Advantages and Challenges of VR in Engineering Education

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***Abstract*— Virtual reality (VR) technology has the potential to revolutionise engineering education by providing students with immersive and interactive learning experiences not possible with conventional methods. Virtual reality can be used to simulate real-world environments and equipment, teach engineering concepts and principles, and prepare students for industry practices. However, the use of Virtual Reality in engineering education presents challenges, such as the limited availability and expense of VR equipment, the need for technical support and training for faculty and students, and the requirement for the creation and maintenance of Virtual Reality content. This issue was developed based on a narrative review and a literature review. The narrative review was conducted after the author studied and gathered the latest information. To effectively implement VR in engineering education, it is necessary to weigh the advantages and disadvantages of the technology and allocate resources accordingly. The benefit of VR in engineering education is increased accessibility to simulations and hands-on learning experiences, increased student engagement and motivation, the ability to visualize and manipulate 3D objects and concepts in a realistic environment, and the chance to safely test and experiment with equipment and processes. Future use of augmented reality (AR) and mixed reality (MR) technology in engineering education might provide students with even more immersive and interactive learning experiences. The use of Virtual Reality in engineering education has the potential to transform how engineering is taught and learnt by offering students more interesting and interactive learning experiences that better prepare them for success in the field.**

***Keywords*—Engineering Education, Engineering Student, Training Programs, Virtual Reality, VR simulations**

I. INTRODUCTION

A. Definition of virtual reality (VR)

Virtual reality (VR) is a computer-generated simulation of a three-dimensional world that may be interacted with using specialised equipment, such as a headset with a screen or displays in front of the eyes, gloves with sensors, or a platform that detects body motions [1]. VR enables users to experience and explore virtual surroundings as if they were physically present in them, and may be utilised for a variety of purposes, such as gaming, entertainment, education, training, and design.

Virtual reality (VR) technology has gained research and market interest in education and training due to its processing power, cost, and form factor. Soliman et al. [2] concludes their paper that VR is considered an effective tool in engineering education based on evidence of its pedagogical benefits and positive cognitivism, which improves students' understanding, performance, educational experience, and grades. VR also offers benefits to universities and institutions, including reduced liability and infrastructure costs, as well as equal educational opportunities for distance learners and students with unique needs [3]. However, current applications of VR for education often lack integration of learning theories as well as objectives in their design. The authors recommend using variation learning theories and constructivist approaches, which are successful in engineering education and could be implemented effectively in VR for education.

Hernandez-de-Menendez and Morales-Menendez [4] reviewed the use of various information and communication technologies (ICTs) in engineering education and analyzed how selected universities from the QS World University Rankings by Engineering and Technology Subject 2018 utilize these technologies to enhance the academic performance and learning experience of students. The review includes a summary of innovative technological trends, teaching practices, and tools used by these universities in engineering education. The goal of the research is to provide a guide to valuable and proven technologies as well as educational practices that can be used to improve teaching and learning in engineering education. Fig. 1 illustrates the competencies that can be cultivated through the utilisation of the identified information and communication technologies (ICTs) in the field of education, based on the cumulative frequency of mentions.

The use of virtual reality (VR) in engineering education has not been extensively explored, but its use has become

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increasingly popular in education in general.

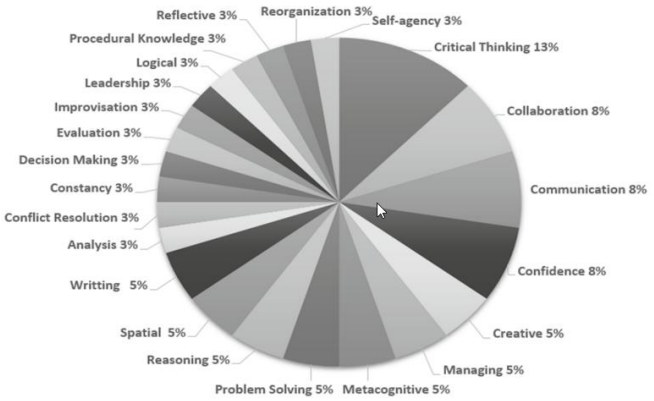


Fig. 1. Competencies that can be developed with classified ICTs (Hernandez-de-Menendez and Morales-Menendez [4])

Di Lanzo *et al.* [5] conducted a review of journal articles and conference proceedings published between 2015 and 2019 on the use of VR in engineering education found that it is commonly used as a supplementary tool to traditional teaching methods, with reported benefits to cognitive and skill-based learning outcomes. However, evaluation metrics and processes that lack clarity, as well as unrealistic virtual scenarios and small evaluation sample sizes, may hinder the ability to compare the use and benefits of VR in engineering education. Further research on the use and merits of VR in engineering education is recommended, considering these issues.

B. Overview of the use of VR in education

Virtual reality (VR) is widely utilised in education to give students immersive and interactive learning experiences. Virtual reality (VR) may be utilised to imitate real-world places, historical events, and scientific concepts, allowing students to connect with and study these topics in a manner not feasible with traditional approaches.

There are several potential benefits of using VR in education, including increased accessibility to simulations and hands-on learning experiences, increased student engagement and motivation, the ability to visualise and manipulate 3D objects and concepts in a realistic environment, and the chance to test and experiment with equipment and processes in a safe environment [6].

Bashabsheh *et al.* [7] performed a study aimed to evaluate the effectiveness of using virtual reality (VR) technology in teaching building construction (BC) courses at Jordan University of Science and Technology. The authors developed a VR software called BC/VR to present 4D models (3D models with a time dimension) for various construction phases in immersive and non-immersive VR experiences. The study found that the BC/VR software was able to provide students with construction information, achieve enjoyment, and integrate with other courses better than traditional teaching methods. The authors concluded that the use of BC/VR tools in building construction courses was very effective and useful for students, and that VR technology could as well be applied to other architectural-related courses.

