Bridging The Gap: The Role of Virtual Reality in Enhancing Hands-On Learning and Engagement in Industrial Engineering Education

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ABSTRACT

This study explores how virtual reality (VR) is being introduced into industrial engineering education, with an emphasis on its ability to enhance hands-on learning, student engagement, and the connection between theory and practice. Using a systematic literature review guided by PRISMA standards, the research identifies recurring challenges, including the lack of consistent assessment methods and difficulties in aligning VR with real industrial contexts. To address these issues, the study proposes key design criteria for a framework that promotes experiential learning through realistic simulations, gamified elements, and spatial reasoning. This offers practical guidance for educators and developers.

OPSOMMING

Hierdie studie verken hoe Virtuele Realiteit (VR) in Bedryfsingenieurswese-onderrig ingevoer word, met ‘n fokus op die vermoë om praktiese leer, studentbetrokkenheid en die verbinding tussen teorie en praktyk te verbeter. Deur gebruik te maak van ‘n sistematiese literatuuroorsig wat deur PRISMA-standaarde gelei word, identifiseer die navorsing herhalende uitdagings, insluitend die gebrek aan konsekwente assesseringsmetodes en probleme om VR met werklike industriële kontekste in lyn te bring. Om hierdie probleme aan te spreek, stel die studie sleutelontwerpkriteria voor vir ‘n raamwerk wat ervaringsleer bevorder deur realistiese simulasies, speletjie gebaseerde elemente en ruimtelike redenasie. Dit bied praktiese leiding vir opvoeders en ontwikkelaars.

1. INTRODUCTION

With the increasing influence of technology in modern society, conventional methods of teaching industrial engineering (IE) are often perceived as unengaging [1,2]. There is a possibility that digital technology could soon replace traditional learning approaches [1] . To adapt to the advancements in modern technology, the integration of virtual reality (VR) into engineering education has been explored as a way to enhance teaching and learning [3]. VR is a digitally generated multimodal immersion that allows participants to perceive the 'virtual' experience [4]. VR offers immersive, interactive environments that simulate real-world scenarios, making it particularly valuable in fields that require practical application, such as IE.

The integration of VR into IE education is transforming the way in which students acquire and apply knowledge [5]. As industries incorporate VR into training and operations, educational institutions are exploring its potential to provide immersive and interactive learning experiences [6]. The rapid advancement of technology has transformed education, with VR emerging as a powerful tool for enhancing learning experiences.

Despite its potential, the integration of VR in IE education remains limited. Many studies focus on VR's benefits in general education or in other engineering disciplines, with little emphasis on its application in IE. This research specifically explores how VR is currently used in teaching and learning environments in IE education. By conducting a systematic literature review, the study identifies key themes, evaluates the current issues together with their root causes, and proposes solutions. It then provides design criteria that could be used to develop a framework for advancing industrial engineering through engineering education using VR. In addition, it provides insights into its role in enhancing learning outcomes. The review focuses on peer-reviewed journal articles and conference proceedings from reputable academic databases.

Addressing this gap of limited focus on VR's benefits in IE, this study explores how VR could be systematically incorporated into IE education to bridge the gap between theory and practice.

The significance of this research lies in its potential to enhance IE education by providing students with hands-on interactive experiences that traditional methods lack. VR could prepare students better for industry's challenges by improving their engagement and understanding.

2. LITERATURE REVIEW

2.1. Industrial engineering and virtual reality: Historical and technological evolution

In the early 20th century, the development of industrial engineering in the United States was driven by research focused on large-scale manufacturing, modern industrial processes, and the broader social and economic framework [7]. Industrial engineering is the combination of labour, equipment, raw materials, capital, and logical concepts [8]. A key trend that has now emerged in industrial engineering is the adoption of Industry 4.0 concepts, which involve incorporating artificial intelligence (AI), the Internet of Things (IoT), virtual reality (VR) and augmented reality (AR) [9]. Over the past 20 years, interest in VR has fluctuated [9]. VR has various definitions, such as being computer programs that enable users to enjoy 3D visual and auditory stimulation [10], or a remarkable interactive computer simulator that replicates the 3D environment [11]. The Karolinska Institute was the first to study and develop VR technology at universities in 1992 [12]. Even though the technology was somewhat basic at the time, it showed that VR could be useful in the classroom.

