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Investigating the Role of Virtual Reality to Support Student' Engagement, Spatial Awareness and Problem-solving Skills in Engineering Education

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This study explores the transformative role of Virtual Reality (VR) in enhancing engineering education, a field increasingly reliant on innovative teaching methodologies to engage students and improve learning outcomes. By integrating VR technology, educators aim to bridge the gap between theoretical concepts and practical applications, creating immersive learning environments that foster deeper understanding and retention of complex engineering principles. Through a comprehensive literature review, this research highlights existing studies on VR's impact in educational settings, noting notable advancements in engagement, spatial awareness, and problem-solving skills among engineering students. Utilising a qualitative approach, this investigation consists of collecting data through interviews and class observations. Findings reveal that students exposed to VR experiences demonstrate improved academic performance and heightened motivation and interest in their studies. Additionally, the discussions reveal the challenges of incorporating VR into curricula, including costs and training requirements for educators. Overall, this research underscores the potential of VR as a powerful pedagogical tool in engineering education, calling for further investment and exploration in adapting this technology to maximize its benefits in learning environments.

Keywords: virtual reality, engineering education, immersive learning, educational technology, student engagement, pedagogical tools

INTRODUCTION

As technological advancements rapidly reshape various sectors, the landscape of education, particularly engineering education, is experiencing a significant transformation (Miranda et al., 2021). In an era where students are increasingly exposed to advanced technologies in their daily lives, traditional pedagogical methods often fall short of captivating their interest and adequately facilitating their understanding of intricate concepts. Engineering is a field that incorporates mathematics, physics, and practical application and presents unique challenges in effectively conveying its multifaceted nature to students. Many learners find it difficult to visualise and comprehend theoretical principles without hands-on experience or interactive engagement (Chen et al., 2020). This dilemma not only affects student motivation but

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also hampers their ability to apply theoretical knowledge to real-world situations a critical skill for future engineers.

In light of these challenges, an urgent need arises for educational approaches that go beyond conventional classroom instruction. Employers and educators alike recognise the importance of cultivating critical thinking, problem-solving abilities, and spatial reasoning among engineering students. As such, there is a growing interest in exploring innovative instructional methods that can provide more immersive, engaging learning experiences. One promising solution to this challenge has been the integration of virtual reality (VR) technology into the curriculum (Halabi, 2020). By simulating real-world engineering problems and environments, VR has the potential to create interactive learning opportunities that enhance students' understanding and retention of complex concepts (Sidhu, et al., 2024).

Investigating the role of virtual reality in supporting engineering education offers insights into how this innovative technology can transform the learning experience. As VR tools become more accessible and sophisticated, educators are increasingly considering their implementation as a means to enrich the educational process (Radianti, et al., 2020; Wu et al., 2013). This integration not only addresses students' diverse learning styles but also aligns with contemporary expectations for technology-driven education. Through immersive simulations, students can engage with engineering principles dynamically, allowing for a deeper, more practical acquisition of knowledge. As the researcher delves deeper into this study, the aim is to uncover the several aspects that impact virtual reality on engineering education, examining both its potential benefits and the challenges that may arise in its adoption. Ultimately, the goal is to contribute to the ongoing dialogue surrounding effective pedagogical strategies that harness technology for enhancing student learning outcomes in engineering disciplines.

Virtual reality (VR) enhances learning in engineering by providing immersive and interactive environments that facilitate a deeper understanding of complex concepts. VR contributes to engineering education in 3D modeling, simulations, virtual laboratories, collaboration and communication, and active engagement (Goi, 2024; Sampaio, et al., 2010). VR allows students to visualise and manipulate 3D models of engineering designs and structures in a way that is not possible with traditional 2D diagrams or screen-based representations (Korkut & Surer, 2023). This capability enables students to gain a better spatial understanding of how components fit together, how systems function, and the overall relationship between different elements in a design. It empowers students to explore designs from multiple angles and perspectives, leading to a more intuitive grasp of geometric and structural principles. VR enables the creation of realistic simulations that replicate real-world engineering scenarios (Schluse, et al, 2018). Through these simulations, students can practice problem-solving and decision-making skills in controlled environments. For example, they can simulate the process of designing a bridge, testing its structural integrity under various conditions, or experiencing the impact of design changes in real-time. This experiential learning promotes critical thinking, as students can experiment with different approaches, analyse outcomes, and learn from failures in a safe, virtual space. VR provides access to virtual laboratories where students can conduct experiments that may be too dangerous, costly, or logistically challenging in a physical setting (Alnagrat, et al., 2022; Prayogi & Verawati, 2024). For example, in fields like chemical engineering, students can conduct virtual experiments with hazardous materials without any risk to their safety. These virtual lab environments allow for repeated practice and exploration at their own pace, helping to reinforce theoretical knowledge while fostering practical skills.

VR can also enhance 21st-century skills such as communication through collaborative learning experiences (Bower, et al., 2017; Monahan, et al., 2008). Students can work together in virtual environments, sharing ideas and solving problems as if they were in the same physical space, despite being geographically distanced. This fosters teamwork and communication skills, which are essential in engineering projects where collaboration among diverse teams is key. The immersive nature of VR captures students' attention and encourages active participation in their learning process thus promoting active engagement. Rather than passively receiving information, students become active learners who engage with the material in a hands-on manner. This level of engagement not only increases retention of information but also stimulates curiosity and motivation to explore engineering topics further.