Arulanand *et al.* [5] discussed the use of augmented reality (AR) technology in engineering education, specifically through the use of mobile devices. Fig. 2 shows the modelling in the Blender Environment. The study proposes a framework for using AR in engineering education and suggests that it can be an effective tool for teaching and learning. The paper also proposes an experimental setup to convert a topic into an Android app using AR technology. The use of mobile devices in education, known as M-learning, is suggested as a way to enhance creativity and motivation among students, as well as to promote collaboration.

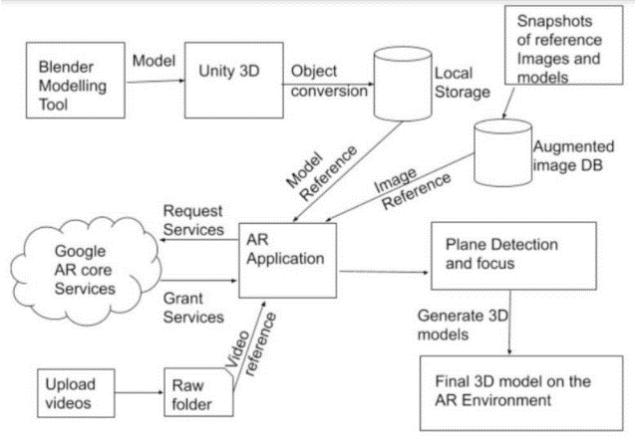


Fig. 2. Blender Environment Modelling (Arulanand *et al.* [5])

Virtual and augmented (VAR) technology has been adopted at the University of Sydney as a teaching platform for higher education, as reported by Marks and Thomas [6]. An evaluation of a purpose-designed virtual reality laboratory found that it was used by 53% of engineering students, 23.8% of arts and social science students, and 23.2% of science students. There was an increase in terms of student numbers up to 250% over the evaluation period, and 71.5% of learners surveyed (n=295) stated enhancement in their learning outcomes. The report states that the cost was AU$ 19.50 only per visit. These findings suggest that investing in infrastructure for authentic VR technology is a worthwhile investment with regard to higher education institutions.

Virtual reality is utilised in a range of educational environments, including elementary and secondary schools, colleges, and professional training programmes [10]. Simulations and hands-on learning experiences may be especially beneficial in disciplines such as engineering, science, technology, and medicine, where they can aid in the comprehension of complicated concepts and procedures.

Before continuing the discussion, to clarify the text. This paper outlines the benefits of virtual reality in engineering education as well as the challenges involved, to foster motivation and enthusiasm for learning through the use of VR

II. Advantages of Using VR in Engineering Education

A. Increased accessibility to simulations and hands-on learning experiences

One advantage of adopting virtual reality (VR) in engineering education is that simulations and hands-on learning experiences are more accessible [11]. Traditional methods of teaching engineering frequently rely on lectures, texts, and demonstrations, which might be unable to provide students with immersive and engaging learning experiences.

Digital prototyping and virtual reality (VR) in the context of project-based learning (PBL) can promote effective communication, increase problem-solving skills, and enhance learning outcomes in engineering education. VR has been

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shown to reduce development costs and time, and increase student zeal and creativity in the context of product design and evaluation. Halabi [13] performed a study in which VR was used together with PBL and a self-directed approach to design and implement a product using 3D software, and to evaluate the design using a virtual reality immersive CAVE display. The design approach comprises a series of ten steps, as depicted in Fig. 3. The results showed that the VR approach noticeably affected the distribution of the cumulative project grade and also improved course outcomes related to project design. problem-solving skills and Communication were also improved in the VR approach in comparison with the traditional approach.

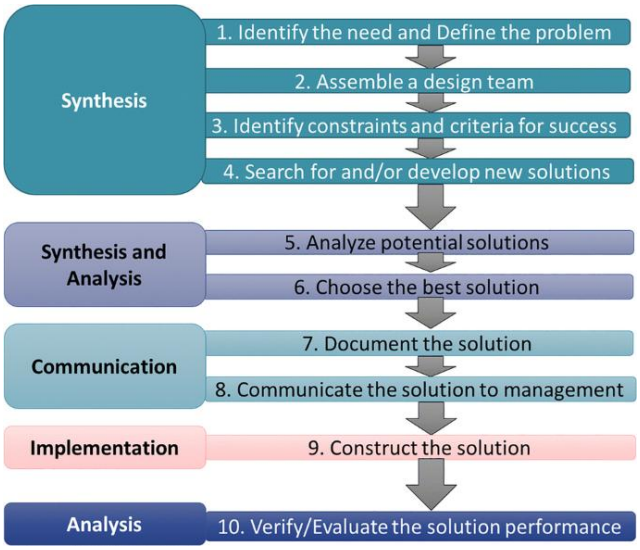


Fig. 3. The design methodology consisting of ten steps (Halabi [13]).

Virtual reality (VR) simulations and games are being used currently to provide engaging, interactive, and contextual learning experiences for students in chemical engineering and industrial environments, but it is important to understand users' perceptions of these technologies for education and training. Udeozor *et al.* [8] surveyed students from the chemical engineering department and professionals about their perceptions regarding VR games with respect to safety and health education as well as training, and found that both groups believe the technology is useful for learning.

However, professionals were more accepting of VR than students, and students had concerns about using the technology in the classroom. The study therefore concluded by discussing the implications of these findings for the practice of higher education.