2.2. Engineering education: Concepts and the role of emerging technologies

Engineering is a demanding subject to teach and to learn. It includes, among other things, mechanical, chemical, polymer, textile, electrical, glass, and ceramic engineering, as well as environmental science [13]. The design, organisation, and efficacy of academic programmes are influenced by curriculum creation, which is a key component of engineering education. Competency-based models, which emphasise the development of practical skills and the capacity to tackle real-world challenges, have gained popularity in recent years [14,15]. Furthermore, there is a growing emphasis on experiential and interdisciplinary learning, which enables students to collaborate between disciplines and to apply engineering principles in a variety of contexts [16,17]. Active learning is encouraged to ensure the understanding of these demanding engineering subjects compared with using the traditional lecture-based methods. Active learning is defined as a teaching method that engages students in the learning process [18]. The integration of emerging technologies, including VR and the IoT, is transforming engineering education, as these technologies equip students with the digital engineering skills they need to tackle future problems [19].

2.3. Opportunities for virtual reality in industrial engineering education

Studying industrial engineering concepts using VR increases engagement and motivation. In addition, VR encourages a more active and hands-on approach than traditional educational methods [20]. VR has the potential to enhance education by offering students more visual and intuitive multisensory stimulation. This could lead to improved understanding, performance, and grades and to a more interesting educational experience [1,11]. In addition, VR could provide equal educational opportunities for students with special needs and for those participating in distant learning programmes while reducing institutional risk, expenses, and infrastructure [3]. To evaluate VR's viability and long-term effects on engineering education, more research is necessary. Thus, the effect of VR on industrial engineering education was examined. The primary conclusion drawn from the study described in [21] is that VR improves industrial engineering teaching. It enhances students' learning experiences by providing a more captivating and immersive setting. However, the constraints and difficulties that come with implementing VR in engineering education should be considered [21]. As the number of studies of VR for engineering education increases, it is clear that many researchers anticipate VR's beneficial effects on the educational system [11,22–26].

2.4. Design science research methodology and the design criteria

Design criteria have been defined in different ways by various scholars [27]. However, they generally refer to the specific requirements that a project must meet to be considered successful. The design science research methodology (DSRM), a methodology consisting of six steps, has been established to assist with determining the design criteria [28]. It begins with identifying the problem and understanding its root causes, ensuring that the issue is clearly defined and supported by logical reasoning and data-driven insights. Once the problem is established, the next step is to define the objectives of a solution by determining what an improved artefact should achieve. This step is guided by theoretical foundations and goal-oriented planning. The third step involves designing and implementing the artefact, focusing on how to develop and apply it efficiently. Following this, the illustration phase examines the artefact in context, demonstrating its ability to address the identified problem using relevant metrics and analysis. Next, the assessment stage evaluates the artefact's success and effectiveness, allowing for refinements based on expert feedback. Finally, the findings are communicated through academic journals and industry publications. DSRM also allows for iterative improvements, enabling researchers to revisit previous steps – particularly refining objectives or implementation – based on assessment results or further insights gained during communication [28].

2.5. Applicable theories

One of the applicable theories is the technology acceptance model (TAM). Research has indicated that the desire to implement VR in schools is influenced by whether the technology actually supports the tasks for which it is intended and by how practical or user-friendly it seems. Students are more inclined to adopt VR if they believe that the system improves their capacity to complete learning tasks in a reasonable amount of time [29].

3. RESEARCH METHODOLOGY

Since one of the essential techniques needed for this research is a systematic literature review, it is important first to comprehend what a systematic literature review is and what it comprises. A systematic literature review involves a number of specific steps: developing the research question, carrying out a comprehensive search, choosing relevant studies, extracting data, evaluating quality, analysing the findings, and sharing the results [30].