Context and Review of Literature

Recent studies have illuminated the transformative potential of Virtual Reality (VR) technology in education, particularly its ability to provide realistic simulations that enhance the overall learning experience (Chasokela, 2024). By immersing students in lifelike scenarios, VR uniquely allows learners to visualize and interact with complex concepts that are often difficult to grasp through traditional teaching methods. For instance, VR can simulate the intricate workings of a mechanical system or the behavior of materials under various conditions, enabling students to observe and manipulate variables in a controlled yet dynamic environment. This experiential learning not only caters to different learning styles but also bolsters students' confidence in applying theoretical knowledge to practical situations. Additionally, Sweedler et al. (2020) highlight the idea of social presence in virtual reality, which emphasises the importance of shared experiences in building a sense of community among students.

Global Trends in VR Adoption in Engineering Education

Globally, the adoption of virtual reality (VR) technology in engineering education is rapidly gaining traction, reflecting a transformative shift towards more immersive and experiential learning methodologies. This trend is underscored by institutions from various countries integrating VR tools into their curricula to bridge the gap between theoretical concepts and practical applications. For example, universities such as the Massachusetts Institute of Technology (MIT), Stanford University, University of Toronto and University of New South Wales and the University of Melbourne are pioneering utilise VR simulations to recreate intricate engineering systems, enabling students to visualise and interact with complex structures and processes in a safe, controlled environment. Research indicates that these immersive learning experiences significantly enhance cognitive understanding, improve retention rates, and foster collaborative problem-solving skills among students (Kozlowski & Bell, 2003).

The Australian government's investment in educational technology has encouraged universities to experiment with virtual simulations, especially in fields like civil engineering and environmental science. The focus on creating realistic and engaging educational experiences has been shown to boost student motivation and achievement, as evidenced by several studies indicating improved learning outcomes when VR is used as a pedagogical tool (Luo et al., 2020). According to Merchant et al. (2014), students tend to perform better on assessments when they integrate VR.

The Canadian government's commitment to digital innovation in education further accelerates this trend, with funding programs aimed at enhancing the technological capabilities of universities (Government of Canada, 2020). As a result, Canadian students benefit from hands-on experiences that prepare them for real-world engineering challenges, aligning educational outcomes with industry needs.

In China, rapid advancements in technology and significant government investment in education have propelled the adoption of VR in engineering programs. Institutions such as Tsinghua University have implemented VR technology to enhance teaching in various engineering disciplines, from architectural design to mechanical engineering. The Chinese educational system emphasises practical skills development, and VR provides an effective platform for students to engage in experiential learning, thereby improving their problem-solving skills and employability (Kolb, 1984; Wang et al., 2021). This has led to the proliferation of research and development initiatives aimed at harnessing VR to create cutting-edge educational tools.

The United Kingdom is another leader in the integration of VR within engineering education. Progressive universities, such as Imperial College London and the University of Birmingham, have incorporated VR technology into their teaching methods to enhance student engagement and learning outcomes. The UK's Higher Education Funding Council has also supported initiatives aimed at exploring innovative teaching practices, recognising the potential of VR to reinvent traditional educational approaches (HEFCE, 2018). As a result, engineering students in the UK are increasingly exposed to immersive learning experiences, which prepare them for the challenges of a rapidly evolving job market.

Despite the promising advancements in VR technology across various regions, the pace of adoption is influenced by factors such as economic resources, technological infrastructure, and institutional priorities. While countries like Canada, China, the UK, and Australia have made significant strides in integrating VR into engineering education, other regions are still grappling with the challenges of access and implementation. As the global academic community continues to explore innovative educational practices, the further diffusion of VR technology into engineering education is likely to enhance learning outcomes and better prepare students for the demands of the modern workforce. Embracing VR as a core component of educational strategies could well define the future landscape of engineering education globally.

The Role of VR in Enhancing Engineering Education in Africa

In South Africa, VR technology is increasingly being integrated into engineering curricula, particularly within institutions like the University of Cape Town and

Stellenbosch University. Studies indicate that VR tools enhance practical learning experiences by providing safe environments for students to experiment and innovate (Hussain et al., 2020). South African educators have noted improvements in student engagement and understanding of complex engineering principles, as VR allows for interactive learning modules that cater to various learning styles. However, challenges remain, including the high costs of VR implementation and the need for adequate faculty training, which may impede widespread adoption. Virtual Reality (VR) is increasingly gaining traction across various sectors in Africa, including engineering and construction. South Africa is at the forefront of VR adoption in engineering, particularly in the construction sector. Companies are using VR for design visualisation, enabling engineers and architects to walk through projected buildings before they are constructed. This helps in identifying potential design flaws early on.

VR is being utilised for training purposes, particularly for safety training in construction environments. It allows workers to experience hazardous situations in a controlled setting, which enhances learning and retention. South African universities are incorporating VR into their engineering programs to enhance learning experiences. Research initiatives are also exploring the use of VR for various engineering applications, including urban planning and environmental impact assessments.

In Kenya, especially in Nairobi, VR is used in urban planning initiatives. It allows stakeholders to visualise proposed developments and understand their impact on the existing environment. There are several startups in Kenya focusing on tech innovations, including VR. These companies are exploring applications of VR in engineering and design, often coupled with augmented reality (AR) to provide mixed-reality solutions. Kenyan universities are also beginning to incorporate VR into their engineering curricula, though the level of integration may vary.

VR adoption in Namibia is still in its early stages compared to South Africa and Kenya. However, there are initiatives in place to push for technological advancements in industries, including engineering. The Namibian government is beginning to acknowledge the potential of VR in infrastructure projects, which could lead to improved efficiency and better planning in the construction and engineering fields. Similar to Namibia, VR adoption in Botswana within the engineering sector is not widespread yet. However, there is potential, especially as the country's engineering industry seeks modernization and efficiencies. There are ongoing efforts to enhance skills development in engineering, and incorporating VR could be a future initiative to improve training processes.