Hernández-de-Menéndez *et al.* [15] reviewed various types of engineering education laboratories, including hands-on, virtual, and remote labs. It discusses the educational effectiveness of each type and presents a report on VR development and implementation at Tecnologico de Monterrey, and the results of the case study indicate that virtual labs can be a viable option that can be used to replace or complement the hands-on labs due to their low cost, ease of replication, and ability to encourage skill development and active learning. The paper also reviews learning outcomes and factors that can influence the success rate of teaching and learning processes like presence, collaboration, and belief. The goal of the research is to serve as a model in designing either a single, blended, or even a hybrid kind of laboratory for the purpose of teaching different types of experiments in 'engineering education'.

By utilising virtual reality, students may access simulations of real-world surroundings, equipment, and processes, allowing them to study and practise engineering ideas and skills in a manner more analogous to their future employment. VR can also allow students to safely test and experiment with equipment and processes that may not be available or practicable to utilise in a real classroom or laboratory. The use of virtual reality (VR) in engineering education can give students a more complete and interesting learning experience, enabling them to better comprehend and apply the concepts and skills they are learning.

B. Enhanced engagement and motivation for students

A further benefit of employing virtual reality (VR) in engineering education is increased student engagement and motivation [16]. VR may give students an immersive and interactive learning experience that is more engaging and interesting than traditional approaches such as lectures and textbooks.

Using virtual reality, students may experience and study engineering topics and abilities in a more engaging and hands-on manner, which can boost their motivation and interest in the subject. Additionally, VR may offer students a sense of presence and immersion in the learning environment, which can further increase their motivation and engagement.

Özyurt *et al.* [17] aims to explore the use of virtual reality in earth science engineering education programs to provide technology-enhanced training alternatives. A systematic review and mapping of the literature was conducted, resulting in the identification of 19 studies on this topic. The majority of these studies were from China and the US and focused on mining and geological engineering. The systematic review found that virtual reality applications in earth science engineering education can positively contribute to student learning outcomes and experiences.

Studies indicated that VR models can be utilized in construction education so as to provide students with immersive, real-life understanding of practical realities safely and conveniently [18]. A VR model of sustainable building features was created and evaluated by construction students with the aid of 'unnamed respondents' to a questionnaire survey, and the results showed that 'VR models' can be an effective means of engaging students in construction studies and improve the learning process, as reported by Samarasinghe *et al.* [19]. Seventy-one and a half percent (71.5%) of the students who partake in the project think that VR models are important and useful because of convenience and ease of access, and also found them to be an asset regarding the learning process. The VR models can assist students in understanding the sustainable features and techniques in earth building that may not be readily accessible in real life, and can assist instructors in terms of engagement with the learning activities through experience so as to improve the teaching quality.

Yüzüak and Yiğit [20] discusses augmented reality (AR) technology usage with respect to engineering education to help learners better understand and retain information about N-type

MOSFET elements, which are commonly used in electronic circuits. It was found that the AR application was effective in making abstract concepts more concrete and increasing students' motivation. The results suggest that AR can be a useful tool in engineering education to enhance learning and engagement.

Students may explore and interact with the VR world at their own speed and in a manner that is most important to them. This can enhance student motivation and engagement by allowing them to customise their learning experience to their own needs and interests.

C. *Ability to visualize and manipulate 3D objects and concepts in a realistic environment*

The capacity to perceive and handle 3D objects and concepts in a realistic environment is another advantage of adopting virtual reality (VR) in engineering education [21]. Frequently, engineering entails the design, fabrication, and analysis of complicated three-dimensional objects and systems. Traditional engineering education techniques, such as lectures and textbooks, might be inadequate for providing students with a genuine knowledge of these ideas.

A virtual reality (VR) learning environment has been developed to enhance electronics engineering laboratory courses and provide prior training to students about laboratory hardware [22]. Singh *et al.* [23] An experimental study was carried out with 65 engineering students, who were divided into a control group and a treatment group using a conventional approach and VR, respectively, to teach each group. The results showed that the VR style had a relevant positive impact on learning motivation, student knowledge, as well as cognition. It was observed that students' interaction with laboratory instruments via 3D virtual models led students to demonstrate an improved understanding of the hardware and reported increased confidence and reduced cognitive load due to reduced worry about equipment malfunction.

Virtual reality (VR) and virtual laboratories (VLs) have become increasingly common tools in engineering education, with the advantages they offer making them widely accepted by students [24]. Research conducted on 420 engineering students at both Portuguese and Spanish universities found that VR-based Virtual learning acceptance and demand were large but that students also considered real laboratories to be important regarding face-to-face teaching and learning, as reported by Vergara *et al.* [25]. After the COVID-19 pandemic, it is expected that VLs and real laboratories will coexist in hybrid models combining online teaching and learning with the face-to-face style.

Wolfartsberger [26] discussed the virtual reality (VR) technology capabilities for engineering design reviews, which is currently often performed using computer-aided design (CAD) software on a computer. The authors describe the development and evaluation of a VR-based tool called VRSmart, capable of visualising CAD data as well as allowing intuitive interactions. In a report on users, it was noted that VRSmart was found to be usable and to provide a positive user experience. The tool was also examined in real industrial environments and subjected to testing using authentic design reviews, and the results showed that VR allowed users to identify partially higher faults with respect to the 3D model compared with the CAD-based approach shown on a computer display, with reduction in terms of risk of excluding particular groups from the process of design review, and enables faster entry into the design review process. The authors conclude that VR can be a useful addition to engineering companies, but won't be a complete replacement for the 'traditional design review' processes on a displayed screen.

