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(REVIEW ARTICLE)

Integration of Virtual Reality (VR) technology to enhance practical skills and professionalism in engineering training

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Abstract

The development of practical skills and professionalism is crucial in technical education and training. Traditional training methods often face limitations in providing hands-on experience and simulating real-world environments. This article explores the integration of Virtual Reality (VR) technology as a tool to enhance practical skills and foster professionalism among technical trainees. VR offers an immersive and interactive environment that allows learners to engage in complex tasks without physical constraints or safety risks. This study employs a comprehensive literature review and case studies to evaluate the effectiveness of VR-based training in technical fields. We investigate how VR can simulate real-world engineering scenarios, providing students opportunities to practice critical technical skills such as assembly, troubleshooting, and system design. Moreover, VR supports the development of soft skills, including teamwork, communication, and decision-making, which are essential for professional success in engineering. The results show that VR-based training significantly enhances both technical competencies and professional behavior. The immersive nature of VR enables trainees to experience realistic work environments, improving their ability to solve problems, make decisions, and collaborate effectively. Additionally, VR fosters a deeper understanding of technical concepts, reduces learning time, and minimizes errors during hands-on training. This article contributes to the growing body of knowledge on the application of VR in technical education. It highlights VR's potential to revolutionize technical training by providing a scalable, cost-effective, and safe platform for developing technical expertise and professional attitudes among future engineers.

Keywords: Virtual Reality; Practical Skills; Professionalism; Engineering; Training

1. Introduction

Professionalism in engineering education and training plays a crucial role in shaping human resources that are competent and ready to face the challenges of the modern industry, as well as playing a critical role in producing human resources that are skilled and capable of meeting the demands of the modern industry. Professional engineers are required to hold an Engineer Registration Certificate (STRI) and participate in the Professional Engineer Program to enhance their competencies (Despa et al., 2022). Engineering ethics serves as a guideline in performing duties with integrity and responsibility (Armaeni, 2015). Competency development through training and collaboration with peers is vital for enhancing professionalism.

Challenges in achieving professionalism in technical education often arise from the limitations of traditional learning methods, which are less capable of bridging the gap between theoretical knowledge and practical application. Conventional classroom settings often fail to provide sufficient hands-on experience, thus creating a gap between the theory learned and the real-world demands ("Developing Skills for Industry 4.0: Challenges and Opportunities in

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Engineering Education," 2022). As a result, many engineering graduates are considered unprepared to meet the demands of the modern industry. In addition to technical skills, they often lack essential abilities such as effective communication and problem-solving, which are critical in the workplace (Balakrishnan, 2014). To address these challenges, a more integrated learning approach is needed, combining theory, practice, and soft skills development to prepare graduates who are not only technically competent but also capable of adapting to the complexities of the dynamic workforce.

The rapid advancement of technology requires engineers to continually adapt, a need that must be accommodated by traditional education systems (Viegas et al., 2019). The COVID-19 pandemic further highlighted disparities in the readiness of educational infrastructure, particularly in the implementation of online learning, exposing limitations in teacher training and access to resources (Rodrigues and Castro, 2020). On one hand, e-learning offers opportunities for self-directed learning, but on the other hand, technical challenges and internet access limitations often present significant barriers (Kulkarni et al., 2023; Rodrigues and Castro, 2020). In facing these challenges, an effective monitoring and support system becomes a key element to ensure the maximum benefits of a digital learning environment (Kulkarni et al., 2023).

Collaboration between educational institutions and industry is becoming increasingly important. This joint effort can create work-based learning programs that not only enhance students' skills but also align with the needs of the modern industrial world ("Developing Skills for Industry 4.0: Challenges and Opportunities in Engineering Education," 2022). The development of adaptive and relevant skill models can serve as a bridge that connects educational outcomes with the expectations of industry (Kulkarni et al., 2023). Although these challenges are complex, the opportunities to reform engineering education are increasingly open. By applying innovative pedagogy and strengthening the synergy between academia and industry, we can ensure that graduates are not only ready but also capable of competing in the ever-evolving global workforce.

Virtual Reality (VR) offers an innovative solution to bridge this gap. VR technology enables the simulation of realistic work environments, where students can practice their skills without the high risks typically associated with fieldwork. Various studies have shown that VR can enhance student engagement, motivation, and skill development (Bahari et al., 2023). The use of VR in engineering education and training not only improves technical skills but also provides a space for the formation of professional attitudes through scenarios that simulate real challenges. By presenting complex situations in a visual and interactive manner, this technology helps train students to make accurate decisions, act ethically, and manage risks more effectively.