3.1. Developing the research questions

This review explored the use of VR in teaching and learning environments in industrial engineering education. The goal was to evaluate the relevance of the selected studies, to identify common themes, and to conduct a comprehensive literature analysis in order to synthesise and discuss the findings [23]. Specifically, the review was guided by the following research question: *What are the current applications* *and educational impacts of using VR in industrial engineering to enhance hands-on learning and engagement?*

3.2. Determining the scope, collecting data, and selecting records

Based on the quantity of accessible information, studies were gathered from three academic databases (Scopus, Wiley Online, and IEEE Xplore). This review is made up of academic papers presented at academic conferences and pieces published in peer-reviewed journals. Search strings were formulated and used with academic databases to obtain publications that would help to address the research question. The final search string to be used was "Virtual Reality", AND "Engineering Education", AND "Industrial Engineering". Nevertheless, distinct methods of selecting the necessary data were used owing to the unique characteristics of each database. The search results were then obtained once the inclusion and exclusion criteria had been factored into the search string. In order to avoid downloading records that were unrelated to the research, the next filtering phase involved skimming the abstracts and titles of the documents. The results are provided in Table 1.

Table 1: Academic database search results with inclusion and exclusion criteria

Academic database	Inclusion criteria	Exclusion criteria	Search results	Final number of chosen articles
Scopus	• Publication date range: 2019-2023 • Language: English • Source type: Conference proceedings and journals • Document type: Conference papers and articles	• Language: Chinese • Conference reviews, book chapters, reviews and books	• 229 results were60 articles • 142 conference papers • 11 conference reviews • 7 book chapters • 7 reviews • 2 books	46
Wiley Online	• Publication date range: 2019-2023 • Language: English • Publication type: Journals • Language: English	Document type: Chapters	6,667 results for articles and chapters	12
IEEE Xplore	• Publication date range: 2019-2023 • Language: English • Document type: Journal articles and conference proceedings	Document type: Magazines and early access articles	277 results were • 46 journal articles • 228 conference proceedings	37

A total of 7,173 search results were initially gathered from the IEEE Xplore, Scopus, and Wiley Online databases. After reviewing the titles and abstracts, 7,078 records were excluded for not meeting the study's inclusion criteria, leaving 95 journal articles. One duplicate was removed, reducing the count to 94. Further screening of titles and abstracts led to the exclusion of 51 more records. The remaining 43 articles underwent a full-text review, from which 24 were found to be ineligible. In the end, only 19 journal articles met the criteria for inclusion in the study, as indicated in the preferred reporting items for systematic reviews and meta-analyses (PRISMA) diagram in Figure 1. Published in 2009, the PRISMA statement was created to assist systematic reviewers to disclose openly the purpose of the review, the actions taken by the authors, and the results obtained [31].

