured in alignment with Bloom's Taxonomy. Bloom's Taxonomy, explained in Figure 3, is a hierarchical framework used to classify learning objectives into levels of specificity and complexity [20]. By framing questions based on this taxonomy, one can gain insights into the obstacles and motivators for educational advancement, moving from the lower levels of rote-learning and memorisation to the higher levels of creativity, analysis, evaluation, and problem-solving.

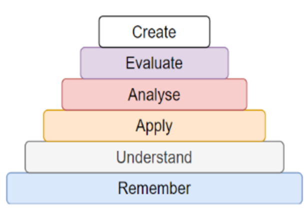

Fig.3. Bloom's Taxonomy

Once key and valuable information has been gathered from the various relevant parties involved in the educational process, it is crucial to conduct a comprehensive analysis of the collected data. During the analysis phase, a QFD chart will be drafted. This tool would facilitate the systematic prioritisation and alignment of the most critical stakeholder requirements with essential requirements outlined in the existing literature. By employing the QFD chart, it becomes feasible to map out the relationships between these requirements and ensure that any newly developed pedagogical methods address the most pertinent and pressing needs of both students and mentors. The most important requirements identified through this process can then be implemented in a proof-of-concept virtual learning factory, where students can actively engage, test, and benchmark its performance. There are various facets on which this new teaching tool can be benchmarked, encompassing its ability to provide a more interactive and enjoyable learning experience through features like gamification, as well as its potential impact on improving students' academic performance. By evaluating the tool's effectiveness in enhancing student engagement, understanding, and performance, educators can gain valuable insights into the efficacy of the proposed pedagogical methods and make informed decisions about their integration into the broader educational framework.

4 Discussion

Integrating cutting-edge technologies like MR into engineering education shows great promise for revolutionising how knowledge is taught and learned. This is backed up since VLFs offer an experiential teaching platform that is based on both Kolb’s Learning Cycle and Edgar Dale’s cone of experience [6]. This innovative approach can create interactive and immersive learning experiences that meet the changing needs of students and educators. It leads to a more engaging educational environment where students play an active role in their learning journey.

The integration of technology in education boosts student engagement by shifting from passive to interactive learning. Incorporating gamification techniques delivers educational content in an entertaining and educational way, fostering creativity, critical thinking, and problem-solving skills in students.

Moreover, the introduction of virtual replicas of industrial settings within the educational curriculum offers students a unique opportunity to explore and interact with real-world scenarios in a simulated environment. This provides them with hands-on experience and enables them to access educational resources at their convenience, irrespective of their physical location. Students can delve into a wide range of manufacturing processes, observe how these processes interact dynamically, and engage in reconfigurable engineering workflows to gain a comprehensive understanding of the subject matter.

The future focus is on implementing and validating a proposed system to enhance student learning experiences. This involves creating a proof-of-concept VLF and then scaling it up. By comparing student performance using traditional methods versus the new technological approach, the research aims to contribute to exploring how technology can improve learning. Through evaluating the system's effectiveness and impact on knowledge acquisition, this study aims to drive advancements in educational technology and teaching methods.

5 Conclusion

The paper delves into the impact of MR technologies in specialised Industry 4.0/5.0 engineering training, proposing a framework for a VLF with MR. By utilising effective learning methods and stakeholder input, the VLF aims to offer an immersive learning environment for engineering students, addressing skill gaps, improving training precision, and overcoming educational challenges. The integration of MR and VLFs shows promise in transforming engineering education, preparing students for advanced manufacturing. This approach fosters critical skills and problem-solving abilities through interactive experiences, aligning with the Six Sigma improvement cycle. The use of MR in engineering education signifies a move towards personalised, engaging learning, empowering students to grasp complex concepts confidently. Future work includes implementing and validating the system to explore technology's potential further in enhancing learning and teaching in engineering education.

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