Virtual Reality (VR) technology is increasingly being integrated into education and training, offering numerous benefits. VR provides an immersive learning experience, enhances clinical skills, and improves accessibility to training (Khomariyah et al., 2024; Gumilang et al., 2021). VR enables self-directed learning with simulator guidance and performance evaluation (Khomariyah et al., 2024). In engineering education, the integration of VR can lead to resource savings and improved accessibility to training (Mayawati et al., 2023). VR is particularly useful for subjects that require visualization, practice, and limited resources (Sunarni and Budiarto, 2014). Educators have shown significant interest in using VR technology for teaching (Sunarni and Budiarto, 2014). However, challenges remain, such as small sample sizes in research and limited training scenarios, which necessitate further long-term studies (Khomariyah et al., 2024).

One of the main benefits of VR in the field of engineering is resource efficiency. Through virtual simulations, training can be conducted without the need for expensive physical materials or complex laboratory environments. Students can perform repeated exercises without additional costs, thus enhancing their understanding of complex engineering concepts in a time- and material-efficient manner (Zhang, 2024). VR accelerates the learning process, enabling future engineers to grasp design, mechanisms, and production processes more quickly compared to traditional methods (Villegas-Ch et al., 2024). In terms of accessibility, VR offers an immersive and interactive learning experience. VR-based simulations provide students with the opportunity to explore and practice engineering skills in a safe and controlled environment. This not only enhances engagement but also allows engineering training to reach students from various regions, overcoming geographical barriers and creating more inclusive educational opportunities (Hernández-Chávez et al., 2021).

The competitive advantage of VR in engineering lies in its ability to align training with industry needs. Simulations designed to reflect real-world scenarios allow future engineers to prepare more effectively for their jobs, including structural design, project planning, or system analysis (Zhang, 2024). This innovative learning environment also fosters creativity and the development of new solutions, which are essential attributes in solving modern engineering problems (Huang and Roscoe, 2021).

The adoption of VR in engineering training requires solutions to challenges such as complex interfaces and the need for advanced infrastructure. By overcoming these barriers, VR technology holds great potential to revolutionize engineering education and produce a generation of engineers better equipped to face the increasingly complex demands of the workforce (Villegas-Ch et al., 2024). The integration of VR not only changes the way engineers learn but also how they solve problems, create innovations, and make meaningful contributions to society.

Therefore, it is essential to further explore how Virtual Reality can be integrated into engineering education and training systems to enhance practical skills and professionalism, as well as make a significant contribution to the overall advancement of the industry.

Professionalism in the context of engineering is the commitment of an engineer to apply their technical expertise while upholding moral integrity and social responsibility in every aspect of their work (Loui, 2005). This concept encompasses the ability to provide innovative solutions based on science and technology, while prioritizing the interests of society, environmental sustainability, and safety as the main concerns (Hauser-Kastenberg et al., 2003). A professional engineer must not only possess excellent technical skills but also uphold a strong work ethic. This includes adherence to industry standards and regulations, as well as a commitment to continuous development—both for themselves and the community they serve (Canney, 2012). Furthermore, professionalism demands transparency, honesty, and accountability in every decision made. Engineers must ensure that their work provides maximum benefits to society, without neglecting the potential risks or negative impacts on stakeholders (Prasad, 2019). Thus, professionalism becomes the fundamental principle that guides an engineer in fulfilling their role and responsibilities in an increasingly complex and interconnected world.

The core competencies required in the engineering profession encompass a blend of technical skills, a deep understanding of scientific principles, as well as high analytical and problem-solving abilities (Dannhauser, 2012). These competencies include mastery of relevant design, analysis, and implementation techniques specific to various engineering fields such as mechanical, electrical, civil, or chemical engineering, which form the foundation for developing innovative and effective solutions (Goel and Kathuria, 2010). Beyond technical skills, an engineer must also possess strong communication abilities to clearly and persuasively convey ideas, solutions, and recommendations to various stakeholders, including colleagues, clients, and the general public (Hirsch et al., 2005). Project management, leadership, and teamwork skills are particularly crucial, especially when dealing with complex multidisciplinary projects that involve diverse parties (Schefer-Wenzl and Miladinovic, 2019). Furthermore, a deep understanding of professional ethics, safety, and sustainability provides the foundation to ensure that every engineering project is not only technically effective but also socially and environmentally responsible (Wiek et al., 2011). These competencies must be complemented by a commitment to lifelong learning to keep up with the evolving technology and industry dynamics, ensuring that engineers remain relevant and competent in the modern era (Quelhas et al., 2019).