Virtual reality (VR) has the potential to support various functions in engineering and product design, including 3D modelling, virtual prototyping, product evaluation, co-design, and design education [27]. However, the use of VR in these applications has not been well-studied, and there are some misalignments among scholars about its effectiveness in early design phases and creative design stages. In a review of 86 sources on the use of VR in design, the authors, Berni and Borgianni [27] found that VR can be used to support products that involve an emotional dimension in addition to functional aspects, particularly in virtual assembly and prototyping. There is some overlap between VR technologies and specific design tasks, but it is not clear that a clear separation can be drawn between the two.

Virtual Reality (VR) can possibly be utilized as a tool in promoting active learning and student engagement in industrial engineering education. Ruiz-Cantisani *et al.* [28] compared the use of VR cases to traditional cases in a private university, with the same group of students participating in both types of cases over two weeks. The results showed that using VR cases increased student motivation and engagement, and led to increased critical thinking and a systemic perspective among students. From the perspective of the professors, the development of VR cases also presented an interesting challenge and allowed for the development of active learning both in and out of the classroom. Overall, the use of VR cases provided a flexible learning space and a real industrial experience, while also promoting innovation and fun among students.

Through the use of VR, students may interact and control 3D objects and concepts in a more realistic and immersive manner than is possible with conventional approaches. This can assist students in better comprehend and grasp the features and relationships of these objects and concepts, as well as test and explore various design configurations and scenarios. The use of virtual reality (VR) in engineering education can give students a more intuitive and engaging learning experience, enabling them to better comprehend and apply the concepts and skills they are learning.

D. *Opportunity to safely test and experiment with equipment and processes*

Using virtual reality (VR) in engineering education provides the possibility to test and experiment with equipment and processes in a safe environment. Numerous engineering disciplines need the use of specialised equipment and techniques that may be prohibitively expensive, hazardous, or otherwise problematic to utilise in a conventional classroom or laboratory context.

A training system called "DMS-VLCC3D" for educational purposes has been recently developed to aid marine engineers and students in learning about the working principle of marine engineering systems to improve their skills in practical operation, as reported by Shen *et al.* [29]. The system uses optimization methods to improve the loading

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speed and efficiency of a virtual marine engine room. This includes interactive and auxiliary learning tools to make it a self-learning and training platform. The system also offers three training modes to fit different training purposes, and has been tested with a group of 60 seniors majoring in marine engineering, who showed promising results in terms of learning effectiveness. Currently, the DMS-VLCC3D training system is being utilized in Chinese maritime universities for training students in their thousands at over twenty (20) maritime higher institutions of learning.

Singh *et al.* [30] evaluated the effect of an 'augmented reality learning environment (ARLE)' on the laboratory skills of students in engineering offering electronics courses. Oscilloscopes and function generators are commonly used electronic equipment in electronics engineering laboratories, and AR technology can provide a unique learning experience for students when using this equipment. The study was conducted with 60 first-year undergraduate engineering students, who were randomly divided into an experimental group and a control group. The experimental group was given ARLE treatment, while the control group received traditional teaching treatment. The results showed that the ARLE had a significant positive impact on student laboratory skills and reduced the cognitive load of students while operating laboratory equipment. Students in the experimental group also felt more confident and less afraid of damaging the equipment because they had already been familiarized with it through the ARLE. The results suggest that AR is an effective technology for developing unique learning experiences in engineering education.

Virtual reality (VR) enables students to safely test and experiment with equipment and processes in a virtual environment, allowing them to learn and practise engineering ideas and skills without the hazards or limits of utilising physical equipment. This can give kids a wider variety of learning options and secure their safety while they are studying. In addition, the use of VR in engineering education can facilitate more flexible and dynamic learning experiences, since students can transition between different equipment and processes without having to physically set up and pull down equipment. This can save time and costs and improve the efficiency and effectiveness of learning.

III. Examples of VR in Engineering Education

A. *Use of VR headsets to simulate laboratory and field experiences*

Using VR headsets to recreate laboratory and field activities is one application of virtual reality (VR) in engineering education. Virtual reality (VR) headsets, such as the Oculus Rift and HTC Vive, are devices that enable users to view and interact with a virtual environment through the use of a headset with one or more screens in front of the eyes.

In engineering education, virtual reality (VR) headsets can be utilised to present students with laboratory and field experiences comparable to those they would face in a real-world situation. Students might utilise a VR headset to imitate a laboratory experiment, allowing them to do the experiment as if they were physically present. Similarly, students might utilise a VR headset to imitate a field trip, such as visiting a building site or industrial facility, allowing them to study and explore these surroundings in a safe and controlled atmosphere.

Trentsios *et al.* [31] described the combination of Virtual Reality and Remote Lab technology in engineering education. The authors established state-of-the-art frontends for an existing engineering education Remote Lab using two different approaches: displaying a physical laboratory represented by a reconstructed virtual 3D-model or 360°-images of the laboratory. In both approaches, implementation was done using the Unity engine, which was tested in a corresponding laboratory.

The usage of VR headsets in engineering education can give students a more immersive and engaging learning experience, hence enhancing their ability to comprehend and apply the concepts and skills they are learning.

B. *Use of VR simulations to teach engineering principles and concepts*

The use of virtual reality (VR) simulations to teach engineering ideas and principles is another example of the application of virtual reality (VR) in engineering education. Virtual reality (VR) simulations are computer-generated settings that allow users to interact realistically with a virtual world.