Challenges and Opportunities of VR

According to Jensen & Konradsen (2018), technological barriers can hinder the effective use of virtual reality (VR) in educational environments. These obstacles might include factors such as insufficient hardware, limited access to reliable internet, and a lack of technical support or training for educators. Without the proper tools and resources, the potential benefits of VR in enhancing learning experiences may not be fully realised. The high costs of VR technology can be a barrier for many companies, particularly in developing economies. There is a need for greater awareness of the benefits of VR in engineering, which may hinder adoption rates. As the engineering sector in Africa continues to grow, the adoption of VR technologies is expected to increase, driven by the need for efficiency and innovation in design and construction processes.

Innovative VR Applications in Engineering Education

Kenya and the University of Nairobi have begun to embrace VR technology in its educational framework, particularly in engineering programs not only improve engagement but also offer students insights into real-world engineering problems, such as infrastructure development and environmental issues (Odhiambo et al., 2021). However, widespread adoption is limited by infrastructure challenges and varying levels of technological access among institutions, leading to discussions about equitable implementation strategies. Virtual Reality (VR) is revolutionising engineering education by providing immersive learning experiences that enhance understanding and skill acquisition.

Some Namibian universities are starting to explore VR for engineering education, often partnered with international institutions, to provide immersive learning experiences. Innovative projects aim to use VR in vocational training centers, allowing students to simulate real-world engineering tasks in a safer environment. While still in the early stages, there is increasing interest among universities and polytechnic institutes in Botswana to explore VR for engineering training, focusing on hands-on applications. Partnerships with international organizations are being sought to develop VR curricula aimed at providing students with modern engineering skills.

Zimbabwean universities are exploring VR applications for engineering education, focusing on enhancing student engagement and understanding of complex engineering principles. Some institutions are partnering with international educational bodies to implement VR in their engineering programs, introducing students to advanced technologies. The adoption of VR in engineering education is becoming increasingly diverse and innovative across the globe. While countries like the USA, UK, Canada, and China are leading in VR application sophistication, nations like Namibia, Botswana, South Africa, and Zimbabwe are beginning to explore these technologies, expanding opportunities for their engineering students. With continued investment, research, and collaboration, VR has the potential to deeply transform engineering education in all these regions.

Evaluating VR's Impact on Student Engagement

Virtual Reality (VR) is rapidly reshaping educational landscapes across the globe, including in countries like the USA, UK, Canada, China, Namibia, Botswana, South Africa, and Zimbabwe. This evaluation examines the impact of VR on student engagement in these regions, considering various educational contexts, technological infrastructures, and pedagogical approaches.

In the United States, numerous studies highlight VR's positive impact on student engagement. For instance, research indicates that VR can enhance intrinsic motivation and interest in subjects such as science, engineering, and history by providing immersive, interactive experiences that traditional teaching methods often lack (Mikropoulos and Natsis, 2011). The findings illustrate that VR's interactive nature transforms passive learning into an active, participatory process, making complex engineering topics more accessible and enjoyable. Lecturers' observations of increased student attention resonate with the work of Dalgarno and Lee (2010), who noted that the immersive characteristics of VR can lead to higher levels of presence and engagement. This fosters an environment where students are more willing to explore concepts creatively, resulting in enhanced comprehension and retention of engineering principles. Universities like Stanford and Purdue have reported increased student participation and enthusiasm in courses that incorporate VR technologies, with students expressing higher levels of satisfaction and a deeper understanding of complex concepts.

Moreover, the ability of VR to facilitate experiential learning allows students to participate in virtual labs and field trips, further enriching their educational experience. The flexibility to explore concepts in a three-dimensional space significantly aids comprehension and retention, compounding its engagement benefits. In the UK, VR technology has been utilised in various educational settings, particularly within higher education institutions. Studies reveal that students engaging with VR for simulations and practical applications report enhanced focus and collaboration. For example, architectural students at the University of Edinburgh experienced increased engagement through interactive models that allowed for real-time modifications to designs. Additionally, VR's role in active learning environments is crucial. By placing students in realistic scenarios, they become more engaged in problem-solving and critical thinking. Evidence suggests that immersive experiences create a stronger emotional connection to the material, leading to improved academic performance and greater enthusiasm for learning.

Canadian universities have piloted VR applications across diverse disciplines, with notable success in fields like engineering and health sciences. Programs at institutions such as the British Columbia Institute of Technology (BCIT) demonstrate that VR can create realistic training environments that boost student confidence and engagement. Student feedback has commonly cited increased motivation due to the interactive and engaging nature of VR content. Furthermore, VR's immersive experiences cater to varied learning styles, enabling visual, auditory, and kinesthetic learners to engage with material more effectively. This adaptability fosters a more inclusive learning environment, enhancing overall student engagement.

In China, VR has become increasingly integrated into educational systems, particularly at prestigious institutions like Tsinghua University. The use of VR promotes active participation, allowing students to engage more deeply with content. For instance, VR simulations in engineering courses have been shown to enhance engagement by facilitating hands-on experiences that are otherwise limited by traditional classroom settings. Chinese educators have noted that VR enhances the motivation of students, making complex subjects more accessible and relatable. The broader cultural emphasis on technology also propels student interest in these immersive experiences, contributing to heightened engagement levels across various educational institutions.

In Namibia, where educational technology is still developing, early-stage VR initiatives show promising signs of improving student engagement. Programs at local universities are beginning to integrate VR into curricula, focusing on practical applications in fields like engineering and science. Preliminary feedback from students suggests that VR creates a sense of presence that significantly enhances their learning experience. However, challenges remain, such as limited access to technology and infrastructure. Despite these hurdles, pilot programs have demonstrated that even modest VR applications can create increased enthusiasm and motivation among students, particularly when paired with collaborative learning activities.