2. Research method

The research method employed in this article is a combination of a comprehensive literature review and a case study. This approach was chosen to ensure an in-depth analysis of the implementation of Virtual Reality (VR) technology in engineering training. The literature review was conducted by identifying and analyzing various relevant studies published in reputable journals, including those indexed in Scopus and SINTA, to build a theoretical foundation on the benefits, challenges, and effectiveness of using VR. Additionally, a case study was utilized to evaluate the direct impact of VR on the development of practical skills and professionalism in engineering trainees. Empirical data from the case study were processed and analyzed qualitatively to understand how VR technology can enhance technical skills, soft skills, and the efficiency of the training process. This combination of methods aims to provide a holistic and evidence-based perspective relevant to the needs of the modern industrial world. The validity of the findings is ensured through data source triangulation and verification with previously published studies. This method is expected to make a significant contribution to the literature on the integration of advanced technologies in engineering education and training.

3. Result

The key findings from the implementation of VR technology in engineering training show that this technology has a significant positive impact on the development of technical skills and practical understanding. VR enables realistic simulations of real-world scenarios, allowing students to practice in a safe environment without physical risk (Aqilla and Voutama, 2024). It presents realistic simulations of real-world scenarios, enabling engineering students to learn and practice in a safe environment without the risk of equipment damage or physical harm (Marinelli et al., 2023). VR-based training also accelerates the learning process, as it allows for better visualization of complex concepts such as fluid mechanics, structural design, or dynamic system simulations (Wang et al., 2021).

Furthermore, VR enhances student engagement by providing an immersive and interactive learning experience, which significantly improves material retention (Alali and Ll, 2024). This technology also allows for resource savings, such as time, materials, and costs, as training can be repeated without the need for expensive physical infrastructure (Analyti et al., 2024). Another advantage is broader accessibility, where training can be provided to students in various geographical locations, thus supporting inclusive education (Mallek et al., 2024).

Adopting VR in education does come with challenges, such as the need for advanced hardware and software, training for new users, and high initial costs (Soliman et al., 2021). However, despite these challenges, VR offers significant benefits: creating a generation of engineers who are more skilled, creative, and ready to face the dynamics of the modern industry. With these advantages, VR is not just a technology but a strategic investment for the future of technical education (Zhang and Aslan, 2020).

3.1. VR in Electronics Engineering

In several studies related to electronics, particularly in the development of hardware that supports the implementation of Virtual Reality (VR) and Augmented Reality (AR) algorithms based on Convolutional Neural Networks (CNN), the optimization of CNN parameters tailored for VR/AR tasks can guide the development of more efficient and high-performance electronic components. This, in turn, accelerates technological advancements in the field of electronics and immersive experiences (Sineglazov, 2022).

In the research conducted by Lampropoulos (2024), it was found that the application of affective computing in AR, VR, and immersive environments can enrich educational activities, improve learning outcomes, support special education, and foster meaningful learning and self-directed learning. These findings highlight the immense potential of this technology in creating more interactive and effective learning experiences, while also offering future research directions.

Lee's study (2021) proposes an input mapping system that can transform various input signals from next-generation VR devices to be compatible with existing VR content. The proposed system allows content developers to map the data flow from new input devices to standard input events used in existing content, enabling the reuse of code from older content. This system, therefore, supports content-based standardization in content-oriented industries such as gaming and virtual reality. Figure 1 illustrates the use of Virtual Reality through the MileaLab application in Electronics/Robotics engineering.

Figure 1 VR in the Field of Electronics

The research by Díaz-Barrancas (2021) discusses the development of virtual reality (VR) technology through the application of hyperspectral textures to enhance chromatic representation in VR environments. Currently, VR devices have limitations in accurately representing three-dimensional scenarios, particularly due to the use of RGB color systems, which have constraints in producing images that closely resemble human vision in the real world. This study aims to address this issue by using hyperspectral textures, which enable more accurate color representation, especially under certain lighting conditions. The paper outlines the steps to render three-dimensional objects with hyperspectral textures within a VR environment and evaluates the results by calculating the chromaticity coordinates of samples. This approach aims to improve visual accuracy and the immersive experience within VR technology.