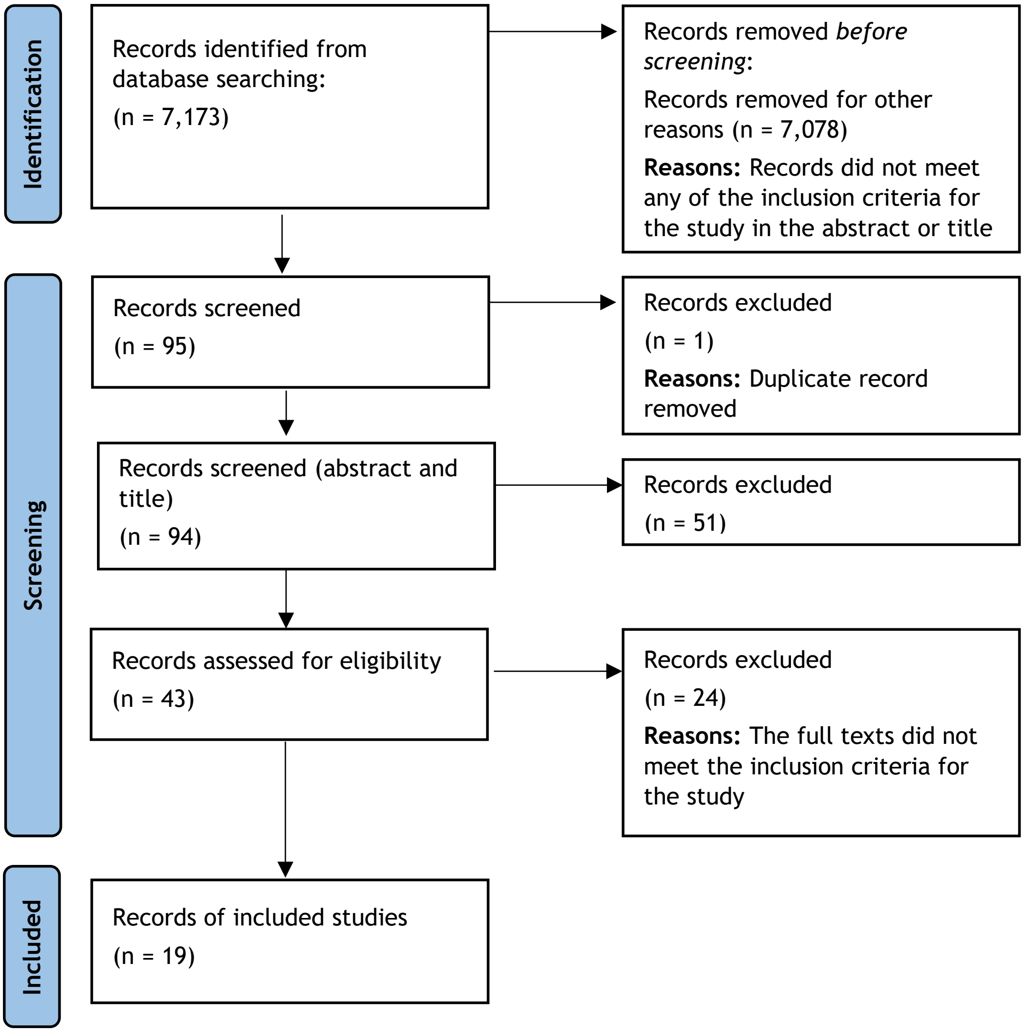

Figure 1: PRISMA flow diagram of the systematic literature review process of the study (Adapted from [32])

The inclusion and exclusion criteria for the Prisma diagram are presented in Table 2.

Table 2: PRISMA diagram inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Abstract or title aligns with the topic of the study • Ful -text addresses the specific topic of the study	• Duplicate records • Full text not applicable to the topic • Abstract or title is not applicable to the topic

3.3. Data extraction and analysis

The 19 selected journal articles were imported into Mendeley, a reference management and research organisation tool, for further data extraction and analysis. The extracted data included identified issues from the articles, the authors' suggested solutions, key virtual reality themes highlighted in the journal articles, and the identified design criteria that were to be used to develop a framework for advancing industrial engineering through engineering education using virtual reality.

4. RESULTS AND DISCUSSION

4.1. Design science research process to identify problems

To analyse further the 19 journal articles, the first stage of the DSRP was used. This step involved analysing each journal article to pinpoint the issue, understand its root cause, and outline the solution suggested by the authors. The results from the problem identification process are given in Table 3.

Table 3: Results from the problem identification stage

Authors	Article name	Issue identified	The cause	Proposed solution
[25]	Engineering education and the use of VR: Idea and possibility	Gap in practical, hands-on learning in engineering education	Lack of immersive and interactive experiences in traditional classrooms	Integrating VR (VR) to enhance project-based learning and virtual labs
[33]	VR-facilitated engineering education: A case study on sustainable systems knowledge	Difficulty teaching complex, interdisciplinary topics such as sustainable systems	Limitations of traditional classroom environments focusing on theoretical knowledge	Use of VR as a pedagogical tool to simulate real-world environments for experiential learning
[34]	Virtual experiential learning in engineering education	Insufficiency of traditional methods in fostering real-world problem-solving skills	Lack of interactive and immersive learning environments in traditional education	Adoption of virtual experiential learning (VEL) technologies to simulate real-world problems
[35]	The VR as a flexible resource to improve engineering education	Difficulty in providing practical experiences in digital learning environments post-pandemic	Reliance on remote/hybrid models limits access to physical labs and resources	Use of VR to simulate engineering environments, offering immersive, flexible experiences
[24]	VR as a tool for active learning and student engagement: Industrial engineering experience	Low student engagement and active participation in traditional education	Passive nature of convention-al methods with rote learning over interactive experiences	Implementing VR to simulate industrial environments, enhancing engagement and understanding
[23]	A review of the uses of VR in engineering education	Inconsistent and fragmented application of VR as a pedagogical tool	Lack of standardised metrics for evaluating VR's impact on learning outcomes	Research to establish evaluation frameworks and standardised VR environments
[36]	Head-mounted display-based VR systems in engineering education: A review of recent research	Uncertainty about the effectiveness of immersive VR in improving learning outcomes	Limited large-scale studies, lack of empirical evaluations, and insufficient standardisation	Comprehensive studies with standardised protocols and metrics for VR use in education