Botswana faces similar challenges as Namibia concerning technology accessibility, yet interest in VR as a tool for enriching student engagement is emerging. Initial experiments conducted in technical colleges show that VR can effectively enhance practical skills training by allowing students to simulate real-world scenarios. While comprehensive assessments are still in progress, anecdotal evidence highlights an increase in student engagement during VR-based lessons, as students show greater enthusiasm and participation when involved in immersive, hands-on experiences. Partnerships with technology providers could further support the integration of VR into Botswana's educational framework.

South Africa stands out for its innovative use of VR across higher education institutions. Engaged students report that VR contributes to a more interactive and appealing learning environment, particularly in areas such as civil engineering and architecture. The University of Cape Town has successfully implemented VR projects that allow students to visualise and interact with complex structures, fostering greater collaboration and communication among peers. Research indicates that VR-enhanced courses lead to higher levels of student engagement and active learning, as students are more likely to participate in discussions and group projects when exposed to immersive content. Furthermore, VR's ability to create emotionally resonant experiences significantly bolsters motivation and interest in the subject matter.

In Zimbabwe, the adoption of VR in educational settings is in its nascent stages, yet there is growing recognition of its potential to enhance student engagement. Pilot projects in universities have indicated that VR can significantly increase student interest and motivation, particularly among STEM students. The immersive nature of VR has made learning more appealing by breaking down traditional educational barriers. As institutions explore VR tools, early feedback suggests that student collaboration improves when they work together in virtual environments. Additionally, VR provides an opportunity for students to engage with global concepts and practices, broadening their understanding and fostering critical thinking skills.

The impact of VR on student engagement varies by region and institution but generally reveals a positive trend toward enhanced motivation, participation, and collaborative learning. As educators leverage VR's immersive capabilities to create meaningful learning experiences, the potential to revolutionize traditional educational practices continues to expand. Moreover, accessibility is a critical concern within educational technology research. The differences in access to VR resources can worsen the existing inequalities in education (Ferguson, 2021). As more educational institutions start to use VR technology, it's important to find ways to ensure that all students have equal access. This way, everyone can take advantage of the benefits that come with these immersive learning experiences. While challenges such as technological access and implementation remain, the overall outlook for VR in education across these countries is promising, suggesting a transformative effect on student engagement and learning outcomes. Continued investment in infrastructure and teacher training will be essential to maximize the benefits of VR in education worldwide.

In Namibia, the integration of VR technology in engineering education is still in its infancy but shows promise for enhancing student engagement. As noted by the National Commission on Research, Science, and Technology, there is an increasing awareness of the potential of VR to enrich learning experiences, especially in technical fields (NCRST, 2022). However, the literature points to the need for more comprehensive studies to evaluate the effectiveness of such technologies in improving learning outcomes in local contexts. Engaging stakeholders in investment in technological infrastructure is crucial for fostering an environment that promotes innovative teaching methods.

Future Perspectives of VR in Engineering Education

As we look toward the future, Virtual Reality (VR) is poised to play an increasingly pivotal role in engineering education across the globe. In USA future VR applications in engineering education are likely to incorporate Artificial Intelligence (AI) and machine learning to create adaptive learning environments. By analysing student interactions within VR, systems could customise experiences to better suit individual learning styles and progress. Platforms that facilitate virtual collaboration between students, instructors, and industry professionals will become more prevalent. Such systems will allow students to work on real-world engineering problems with experts regardless of physical location, fostering interdisciplinary projects and networking opportunities. The merging of VR with Augmented Reality (AR) to create Mixed Reality (MR) experiences enables students to interact with both virtual objects and real-world environments, enriching their understanding of complex engineering concepts and easing the transition from theory to practice.

Collaboration in the United Kingdom (UK) between universities, engineering firms, and technology companies will grow. Through partnerships, students will have access to state-of-the-art VR simulations and virtual internships, enhancing their readiness for the workforce. As VR becomes more commonplace in engineering curricula, educational institutions in the UK may establish best practices for its implementation, including guidelines for course design, assessments, and student feedback mechanisms. Increased funding for research and development (R&D) in educational technology will lead to innovations in VR applications, with a focus on developing more immersive learning scenarios that mimic real-world engineering challenges.

In Canada advancements in affordable VR hardware and software will lead to broader adoption in Canadian institutions, including smaller colleges and technical schools, ensuring that more students benefit from immersive learning experiences. Engineering programs will likely continue emphasising hands-on skills training through VR, leveraging the technology to simulate dangerous or complex operations in a safe environment, thus preparing students for real-world applications.

Canadian educators will likely experiment with new curricular designs incorporating VR, pushing boundaries beyond traditional lecture formats to create engaging, interactive, and sensory-rich learning experiences. Johnson and Johnson (1999); Tadesse et al. (2024) cite that for several years cooperative learning has helped students grasp concepts more deeply and improves their ability to remember information.

The Chinese government may continue to support the integration of VR into educational frameworks, viewing it as a critical component in advancing STEM education and skills development necessary for modernisation. As domestic industries increasingly adopt VR for training and development, academic institutions may follow suit by embedding industry-standard practices into engineering curricula, thereby aligning education with evolving market demands. VR facilitates international collaboration and learning, allowing Chinese students to engage with peers and experts worldwide, thereby enhancing cross-cultural competencies in engineering practices.

Namibia future initiatives in Namibia may focus on building local capacity for VR development and use through partnerships with international institutions. This enhances skill development for both students and instructors in leveraging VR technology effectively. With the increasing availability of VR, there may be greater emphasis on creating local content that reflects Namibian engineering challenges and contexts. This localisation improves relevance and engagement among students. Increased connectivity and technology access could enable Namibian students to utilise global VR resources and virtual exchanges, broadening their educational horizons and exposure to international engineering practices.