In engineering education, virtual reality simulations may be used to teach a variety of ideas and principles, including the functioning of equipment, the characteristics of materials, and the behaviour of systems. By operating a virtual pipe network and witnessing the movement of fluids through the pipes, for instance, students may utilise a VR simulation to study the fundamentals of fluid dynamics. Similarly, students may utilise a VR simulation to evaluate the strength and durability of various virtual materials to learn about the qualities of materials.

Segura *et al.* [32] presented a virtual reality (VR) system prototype called VR-OCKS for training learners in the initial concepts of programming. The system works through proposition of puzzles to users such that it requires the use of basic commands and control flow structures in a 3D environment. The goal of VR-OCKS is to attract children and teenagers to programming by using the potential and appeal of VR. The use of VR-OCKS was found to improve spatial orientation, autonomy, creative thinking, systematic reasoning, and common sense in users. In experiments, adults and children accepted VR-OCKS as it showed great potential to be utilized as an educational tool.

Lee and Coiado [33] described the design of a virtual reality (VR) platform for teaching medical and engineering students about anatomy using 3D models generated from ultrasound imaging. The VR platform will allow students to learn about the theory of wave propagation in tissues through immersive and engaging 3D visualizations of abstract physics concepts and organ systems. The project involves converting DICOM files into 3D meshes that can be displayed and manipulated in a VR environment using the Unity 3D Development platform. The VR environment will give students the chance to explore ultrasound without the limitations of an actual patient and will help them understand the physics principles underlying ultrasound propagation in the human body, which will aid in the transfer of skills to point-of-care ultrasound.

The use of virtual reality (VR) simulations in engineering

education can give students a more engaging and dynamic learning experience, allowing them to better comprehend and apply the concepts and skills they are learning.

C. *Use of VR training programs to prepare students for industry practices and procedures*

The usage of VR training packages to educate students for industrial practises and procedures is another application of virtual reality (VR) in engineering education. VR training programmes are computer-based applications that employ VR simulations to instruct students in field-specific skills and processes.

VR training programmes may be utilised in engineering education to instruct students on industrial practices and procedures, such as safety measures, equipment operation, and technical processes. For instance, students may utilise VR training software to master the correct techniques for operating forklifts and bulldozers. Similarly, students might utilise a VR training programme to learn safety rules and procedures, such as how to respond to crises or handle dangerous chemicals.

The use of virtual reality (VR) training programmes in engineering education can give students a more realistic and interactive learning experience, enabling them to better comprehend and apply the skills and processes they will need in the field.

IV. Challenges of Using VR in Engineering Education

A. *Limited availability and cost of VR equipment*

Virtual reality in engineering education is complicated by the limited availability and high cost of VR equipment. VR technology, including VR headsets and VR simulations, can be costly and may not be easily accessible to all students or educational institutions.

It may not be possible for many schools or programmes to acquire and maintain the necessary equipment due to the high cost of virtual reality (VR) technology. Additionally, the availability of VR technology may be limited, particularly for schools and programmes situated in regions with little or no access to VR resources.

To overcome these obstacles, schools and programmes may need to rely on partnerships or grants to acquire VR equipment, or they may need to employ alternate approaches to teach engineering ideas and skills. Additionally, it may be required to carefully analyse the cost-benefit ratio of employing virtual reality in engineering education, evaluating the potential benefits of using VR against the expenses of acquiring and maintaining the necessary equipment.

B. *Need for technical support and training for faculty and students*

The requirement for technical assistance and training for teachers and students is a further difficulty posed by the use of virtual reality (VR) in engineering education. VR technology, such as VR headsets and VR simulations, can be sophisticated and may need technical knowledge for installation and operation.

Faculty and students may need training on the usage of the equipment and the creation and use of VR material in order to properly implement VR in engineering education. This can be time-consuming and may necessitate the deployment of additional training and support resources.

In addition, the use of VR in engineering education may need continuing technical assistance to verify that the technology is operating effectively and to resolve any potential concerns. This can be difficult, particularly for schools or programmes with limited technical resources or support personnel.

To overcome these obstacles, it may be required to provide funds for technical assistance and training, or to seek out partnerships or external support to assist with the maintenance and utilisation of VR equipment in engineering education.

C. *Need for development and maintenance of VR content*

The necessity for the production and management of virtual reality (VR) material in engineering education is a further obstacle posed by the use of VR. VR content refers to the virtual worlds, simulations, and other interactive components employed by VR applications.

It may be difficult and time-consuming to create and manage virtual reality (VR) content since it requires specialised tools and technical knowledge. In addition, producing VR content may be costly, particularly if it is very complicated or personalised.

The necessity for the creation and management of virtual reality (VR) material can be a difficulty for schools and programmes that use VR in engineering education, since it involves the allocation of resources. To overcome this obstacle, schools and programmes may need to invest funds for the creation and maintenance of virtual reality (VR) material, or seek partnerships or external support to assist with these duties.

Several additional challenges are faced, viewed from various aspects. Students and instructors sometimes see VR as a novelty rather than a tool that improves learning outcomes, especially for abstract engineering concepts (e.g., fluid dynamics, structural stress) where the link between the simulation and real-world skill transfer isn't obvious to them. Faculty may doubt VR adds value over traditional CAD, physical labs, or 2D simulations, particularly for well-established curricula. Steep learning curves with headsets, controllers, and navigation reduce willingness to adopt, especially among older faculty or students unfamiliar with gaming-style interfaces. Technical friction (setup time, calibration, software bugs) discourages repeated use even if initial experience is positive.

Cybersickness (nausea, dizziness, eye strain) is a well-documented deterrent, particularly in prolonged sessions or fast-motion simulations common in engineering walkthroughs. Some users report anxiety or self-consciousness using headsets in group settings. Students with low confidence in tech skills often underestimate their ability to use VR effectively, which lowers behavioral intention to use it independently for self-study. Lack of peer/instructor modelling-if students don't see instructors actively using VR or don't see classmates successfully engaging with it, adoption drops.