Authors	Article name	Issue identified	The cause	Proposed solution
[37]	Engineering education gaming: Case study of engineering ethics game modelling	Difficulty in teaching engineering ethics effectively	Traditional methods lack interactive elements to simulate real-world ethical dilemmas	Development of an engineering ethics game for practical, dynamic ethical scenario engagement
[38]	Evaluation of the learning effect of VR on engineering education - Case study in machine elements	Effectiveness of VR in teaching engineering concepts, specifically machine elements	Difficulty evaluating whether VR enhances learning better than traditional methods	Case study on VR's impact on comprehension and retention of engineering concepts
[6]	Work in progress: Do students benefit from using VR as a tool in engineering exercises?	Uncertainty about VR's effectiveness in enhancing engineering education	Lack of evidence of VR's benefits in student learning outcomes	Empirical study comparing VR-based exercises with traditional methods
[39]	VR in engineering education: A virtual introduction to unit operations and process scaling	Difficulty teaching unit operations and process scaling effectively	Lack of practical, hands-on experience in traditional instruction-al methods	Implementation of a VR-based approach to simulate and explore engineering processes
[40]	Exploring the facilitating and obstructing factors of using VR for 5S training: An exploratory qualitative study from students' perspectives in an industrial engineering undergraduate course	Effectiveness and difficulties of using VR for 5S training	Variability in students' experiences and perceptions	Study to identify facilitating/ obstructing factors in improving VR in training
[41]	A comprehensive statistical assessment framework to measure the impact of immersive environments on skills of higher education students: A case study	Difficulty of accurately measuring the impact of VR on skill development	Lack of robust assessment frameworks for evaluating immersive technologies	Comprehensive statistical framework to evaluate the impact of immersive environments
[42]	Using VR to facilitate teaching-learning of technology innovation systems	Difficulties in teaching technology innovation systems	Complexity of systems that are hard to visualise through traditional methods	Use of VR to simulate and explore technology innovation systems for better comprehension
[43]	Advancement in production engineering education through virtual learning factory toolkit concept	Difficulty teaching production engineering with traditional methods	Complexity of production processes hard to convey in conventional classrooms	Virtual learning factory toolkit to simulate production processes in virtual environments
[44]	VR as an immersive teaching aid to enhance the connection between education and practice	Gap between theoretical education and practical application	Traditional methods focus on theory without real-world context	VR-based simulations to bridge theory and practice, improving engagement and retention

Authors	Article name	Issue identified	The cause	Proposed solution
[45]	The impact of VR application on students' competency development: A comparative study of regular and VR engineering classes with similar competency scope	Difficulty in determining VR's effectiveness in enhancing competencies	Lack of comparative evidence on VR's effectiveness versus traditional methods	Comparative study of VR-based classes versus regular classes to evaluate competency development
[46]	The influence of immersive and collaborative virtual environments in improving spatial skills	Difficulty of developing strong spatial skills	Traditional methods rely on static models that do not enhance spatial understanding.	Use of immersive and collaborative VR environments to improve spatial reasoning
[47]	Gamification and simulation: Distance education for industrial engineering students	Difficulty of engaging industrial engineering students in distance education	Lack of practical engagement in remote learning	Gamification and simulation in virtual environments to enhance interaction and learning outcomes

Microsoft Excel was a useful tool to arrange and synthesise the gathered data in addition to the systematic literature review. The identified issues, their root causes, and the solutions proposed in the literature were all included in tabular form for each entry from the examined research. This approach made it possible to organise the data in a clear way, guaranteeing that any discovery could be directly connected to its original source. The Excel spreadsheet made it possible to handle data by using the filtering, sorting, and categorisation tools. The results are shown in Figure 2.