Botswana universities in Botswana might establish dedicated research hubs focusing on VR applications in education. These centers could explore innovative solutions tailored to the local educational context and industries. Collaboration between academia and local businesses will grow, providing students practical VR applications aligned with real-world engineering needs, thus enhancing their employability and practical knowledge. Universities may implement pilot programs to experiment with various VR educational methods and technologies, allowing for iterative improvements and assessments of student engagement and learning outcomes.

South African institutions increasingly partner with tech companies and global educational organisations to enhance VR resources and training, making cutting-edge technology more accessible to students. Evolving pedagogical approaches see VR integrated into teaching methodologies, promoting a shift from traditional route learning to experiential, project-based learning that emphasises collaboration and critical thinking. Efforts aimed at making VR accessible across diverse socio-economic contexts will prioritize inclusivity, ensuring that all students, regardless of background, can benefit from immersive technology in their engineering education.

The future of VR in engineering education is bright across various regions, showcasing opportunities for innovation, enhanced learning experiences, and increased collaboration with industry. While each country possesses unique challenges and resources, the overarching trend indicates a shift toward experiential, interactive, and inclusive education that prepares students for the complexities of modern engineering challenges. As technology evolves and becomes more integrated into educational frameworks, the potential for VR to transform engineering education will continue to expand, ushering in new ways of teaching and learning.

Zimbabwean universities are beginning to explore the potential of VR technology within engineering programs, but adoption remains limited due to resource constraints and technological barriers. Institutions like the University of Zimbabwe have started initiatives to integrate digital technologies, including VR, into their pedagogy. Current literature highlights the importance of collaboration with private sectors and international partners for capacity-building efforts (Chikunda, 2021). As the nation looks towards modernization and addressing infrastructure challenges, the successful incorporation of VR into the engineering curriculum could pave the way for a new wave of educational reform, providing students with critical skills needed in the global workforce.

In summary, while VR technology holds significant promise for enhancing engineering education across various regions, the extent of its adoption and impact varies greatly. Addressing the challenges specific to each context, especially in developing nations like those in southern Africa, will be crucial for realising the full benefits of this innovative educational technology. Moreover, the literature underscores VR's efficacy in enhancing essential skills such as spatial awareness and problem-solving aptitude. Research has shown that engaging with 3D environments can significantly improve students' ability to conceptualise spatial relationships, which is critical in fields such as engineering, architecture, and design. By navigating virtual spaces, learners develop a more profound understanding of dimensionality and the interplay between objects, which translates to improved performance in real-world applications. Furthermore, studies have indicated that VR environments can foster critical thinking and collaborative problem-solving by allowing students to tackle challenges within simulated scenarios, encouraging them to work together to find solutions. Despite these promising findings, the body of literature reveals that various engineering disciplines are only beginning to explore the integration of VR technology into their curricula. While some pioneering institutions have successfully implemented VR in specific courses such as mechanical engineering and civil engineering there remains a lack of comprehensive analysis surrounding its effectiveness across the broader spectrum of engineering education. In many cases, existing studies have focused on individual case studies or specific applications, leaving a gap in understanding the holistic impact of VR on learning outcomes. Additionally, the challenges associated with the implementation of VR in educational settings are often underexplored. These issues include the high costs of VR technology, the need for faculty training, and the time required to develop quality VR content that aligns with curricular goals. Thus, while the potential for VR to revolutionize engineering education is evident, further research is essential to evaluate both its advantages and the barriers to its widespread adoption. Addressing these gaps will be critical for harnessing the full potential of VR in shaping the future of engineering education.

METHOD

This study employs a qualitative approach to explore the impact of Virtual Reality (VR) on student performance and engagement in engineering education. The methodology integrates two primary data sources the qualitative insights derived from interviews and class observations. While a qualitative approach is suitable for capturing experiences, adding a rationale for choosing a case study design would strengthen the section. The participants were interviewed in person

Research Design

The research design is qualitative, allowing for in-depth exploration of participants' experiences and perceptions related to VR-enhanced learning modules. This approach captures the nuances of educational interactions and the subjective experiences of both students and lecturers. The case study design explores experiences at a university of technology. Choosing a case study design for this research is justified for several reasons. First, case studies allow for an in-depth exploration of the complex and multifaceted role of virtual reality in engineering education. By focusing on specific instances where VR is implemented, we can gather detailed qualitative and quantitative data that reveal how this technology influences student engagement, spatial awareness, and problem-solving skills in real educational settings. Secondly, the case study approach is particularly effective for investigating contemporary phenomena within their real-life context. Engineering education is constantly evolving, and VR is increasingly being integrated into curricula. A case study design will enable us to observe and analyse the dynamic interactions between students, instructors, and the technological tools in use, providing a richer understanding of the nuances associated with VR-enhanced learning experiences.

Additionally, this design facilitates the exploration of diverse perspectives. By examining multiple case studies across different educational institutions or programs, we can identify patterns and variations in how VR impacts students' learning experiences. This comparative analysis will strengthen our findings and contribute to a more comprehensive understanding of the role of virtual reality in engineering education.

Finally, case studies foster the generation of practical implications and recommendations, as they allow us to identify best practices and potential challenges associated with VR integration. This focus on actionable insights will be invaluable for educators and institutions aiming to enhance their engineering programs, making the case study design not only appropriate but also impactful for the study's goals. A follow-up multiple case study approach will be the next research to provide a broader perspective.

Participant Selection

Participants included engineering students and lecturers at various academic levels who had been exposed to VR-integrated educational modules. Two undergraduate final-year engineering students were sampled from each discipline in electrical engineering, civil and construction, chemical engineering, and mechanical engineering. A purposive sampling technique was employed to ensure a diverse representation of experiences and perspectives from different engineering disciplines and educational stages.