Limited institutional support (IT help, dedicated lab time) reduces sustained use even after initial acceptance. High hardware costs create disparities-students without personal access to headsets rely solely on limited lab time, weakening habitual use and long-term acceptance. Some educators and students question whether VR-based assessment/evaluation is

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as rigorous or fair as traditional methods, especially for high-stakes engineering competencies (safety-critical simulations, certification - linked skills).

V. Conclusion

A. Summary of the benefits and challenges of using VR in engineering education

Virtual reality has the potential to provide numerous benefits for engineering education, including increased accessibility to simulations and hands-on learning experiences, increased student engagement and motivation, the ability to visualise and manipulate 3D objects and concepts in a realistic environment, and the chance to safely test and experiment with equipment and processes.

However, the use of virtual reality in engineering education involves a number of obstacles, including the restricted availability and expense of VR equipment, the need for technical assistance and training for professors and students, and the requirement for the creation and maintenance of VR material.

To effectively use VR in engineering education, it is necessary to weigh the advantages and disadvantages of the technology and spend resources accordingly. The procurement and maintenance of VR equipment and content may also necessitate the formation of partnerships or the solicitation of external assistance. The use of virtual reality (VR) in engineering education has the potential to give students a more immersive and dynamic learning environment, hence enhancing their ability to comprehend and apply the concepts and skills they are learning.

B. Future directions for the use of VR in engineering education

Future applications of virtual reality in engineering education. Virtual reality (VR) has the potential to be a transformational tool in engineering education, offering students immersive and interactive learning experiences that are impossible to achieve with conventional approaches. As VR technology continues to advance, the application of VR in engineering education might develop in a variety of ways in the future.

The use of VR to give students more tailored and adaptable learning experiences is one possible option. VR might be used to personalise learning experiences to students' specific needs and interests, or to adapt learning experiences based on students' progress and performance.

The creation of increasingly realistic and sophisticated VR material and simulations, allowing students to study and practise engineering ideas and skills in a more true and complete manner, is another area for the use of VR in engineering education. This might involve utilising virtual reality to imitate real-world locations and equipment, or providing students with the opportunity to work on genuine projects and circumstances.

The use of virtual reality in engineering education might be expanded to incorporate augmented reality (AR) and mixed reality (MR) technologies, which allow users to superimpose virtual features on the actual world or combine virtual and real elements in a single setting. This might give students even more immersive and engaging learning experiences, allowing them to explore and engage with real-world surroundings and things in a manner not conceivable with conventional approaches.

The use of virtual reality (VR) in engineering education has the potential to transform how engineering is taught and learnt by offering students more interesting and interactive learning experiences that better prepare them for success in the field.

C. Summary Table

Table I presents a comparative summary of the reviewed studies, highlighting each article's title, research method, principal findings, and corresponding reference. This comparison facilitates the identification of methodological trends, recurring themes, and research outcomes, providing a structured overview of the existing literature and supporting the synthesis of evidence across the selected studies.

TABLE I. Comparison of Findings Across the Reviewed Studies

No	Article title	Article method	Article result	Ref
1	Virtual reality in engineering education: a scoping review	Systematic approach: a scoping review approach and focusing on bibliometric analysis	Virtual reality was proven to be an effective educational tool that supports engineering education and complements existing learning	[34]
2	The impact of virtual reality on practical skills for students in science and engineering education: a meta-analysis	Meta-analysis	The results, effect sizes, and random-effects model were employed to account for heterogeneity among studies	[21]
3	Virtual reality assisted engineering education: a multimedia learning perspective	Before continuing the discussion, to clarify the text. This paper outlines the benefits of virtual reality in engineering education as well as the challenges involved, to foster motivation and enthusiasm for learning through the use of VR	VR-assisted engineering education research Engineering VR studies should be informed by theories of learning and instruction that address the cognitive and socio-cognitive aspects of learning	[35]
4	Analysis of virtual reality teaching methods in engineering education: assessing educational effectiveness and understanding of 3D-structures	VR-based learning and 2D video-based learning (2DLM)	VR is more effective than conventional learning resources in supporting general memorization, understanding, and the specific comprehension of 3D structures	[12]
5	Applications of Augmented and virtual reality in electrical engineering education: a review	Methodological review of all available publications in this area and according to the application	3D modelling software	[36]

D. *Future research directions: emerging technologies and acceptance implications*

The technical trajectory of VR in engineering education is shifting toward hybrid systems that combine immersive environments with AI-driven personalization, live physical-system data, and multi-user mixed-reality collaboration. These developments introduce new acceptance constructs that existing TAM/UTAUT-based studies have not yet systematically incorporated. Four converging trends stand out.

AI-enhanced VR learning. A growing body of work integrates generative AI directly into VR training pipelines rather than treating VR as a static, pre-scripted environment. The PRISM framework, for instance, combines generative AI with digital twins to deliver personalized, adaptive experiential learning: it uses sentiment analysis and retrieval-augmented generation to monitor learner comprehension in real time and dynamically adjust VR content, validated across four Industry 4.0 training modules [37]. This shifts the acceptance question from "is the VR environment usable and useful" toward "do learners trust an AI system that is actively adapting their instruction," introducing trust-in-automation and perceived algorithmic fairness as candidate constructs that classical TAM/UTAUT models do not capture.