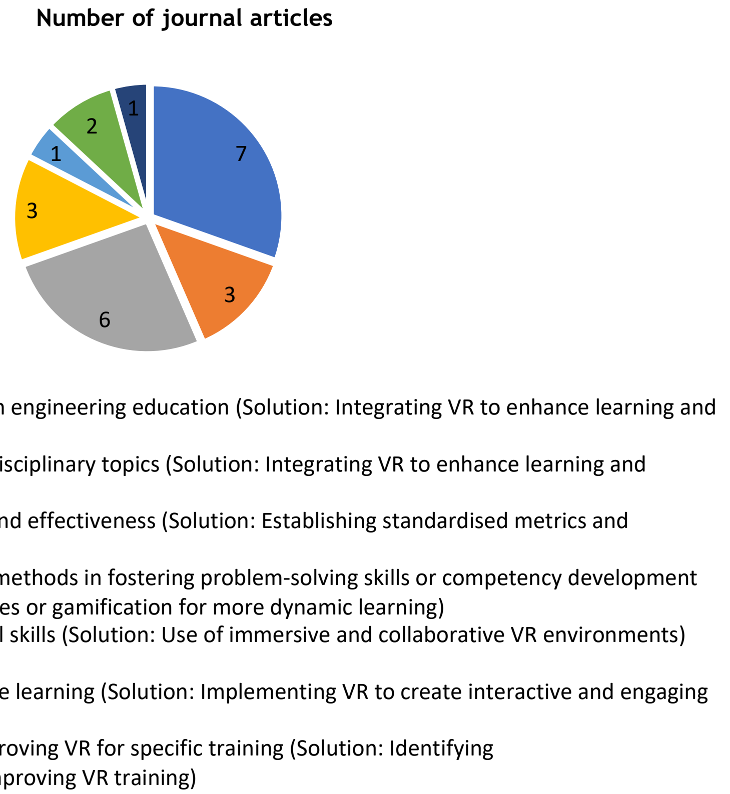

Figure 2: Results of identified issues, solutions, and the number of journal articles in each case

Figure 2 highlights that the most common issue, cited in seven journal articles, is the lack of hands-on learning in engineering education. Six articles discuss the difficulty of assessing VR's impact, while three each highlight the limitations of traditional teaching in developing problem-solving skills and handling complex topics. Fewer studies address low student engagement and passive learning, with individual articles noting difficulties in spatial skill development and VR implementation. These findings emphasise the need to enhance practical learning while improving VR's effectiveness in tackling broader educational problems. A balanced approach that integrates VR with targeted strategies would be essential for meaningful progress.

4.2. Identifying key virtual reality themes in the literature

Four themes were identified after extracting from the journal articles. The identified themes in the literature can be categorised into four main areas. First, nine journal articles explore how VR is used to enhance practical learning experiences, providing students with immersive, hands-on training [24,25,33–35,39,42,43,46]. Second, a significant portion of the research, with five journal articles, focuses on evaluating the impact and effectiveness of VR in education, assessing its benefits and limitations [6,23,36,38,41]. Third, studies in two journal articles examine the role of VR in promoting ethics and student engagement through interactive learning methods [37,47]. Last, three journal articles highlight the integration of theoretical knowledge with practical application, demonstrating how VR bridges the gap between classroom concepts and real-world industrial engineering scenarios [40,44,45].

4.2.1. Enhancing hands-on learning with virtual reality

Nearly half (47%) of the articles highlight the lack of practical, hands-on learning opportunities in traditional engineering programmes. VR is proposed as a powerful tool to simulate real-world environments, thus addressing this gap and offering students a more immersive learning experience.

4.2.2. Evaluating virtual reality's impact on learning

About 26% of the articles emphasise the absence of standardised methods for measuring the effectiveness of VR in education. This presents a challenge in assessing how well VR enhances student learning, underscoring the need for consistent evaluation frameworks.

4.2.3. Using interactive virtual reality to boost engagement and teach ethics

A smaller portion (11%) of the studies explores how VR, through gamification and simulations, could improve student engagement and support ethical education. While VR has potential in these areas, it remains underused in fostering interactive and ethical learning in engineering.

4.2.4. Bridging the gap between theory and practice with virtual reality

Around 16% of the reviewed studies highlight the ongoing difficulty of connecting theoretical knowledge to real-world applications in engineering education. This points to a need for a better integration of VR tools to help students to make the transition from understanding concepts to applying them in practice.

While VR creates immersive experiences, bridging the gap between theory and practical skills remains difficult. Effective integration is needed to ensure that simulations translate into meaningful learning. Refining VR applications seamlessly to combine theory and practice would be key to maximising its impact on engineering education.