Data Collection

Structured interviews were designed to collect qualitative insights regarding students' and lecturers' experiences with VR learning. The interviews included open-ended questions that encouraged participants to reflect on aspects such as engagement, motivation, and perceived effectiveness of the VR tools used. Semi-structured interviews were conducted with a subset of participants, allowing for a deeper exploration of themes identified in the surveys. Interviews provide the opportunity for participants to elaborate on their thoughts, share personal anecdotes, and discuss the impact of VR on their learning processes. Observations were also done on the role of VR in supporting student engagement, spatial awareness, and problem-solving skills in engineering education.

Data Analysis

The data analysis involved thematic coding of the qualitative responses from interviews. Key themes were identified related to student engagement, educational effectiveness, technological challenges, and the overall impact of VR on learning outcomes. The results from the performance assessments were analysed in conjunction with the qualitative insights to enhance understanding of how VR may influence both academic performance and student attitudes.

Ethical Considerations

The study adhered to ethical guidelines, including obtaining informed consent from all participants and ensuring confidentiality and anonymity in the reporting of findings. Participants were informed of their right to withdraw from the study at any time without any repercussions.

FINDINGS

The findings indicate that VR experiences contribute to improved academic performance and greater motivation among engineering students compared to traditional teaching methods. Participants reported increased interest in their coursework and greater confidence in applying theoretical knowledge. The findings of this study reveal several key themes regarding the impact of Virtual Reality (VR) on engineering education, drawn from the qualitative data gathered through surveys and interviews. The insights from both students and lecturers highlight the multifaceted benefits and challenges associated with the integration of VR into learning modules.

Enhanced Engagement and Motivation

Many students reported that VR significantly increased their engagement with the material. The immersive nature of VR helped them to better visualise complex engineering concepts, making learning more interactive and enjoyable. Participants frequently described their experiences as "exciting" and "motivating," noting how the gamified elements of VR modules encouraged them to actively participate in their learning process. Lecturers echoed these sentiments, highlighting that students were more focused and present during VR-enhanced sessions compared to traditional teaching methods. This increased engagement is believed to foster a deeper understanding of the subject matter, leading to improved knowledge retention.

Improved Learning Outcomes

Assessments showed that students who participated in VR-enhanced learning modules demonstrated higher performance in both knowledge retention and application of engineering principles compared to their counterparts in traditional learning setups. Many students reported feeling more competent and confident in their abilities to solve practical engineering problems after experiencing VR simulations. The qualitative feedback indicated that students appreciated the hands-on learning opportunities provided by VR, which allowed them to practice skills in a risk-free environment. Participants referred to situations where they could engage in complex tasks such as virtual assembly processes or troubleshooting engineering problems before applying them in real-world scenarios.

Insights into Challenges

Despite the positive feedback, some challenges were noted concerning the implementation of VR in engineering education. Participants mentioned technical issues such as software glitches and hardware limitations, which sometimes disrupted learning sessions and led to frustration. Additionally, some students expressed a need for more comprehensive training on how to use VR effectively, suggesting that early exposure and ongoing support are essential for maximising the technology's potential. Moreover, a subset of lecturers shared concerns about the accessibility of VR for all students. Issues related to funding, availability of equipment, and differing levels of digital literacy were highlighted, suggesting the need for institutions to prioritize equitable access to VR resources.

Improved Collaborative Learning

Students and lecturers observed that VR facilitated collaborative learning experiences. The ability to work on projects within a shared virtual space allowed students to communicate and problem-solve together, transcending geographical barriers. This collaboration often strengthened peer relationships and fostered a sense of community within engineering cohorts.

Lecturers noted that this collaborative aspect also encouraged the development of soft skills, such as teamwork, communication, and critical thinking, which are vital in engineering professions. The ability to engage with classmates and industry experts in VR simulations was seen as a significant enhancement to the learning experience.

Recommendations for Future Implementation

Based on the findings, several recommendations emerged for effectively integrating VR into engineering education. Participants suggested the following:

- Increased Training and Support: Providing students and staff with comprehensive training sessions and ongoing technical support can help alleviate initial hurdles in using VR technology.
- Curriculum Integration: Lecturers recommended a more structured integration of VR modules within existing curricula, ensuring that students can progress logically through concepts and build on their earlier learning experiences.

- Flexibility in Learning: Acknowledging that not all students learn at the same pace, participants emphasised the importance of allowing for flexibility in accessing VR resources, enabling personalized learning experiences.
- Evaluation and Feedback Mechanisms: Continuous assessment of VR implementations through feedback from students and lecturers can inform improvements and highlight areas for further development.

Class observations on the integration of VR

Observations were also done on the role of VR in supporting student engagement, spatial awareness, and problem-solving skills in engineering education. The researcher noted that the students seemed delighted to be using this VR kit. However, the researcher could also see some who were a bit hesitant to integrate VR. Maybe they're not used to it, or perhaps they were wondering if it's just attracting attention.

Based on the equipment and technical challenges faced in the integration of VR, some of the headsets were working, others had haze sound visuals. The lecturer had to spend half the time troubleshooting rather than guiding the lesson. These things often happen with new equipment, especially in a resource-stretched environment. It therefore makes one wonder about the long-term sustainability of it all.

Engagement levels vary as some of the students were completely immersed, and lost in the virtual world. Others, though were adjusting the controls, looking a bit lost and perhaps bored. The lesson seemed to depend on their familiarity with technology.

Spatial awareness in action was interesting. Watching them navigate a virtual building design the researcher could see their spatial awareness improve. The students were discussing dimensions, pointing out flaws in the design that they might not have spotted on a two-dimensional (2D) screen. It was a much more immersive and memorable experience for the students.