Digital twins as the substrate for VR simulation. Rather than building purely synthetic VR scenes, several recent engineering-education systems couple VR front-ends to digital twins, live or historically informed virtual replicas of physical equipment, processes, or systems. One framework aligns digital-twin fidelity levels with Bloom's taxonomy, proposing that lower-fidelity twins suit foundational "remember/understand" tasks while higher-fidelity, sensor-fed twins support graduate-level "apply/analyze/evaluate" tasks. Separately, VR-plus-digital-twin systems have been piloted for composite-manufacturing lab training, where learners reported reduced mental and physical workload alongside procedural learning outcomes comparable to physical labs, though with elevated frustration tied to navigation and motion discomfort [38].

REFERENCES

[1] S. K. Renganayagalu, S. Mallam, and S. Nazir, "Effectiveness of VR Head Mounted Displays in Professional Training: A Systematic Review," Technology Knowledge and Learning, vol. 26, no. 4, pp. 999–1041, Jan. 2021, doi: 10.1007/s10758-020-09489-9.

[2] M. Soliman, A. Pesyridis, D. Dalaymani-Zad, M. G. Gronfula, and M. Kourmpetis, "The Application of Virtual Reality in Engineering Education," Applied Sciences, vol. 11, no. 6, pp. 2879–2879, Mar. 2021, doi: 10.3390/app11062879.

[3] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, "A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda," Computers & Education, vol. 147, pp. 103778–103778, Dec. 2019, doi: 10.1016/j.compedu.2019.103778.

[4] M. Hernández-de-Menéndez and R. Morales-Menéndez, "Technological innovations and practices in engineering education: a review," International Journal on Interactive Design and Manufacturing (IJIDeM), vol. 13, no. 2, pp. 713–728, Feb. 2019, doi: 10.1007/s12008-019-00550-1.

[5] J. A. di Lanzo, A. Valentine, F. Sohel, A. Y. T. Yapp, K. C. Muparadzi, and M. Abdelmalek, "A review of the uses of virtual reality in engineering education," Computer Applications in Engineering Education, vol. 28, no. 3, pp. 748–763, Apr. 2020, doi: 10.1002/cae.22243.

[6] Γ. Λαμπρόπουλος and K. Kinshuk, "Virtual reality and gamification in education: a systematic review," Educational Technology Research and Development, vol. 72, no. 3, pp. 1691–1785, Mar. 2024, doi: 10.1007/s11423-024-10351-3.

[7] A. K. Bashabsheh, H. H. Alzoubi, and M. Z. Ali, "The application of virtual reality technology in architectural pedagogy for building constructions," Alexandria Engineering Journal, vol. 58, no. 2, pp. 713–723, Jun. 2019, doi: 10.1016/j.aej.2019.06.002.

[8] N. Arulanand, A. R. Babu, and P. K. Rajesh, "Enriched Learning Experience using Augmented Reality Framework in Engineering Education," Procedia Computer Science, vol. 172, pp. 937–942, Jan. 2020, doi: 10.1016/j.procs.2020.05.135.

[9] B. Marks and J. Thomas, "Adoption of virtual reality technology in higher education: An evaluation of five teaching semesters in a purpose-designed laboratory," Education and Information Technologies, vol. 27, no. 1, pp. 1287–1305, Jul. 2021, doi: 10.1007/s10639-021-10653-6.

[10] S. Alhawsawi and F. Alzaid, "Systematic review of virtual reality's uses on vocabulary learning in higher education," Smart Learning Environments, vol. 12, no. 1, Sep. 2025, doi: 10.1186/s40561-025-00414-0.

[11] W. Terkaj, M. Urgo, P. Kovács, E. Tóth, and M. Mondellini, "A framework for virtual learning in industrial engineering education: development of a reconfigurable virtual learning factory application," Virtual Reality, vol. 28, no. 3, Aug. 2024, doi: 10.1007/s10055-024-01042-8.

[12] J. Ka, H. Kim, J. Kim, and W. Kim, "Analysis of virtual reality teaching methods in engineering education: assessing educational effectiveness and understanding of 3D structures," Virtual Reality, vol. 29, no. 1, Jan. 2025, doi: 10.1007/s10055-024-01081-1.

[13] O. Halabi, "Immersive virtual reality to enforce teaching in engineering education," Multimedia Tools and Applications, vol. 79, pp. 2987–3004, Dec. 2019, doi: 10.1007/s11042-019-08214-8.

[14] C. Udeozor, R. Toyoda, F. R. Abegão, and J. Glassey, "Perceptions of the use of virtual reality games for chemical engineering education and professional training," Higher Education Pedagogies, vol. 6, no. 1, pp. 175–194, Jan. 2021, doi: 10.1080/23752696.2021.1951615.

[15] M. Hernández-de-Menéndez, A. V. Guevara, and R. Morales-Menéndez, "Virtual reality laboratories: a review of experiences," International Journal on Interactive Design and Manufacturing (IJIDeM), vol. 13, no. 3, pp. 947–966, Feb. 2019, doi: 10.1007/s12008-019-00558-7.

[16] E. S. Animashaun, B. T. Familoni, and N. C. Onyebuchi, "The role of virtual reality in enhancing educational outcomes across disciplines," International Journal of Applied Research in Social Sciences, vol. 6, no. 6, pp. 1169–1177, Jun. 2024, doi: 10.51594/ijarss.v6i6.1178.

[17] Ö. Özyurt, N. E. Çağıltay, H. Özyurt, and A. Akgün, "A systematic review and mapping of the literature of virtual reality studies in earth science engineering education," Journal of Pedagogical Research, pp. 1–20, Mar. 2021, doi: 10.33902/jpr.2021067651.