4.3. Identified design criteria

A deeper examination was carried out to identify the recurring problems in all the journal articles, to explore their underlying causes, and to assess the design criteria applied in each study. The extracted design criteria are detailed below.

4.3.1. Incorporating VR for hands-on learning enhancement

Integrating VR and virtual experiential learning (VEL) could bridge the gap in hands-on practical education. This integration would also be crucial to optimise process scaling and unit operations [25,34,35,39,44].

4.3.2. Simulating complex systems and real-world scenarios with VR

VR technology enables the replication of real-world environments and intricate systems, making it a valuable tool for teaching complex or interdisciplinary subjects [33,42,43].

4.3.3. Boosting student engagement through interactive VR experiences

Using VR to develop industrial simulations and interactive learning environments fosters higher levels of student engagement and active participation in the learning process [24,47].

4.3.4. Assessing the effectiveness of VR in education

Thorough empirical research and standardised evaluation metrics are necessary to measure the impact of VR on educational outcomes [6,23,36,41,45].

4.3.5. Designing gamified VR for ethical and engaging learning

Developing gamified VR environments could enhance ethical education by encouraging dynamic student participation in ethical decision-making [37].

4.3.6. Enhancing spatial reasoning through immersive VR

Immersive and collaborative VR experiences could contribute to improved spatial reasoning and related cognitive skills in students [46].

4.3.7. Identifying key elements for effective VR training

Research should focus on determining the factors that enhance or hinder effective VR-based training to improve learning experiences and accommodate diverse student responses [40].

These design criteria inform the development of a proposed framework for advancing industrial engineering through engineering education using VR.

5. RECOMMENDATIONS AND CONCLUSION

The use of VR in IE education presents a promising opportunity to overcome the constraints of traditional teaching techniques. This review highlights how VR enhances student engagement, understanding, and practical learning through immersive simulations. However, its implementation faces key challenges, including the absence of standardised assessment metrics, high costs, and difficulties in aligning VR learning with industry needs. Addressing these challenges requires a structured framework that integrates VR with conventional teaching methodologies to balance theoretical and practical skills.

To maximise the benefits of VR in IE education, several key recommendations should be considered.

Several considerations need to be prioritised to harness fully the potential of VR in IE education. One of the most important steps would be the development of clear assessment metrics. Without standardised ways of evaluating VR-based learning, it is difficult for educators to determine whether the technology is genuinely improving student outcomes or simply adding novelty. Creating consistent frameworks would also help to align VR teaching practices with broader academic expectations and industry requirements.

It would also be important to design VR experiences that truly enhance experiential learning. By replicating real-world industrial environments, students could safely explore complex systems, test different approaches, and gain a deeper understanding of processes that would otherwise be difficult to access in a classroom. This kind of immersive practice would help to bridge the gap between theoretical knowledge and practical application.

The discussion must also focus on accessibility and participation. Gamification and other interactive elements could make VR more engaging and dynamic, which would keep students engaged and driven to study. To ensure that the advantages of VR are not restricted to a small group of students, educational institutions should simultaneously make sure that these tools are accessible to all students, especially those with financial limitations or disabilities.

The study of learning outcomes is another topic that merits consideration. More empirical data is required to evaluate VR's long-term effects on cognitive skills, spatial thinking, and problem-solving abilities, even if much early research show promise. In order to improve VR applications and make sure that they aid students' development significantly, data-driven insights would be essential.

Ideally, VR should complement conventional teaching methods rather than replace them. A better-rounded educational experience could be offered by a blended approach that incorporates case studies, practical training, lectures, and immersive technologies. This would guarantee that students acquired the analytical and critical thinking skills needed for professional practice in addition to technical proficiency.

In the end, cost is still a practical consideration. Institutions could investigate less expensive approaches to VR implementation, such as using cloud-based technologies, forming alliances with industry stakeholders, or embracing open-source platforms. These tactics could reduce costs without compromising VR's instructional potential, increasing its long-term viability and scalability.

By addressing these key areas, VR could become a powerful tool in IE education, preparing students for the demands of modern industry while making learning more engaging and effective. Continued collaboration in the future between educators, researchers, and industry professionals would be essential to refining VR's role in engineering education and ensuring its long-term success.

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