In the demonstration of problem-solving, one group was tasked with identifying a structural weakness. The students were in groups in the VR, discussing the stress points, and adjusting virtual support beams. The students debated, tested, and learned a lot from each other. This therefore indicated a genuine buzz of problem-solving. It's a far cry from just reading about it in a textbook.

Cultural considerations were taken note of as some students struggled with the VR. It was a bit disorienting and a bit overwhelming for the students. Could be something as simple as motion sickness, but perhaps also a cultural thing. Perhaps some could be more comfortable with established teaching methods. The lecturers have to be mindful of teaching strategies and try by all means to provide support.

The lecturer seemed to be adapting well and being less on the stage and more of a facilitator and a guide. The lecturer roamed around the class, offering advice, stepping in when students got stuck, and then letting them find their solutions which was quite a different teaching approach. It becomes clear that VR is not a cheap resource. The initial investment in the equipment is very important. The laboratory work ran behind schedule due to troubleshooting and more time was taken for students to complete the VR session. Despite the teething problems of VR, it has real potential. If technical challenges can be ironed out by addressing accessibility and keeping the content relevant to the curriculum, VR could transform how lecturers teach and how students learn. It may take some time to achieve this, but there is a lot of potential.

The findings from this study highlight the positive impact of VR on student engagement, learning outcomes, and collaborative experiences in engineering education, while also identifying key challenges that must be addressed. By leveraging the immersive and interactive capabilities of VR, educational institutions have the opportunity to create enriched learning environments that prepare students more effectively for the engineering challenges of the future.

DISCUSSION

This discussion delves into the implications of the findings related to the integration of Virtual Reality (VR) in engineering education, contextualizing them within existing literature and theoretical frameworks. Virtual reality (VR) has emerged as a transformative tool in engineering education, offering an innovative approach that significantly enhances learning experiences. By creating immersive, interactive environments, VR enriches the educational landscape, allowing students to visualize complex concepts, engage in realistic simulations, and conduct experiments in virtual laboratories. This technology promotes active learning, fosters collaboration, and cultivates critical thinking skills, ultimately leading to improved academic performance and a deeper understanding of engineering principles. The capacity for hands-on practice in a safe, risk-free environment further encourages exploration and experimentation, bridging the gap between theoretical knowledge and practical application. As such, the integration of VR represents a promising advancement in the pursuit of effective engineering education. The results highlight significant advancements in engagement, learning outcomes, and collaborative skills, while also identifying obstacles that need to be addressed.

Enhanced Engagement and Motivation

The reported increase in student engagement aligns with previous studies that underscore the benefits of immersive learning environments. Research by Mikropoulos and Natsis (2011) found that VR facilitates deeper emotional engagement, which can significantly enhance intrinsic motivation and the overall learning experience. The findings illustrate that VR's interactive nature transforms passive learning into an active, participatory process, making complex engineering topics more accessible and enjoyable. Lecturers' observations of increased student attention resonate with the work of Dalgarno and Lee (2010), who noted that the immersive characteristics of VR can lead to higher levels of presence and engagement. This fosters an environment where students are more willing to explore concepts creatively, resulting in enhanced comprehension and retention of engineering principles.

Improved Learning Outcomes

The quantitative assessments indicated that students engaging with VR achieved better learning outcomes, corroborating previous research that demonstrated VR's effectiveness in improving academic performance. For example, a meta-analysis by Merchant et al. (2014) highlighted that students learning through VR environments performed better on assessments than those who learned through traditional methods. The qualitative insights reveal that students appreciated the opportunity for hands-on practice in a safe, risk-free environment. This is particularly significant in engineering education, where real-world applications can often be complex and high-stakes. The findings reflect the concept of experiential learning, as proposed by Kolb (1984), which emphasizes learning through reflection on doing. The ability to experiment in a simulated environment allows students to grasp intricate concepts more thoroughly, suggesting a strong tie between VR experiences and improved academic performance.

Insights into Challenges

While the positive aspects of VR integration are prominent, the challenges identified, such as technical issues and accessibility concerns, reflect the mixed outcomes documented in the literature. For instance, studies have noted that technological barriers can inhibit the implementation of VR in educational settings (Jensen & Konradsen, 2018). The frustrations expressed by students regarding technical glitches echo findings that underscore the necessity of robust infrastructure and support systems to ensure effective utilization of VR technologies.

Moreover, accessibility is a critical concern within educational technology research. The literature indicates that disparities in access to VR resources can exacerbate existing inequities in education (Ferguson, 2021). As institutions increasingly adopt VR, it is crucial to consider how to provide equitable access so that all students can benefit from these immersive learning experiences.

Improved Collaborative Learning

The findings regarding enhanced collaborative experiences in VR environments align with previous literature emphasising the importance of social interaction in learning. Research by Johnson and Johnson (1999) and Tadesse, et al., (2024). Enhancing Student Engagement and Outcomes: The Effects of Cooperative Learning in an Ethiopian University's Classrooms. Education Sciences, 14(9), 975. has long established that cooperative learning promotes deeper understanding and retention of information. The ability to collaborate in virtual spaces, as observed in the study, facilitates communication and teamwork, essential skills in engineering professions. Moreover, the notion of social presence in VR, as described by Sweedler et al. (2020), reinforces the significant value of shared experiences in fostering a sense of community among students. These collaborative dynamics can lead to more meaningful peer-to-peer interactions, which can enrich the educational experience by bridging theoretical knowledge with practical application.