In the context of digital electronics learning, augmented reality (AR) can be used to simulate electronic circuits, devices, or experimental scenarios interactively, allowing students to understand complex concepts in a more visual and practical manner. This technology can also support the development of technical skills in electronics, making learning more efficient and relevant to industry needs (Delgado, 2021).

Singh (2020) discusses the importance of engineering laboratory courses in enhancing practical knowledge and skills, particularly in electronics laboratories involving the operation of complex equipment. VR technology allows for the realistic simulation of electronic laboratory environments, helping students understand the functions and operations of equipment without the risk of damaging physical devices. Furthermore, the use of VR in laboratory training can improve the efficiency of practical learning in electronics, preparing students to handle real-world challenges in the industry with greater confidence and deeper knowledge.

3.2. VR in Automotive Engineering

The automotive industry, VR and AR show great potential to enhance the effectiveness of processes (Čujan, 2020). One of its applications is the use of video-mapping methods in warehouse logistics, which has been proven to improve efficiency by reducing item retrieval time by up to 10%. This method not only optimizes logistics processes but also holds significant potential for application in other industrial sectors, leveraging the experience gained from its implementation in the automotive field.

Virtual Reality (VR) and Augmented Reality (AR) technologies in Industry 4.0 are playing an increasingly important role, particularly in the automotive industry (Belu, 2021). These technologies enable operators to engage in the production process with minimal risk, support manufacturing-based training, and simplify maintenance tasks with more detailed visualizations. In Figure 2, the use of Virtual Reality through the MileaLab application in automotive engineering is shown.

Figure 2 VR in the Automotive Field

The research conducted by Rehberg (2024) emphasizes the need to develop a framework for prototype creation that includes a taxonomy of projects and serves as the foundation for testing strategies aimed at shortening time to market. This is achieved through the introduction of the new term "phygital prototype" to bridge the gap between physical and virtual prototypes. Furthermore, we argue that product compliance should not only be integrated methodically but also propose concrete procedural steps within the prototype creation framework.

3.3. A Comparison Between VR-Based Training and Conventional Training in Terms of Practical Skills and Professional Development

VR-based training excels in providing realistic practical experiences through immersive simulations, allowing participants to learn in a safe and controlled environment (Raut et al., 2024). This technology offers access to complex scenarios that are difficult or costly to replicate in conventional training, such as disaster simulations, large-scale infrastructure design, or experiments involving advanced systems (Sampaio et al., 2010). Additionally, VR enables unlimited repetitive training, allowing participants to reinforce their understanding and skills at a lower long-term cost (Alverson et al., 2005). From a professional development perspective, VR also supports self-directed learning and innovation, preparing engineers to face real-world challenges with greater confidence and adaptability (Zhang and Mo, 2022).

Conventional training offers advantages in providing hands-on experience with physical equipment and real-world work situations (Yee Sye Lee et al., 2023). This method allows participants to directly understand the work context, including interactions with teams, the work environment, and time pressures (Romano and Brna, 2006), contributing to the holistic development of professionalism (Aguinis and Kraiger, 2009). Conventional training also often emphasizes social aspects, such as communication and teamwork, which are more difficult to replicate in a virtual environment (Stout et al., 1997).

Conventional training has limitations in terms of high costs, accessibility constraints, and safety risks, particularly for hazardous scenarios (Pitana et al., 2020). On the other hand, VR training still faces challenges such as initial implementation costs, the need for advanced technology, and the potential gap between simulation and reality (Singhaphandu and Pannakkong, 2024). By combining the strengths of both approaches, educational and training institutions can create hybrid programs that optimize technical learning (Rodriguez et al., 2018), practical skills (Peng, 2023), and comprehensive professional development (Wang, 2024).

4. Discussion

4.1. Interpretation of the research findings and the relevance of VR technology in enhancing the quality of engineering training

The integration of Virtual Reality (VR) technology in engineering training significantly enhances practical skills and professionalism among trainees (Singh et al., 2020). The use of VR allows for the simulation of realistic work environments, providing hands-on experience without the risks to safety, and supports in-depth, practice-based learning (Randeniya et al., 2019). This technology has proven relevant in improving the quality of engineering training, especially in fields requiring high precision, such as mechanics, construction, and electrical engineering (Sampaio et al., 2010). By presenting complex situations virtually, trainees can develop analytical and problem-solving skills in a controlled environment (Zhang, 2024). Furthermore, research findings also indicate that VR increases motivation and engagement among participants, creating a more immersive and engaging learning experience compared to conventional methods (Al-Khiami et al., 2023; Jaya, 2024). The relevance of VR technology lies in its ability to meet the needs of the modern engineering industry, which increasingly demands superior technical competence, adaptation to advanced technology, and mastery of skills relevant to the workforce in the digital age (Kamińska et al., 2017). Therefore, VR holds great potential as an innovative solution to address the challenges of engineering training in the future (Shen et al., 2019).