[18] D. W. McCloskey et al., "Embedding Civil Engineering Understanding through the Use of Interactive Virtual Reality," Education Sciences, vol. 14, no. 1, pp. 6–6, Dec. 2023, doi: 10.3390/educsci14010006.

[19] D. A. S. Samarasinghe, S. A. Latif, and N. Baghaei, "Virtual Reality Models for Promoting Learners Engagement in Construction Studies," pp. 1331–1335, Apr. 2019, doi: 10.1109/educon.2019.8725120.

[20] Y. Yüzüak and H. Yiğit, "Augmented reality application in engineering education: N-Type MOSFET," International Journal of Electrical Engineering Education, vol. 60, no. 3, pp. 245–257, Aug. 2020, doi: 10.1177/0020720920954150.

[21] C. Yang et al., "The impact of virtual reality on practical skills for students in science and engineering education: a meta-analysis," International Journal of STEM Education, vol. 11, no. 1, Jun. 2024, doi: 10.1186/s40594-024-00487-2.

[22] A. A. Fadzil et al., "Metaverse and Virtual Reality Integration in Electrical Engineering," 2026, pp. 45–59. doi: 10.1201/9781003557555-3.

[23] G. Singh, A. Mantri, O. Sharma, and R. Kaur, "Virtual reality learning environment for enhancing electronics engineering laboratory experience," Computer Applications in Engineering Education, vol. 29, no. 1, pp. 229–243, Sep. 2020, doi: 10.1002/cae.22333.

[24] A. J. A. Alnagrat, R. C. Ismail, and S. Z. S. Idrus, "The Opportunities and challenges in virtual reality for virtual laboratories," Innovative Teaching and Learning Journal, vol. 6, no. 2, pp. 73–89, Jan. 2023, doi: 10.11113/itlj.v6.91.

[25] D. Vergara, "Educational trends post COVID-19 in engineering: Virtual laboratories," Materials Today: Proceedings, vol. 49, pp. 155–160, 2022.

[26] J. Wolfartsberger, "Analyzing the potential of Virtual Reality for engineering design review," Automation in Construction, vol. 104, pp. 27–37, Apr. 2019, doi: 10.1016/j.autcon.2019.03.018.

[27] A. Berni and Y. Borgianni, "Applications of Virtual Reality in Engineering and Product Design: Why, What, How, When and Where,"

Electronics, vol. 9, no. 7, pp. 1064–1064, Jun. 2020, doi: 10.3390/electronics9071064.
[28] M. I. Ruiz-Cantisani, F. del C. Lima-Sagui, N. Aceves-Campos, R. I. Sifuentes, and E. G. Rincón-Flores, "Virtual Reality as a tool for active learning and student engagement: industrial engineering experience," pp. 1031–1037, Apr. 2020, doi: 10.1109/educon45650.2020.9125225.
[29] H. Shen, J. Zhang, B. Yang, and B. Jia, "Development of an educational virtual reality training system for marine engineers," Computer Applications in Engineering Education, vol. 27, no. 3, pp. 580–602, Jan. 2019, doi: 10.1002/cae.22099.
[30] G. Singh, A. Mantri, O. Sharma, R. Dutta, and R. Kaur, "Evaluating the impact of the augmented reality learning environment on electronics laboratory skills of engineering students," Computer Applications in Engineering Education, vol. 27, no. 6, pp. 1361–1375, Aug. 2019, doi: 10.1002/cae.22156.
[31] P. Trentsios, M. Wolf, and S. Frerich, "Remote Lab meets Virtual Reality – Enabling immersive access to high tech laboratories from afar," Procedia Manufacturing, vol. 43, pp. 25–31, Jan. 2020, doi: 10.1016/j.promfg.2020.02.104.
[32] R. J. Segura, F. J. del Pino, C. J. Ogáyar, and A. J. Rueda, "VR-OCKS: A virtual reality game for learning the basic concepts of programming," Computer Applications in Engineering Education, vol. 28, no. 1, pp. 31–41, Sep. 2019, doi: 10.1002/cae.22172.
[33] J. Lee and O. C. Coiado, "Design of virtual reality for teaching ultrasound in medical and engineering education," The Journal of the Acoustical Society of America, vol. 150, Oct. 2021, doi: 10.1121/10.0007617.
[34] Γ. Λαμπρόπουλος, P. Fernández-Arias, A. del Bosque, and D. Vergara, "Virtual Reality in Engineering Education: A Scoping Review," Education Sciences , vol. 15, no. 8, pp. 1027–1027, Aug. 2025, doi: 10.3390/educsci15081027.
[35] A. V. Oje, N. Hunsu, and D. May, "Virtual reality assisted engineering education: A multimedia learning perspective," Computers & Education X Reality, vol. 3, pp. 100033–100033, Jul. 2023, doi: 10.1016/j.cexr.2023.100033.
[36] Y. Asham, M. H. Bakr, and A. Emadi, "Applications of Augmented and Virtual Reality in Electrical Engineering Education: A Review," IEEE Access, vol. 11, pp. 134717–134738, Jan. 2023, doi: 10.1109/access.2023.3337394.
[37] Y.-Z. Lin et al., "PRISM: A Personalized, Rapid, and Immersive Skill Mastery Framework for Personalizing Experiential Learning Through Generative AI," 2025, pp. 45–69. doi: 10.1007/978-3-032-01638-6_3.
[38] A. Darejeh, G. Chilcott, E. Oromiehie, and S. Mashayekh, "Virtual Reality and Digital Twins for Mechanical Engineering Lab Education: Applications in Composite Manufacturing," Education Sciences, vol. 15, no. 11, pp. 1519–1519, Nov. 2025, doi: 10.3390/educsci15111519.