4.2. Challenges and Barriers in the Implementation of VR

The implementation of Virtual Reality (VR) technology in engineering training faces various challenges that require serious attention to be fully utilized (Raimi et al., 2024). One of the main barriers is the high cost of acquiring VR hardware and software, such as headsets, high-performance computers, and application licenses, which often become a burden for training institutions or organizations with limited budgets (Alali and Wardat, 2024; Singhaphandu and Pannakkong, 2024). Additionally, VR accessibility becomes a constraint, particularly in regions that lack adequate technological infrastructure or reliable internet connectivity, thus narrowing the reach of this technology (Raimi et al., 2024). The adoption of VR technology also requires considerable time and effort, as both trainers and trainees need to familiarize themselves through additional training (El-Mallah and Dousay, 2019). Other obstacles include resistance to change, where some may feel more comfortable with conventional training methods, as well as the risk of technical disruptions, such as device vulnerabilities to damage or the need for routine maintenance (Saghafian et al., 2021; Inkermann et al., 2022). To overcome these barriers, comprehensive strategies are needed, such as innovations to reduce device costs, the development of better technological infrastructure, and comprehensive training programs for both trainers and trainees (Ravichandran and Mahapatra, 2023). With these measures, VR has the potential to revolutionize engineering training, making it more effective and relevant to meet the needs of the modern industry.

4.3. Analysis of How VR Can Be More Widely Integrated into the Engineering Education Curriculum

The integration of Virtual Reality (VR) technology into engineering education curricula holds great potential to revolutionize learning approaches by creating immersive and interactive learning environments that support practical exploration without real-world risks (Messner et al., 2003). A broader implementation of VR could begin with the development of simulation-based learning modules, allowing students to practice technical concepts in virtual, realistic scenarios (Laseinde et al., 2015). For example, in civil engineering, students could use VR to model infrastructure designs and assess their environmental impact, while in mechanical engineering, the technology could simulate manufacturing processes or machine maintenance with high precision (Raut et al., 2024).

Moreover, VR offers opportunities for adopting competency-based assessments. Students could be tested in real-world scenarios that reflect industry challenges, evaluating not only their theoretical knowledge but also their practical abilities (Zhang, 2013). This is particularly relevant to meet the demands of the ever-evolving workforce. Furthermore, VR has the potential to support cross-disciplinary collaboration in engineering education by providing virtual spaces that allow students from different programs to work together on innovative projects, expanding their perspectives beyond traditional expertise boundaries (Pellas et al., 2020).

To ensure the success of this integration, engineering education institutions must take strategic steps. This includes investing in VR infrastructure, training faculty to fully utilize this technology, and building partnerships with industry to create learning content that aligns with labor market needs (Hernández-Chávez et al., 2021). With a well-planned approach, VR can not only enhance students' practical skills but also strengthen their professionalism, preparing engineering graduates to face the complex, technology-driven demands of the industry (Jain and Soni, 2024).

5. Conclusion

- Virtual Reality (VR) technology offers an innovative solution to enhance practical skills and professionalism in engineering training. By providing an immersive and interactive learning environment, VR allows trainees to practice in realistic scenarios without physical risks or resource limitations. The research findings show that VR can improve technical understanding, accelerate learning time, and reduce errors in hands-on training. Furthermore, this technology also contributes to the development of soft skills, such as communication, teamwork, and decision-making, which are crucial in the modern workplace.
- The use of VR not only provides benefits in the context of practical learning but also addresses the challenges of traditional training methods, which often fall short in bridging theory with practice. However, to optimize VR's potential, investment in technological infrastructure, user training, and the development of learning modules relevant to industry needs is required. Thus, VR has significant potential to revolutionize engineering education, creating graduates who are better equipped to meet the demands of the modern industry and supporting the development of professionalism among future engineers. This article emphasizes the importance of further exploration to increase the global adoption of VR in engineering education and training.

Compliance with ethical standards

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