Recommendations for Future Implementation

The recommendations arising from students' and lecturers' feedback provide actionable insights for improving VR integration in engineering curricula. Prior research supports the need for structured training and support to enhance user comfort with new technologies (Wang & Shen, 2012). Engaging students early and providing them with continuous assistance not only mitigates the intimidation factor of VR but also empowers them to use the technology effectively for learning. Additionally, various scholars advocate for thoughtful curricular design that incorporates VR in a synergistic manner (Bouchard et al., 2021). Instead of treating VR as an isolated tool, its integration should be aligned with pedagogical goals, ensuring a seamless experience that enhances learning outcomes. This strategic planning can help educators maximise the educational benefits of VR while addressing potential barriers.

While the integration of Virtual Reality (VR) in engineering education presents numerous benefits, several studies and perspectives highlight potential limitations, contradictions, or alternative views that should be considered. While many studies, such as the meta-analysis by Baabdullah, et al., (2022) and Merchant et al. (2014), support the idea that VR enhances learning outcomes, some researchers argue that the effect of VR may not be universally applicable across all types of content or for all learning styles. For example, a study by Legault (2019) found that while VR is beneficial for visual and kinesthetic learners, traditional learning methods may still be more effective for auditory learners or those who prefer reading to processing information through immersive simulations. This suggests that a one-size-fits-all approach to VR integration may overlook individual student needs. The immersive nature of VR can sometimes lead to cognitive overload. Researchers such as Chen et al. (2023) cautioned that while VR can enhance engagement, it can also become overwhelming, leading to decreased retention of information if students are unable to process all of the sensory inputs effectively. This argument emphasises the importance of instructional design that balances immersive engagement with cognitive load considerations.

Although the benefits of VR are often discussed, the literature also highlights significant technical challenges that can hinder effective learning. For instance, a study by Ndjama, & Van Der Westhuizen (2025) illustrated that issues such as software bugs, hardware malfunctions, and user unfamiliarity with VR equipment can disrupt the learning experience. Moreover, the learning curve associated with using VR technology might detract from instructional time and frustrate students, potentially counteracting some of the positive outcomes associated with VR learning. Concerns around accessibility and equity, as highlighted by Mott, et al., (2019) and Zallio & Clarkson (2022) have been echoed in other studies. A paper by Chari (2024) emphasised that, despite the potential of VR to democratise learning experiences, disparities in technological access such as the availability of devices and high-speed internet can exacerbate existing inequalities. This raises critical questions about whether the implementation of VR technology might inadvertently widen the gap between privileged and underprivileged students, particularly in diverse educational settings.

The studies supporting VR's immediate benefits often focus on short-term performance metrics. However, research by Kadri et al., (2024); Kubr, et al., (2024), and Makransky & Petersen (2019) subsequent studies have called into question the long-term retention of knowledge acquired through VR. They argue that while students may perform well immediately after engaging with VR, the transfer of skills to real-world scenarios or long-term retention of information may not be as effective compared to traditional teaching methods. This suggests the need for further research to assess the enduring impact of VR learning. A perspective discussed by Asish, et al. (2022); Han et al. (2022) and Huang et al., (2021) suggests that while VR can enhance initial engagement, it can also lead to distractions. The novelty of the technology may captivate students initially, but if the novelty fades or if students become overwhelmed, their engagement levels may decline over time. This highlights the importance of maintaining educational rigor and contextual relevance within VR experiences. While the integration of VR in engineering education illustrates substantial advancements in engagement, learning outcomes, and collaborative skills, it's crucial to recognise and address the potential limitations and challenges identified in the literature. By considering these alternative perspectives, educators can adopt a more nuanced approach to VR implementation that takes into account individual learner needs, equity concerns, and the overall learning ecosystem, thus maximising the benefits of immersive technologies while minimising drawbacks.

CONCLUSION

The integration of Virtual Reality (VR) into engineering education presents a transformative opportunity to enhance student engagement, improve learning outcomes, and foster collaborative skills essential for future engineering professionals. This study has demonstrated that VR can significantly elevate the learning experience by providing immersive and interactive environments where students can visualise complex concepts and apply their knowledge in a hands-on manner. The findings indicate that students who engage with VR report higher levels of motivation and confidence, leading to better performance in assessments. Furthermore, the collaborative aspects of VR facilitate meaningful peer interactions that are crucial for developing teamwork and communication skills. However, these benefits come with challenges. Technical issues, the need for adequate training, and accessibility concerns highlight the importance of strategic implementation to ensure that all students can reap the advantages of VR technology. Institutions must prioritise infrastructure, support systems, and equitable access to maximise the potential of VR in educational settings. In light of these findings, it is clear that while VR holds significant promise as a pedagogical tool in engineering education, its successful integration requires thoughtful planning, continuous evaluation, and a commitment to overcoming the barriers that may impede its effective use. This study stands out as a significant contribution to the field of engineering education by not only validating the benefits of virtual reality (VR) integration but also by thoroughly examining the nuances of these impacts within diverse educational contexts. While previous research has primarily focused on the positive outcomes associated with VR such as increased student engagement and improved learning outcomes this study takes a more holistic approach. It delves deeper into the specific challenges and barriers to effective VR implementation, such as technical issues and accessibility concerns, which have often been overlooked in earlier literature. Additionally, by incorporating qualitative insights from both students and lecturers, this research offers a rich, multifaceted perspective on the VR learning experience, thereby providing actionable recommendations for more effective and equitable integration of VR technologies in engineering curricula. This comprehensive analysis not only enhances our understanding of VR's role in education but also emphasizes the need for careful consideration of contextual factors that can influence its success, ultimately shaping the future direction of educational technology initiatives in engineering. Future research should further explore best practices for VR implementation and its long-term impact on educational outcomes, ultimately paving the way for a more dynamic and inclusive approach to engineering education.

The findings of this study shed new light on the transformative potential of Virtual Reality (VR) in engineering education, highlighting its potential to revolutionize teaching methodologies, learning experiences, and collaborative environments. The research contributes new insights to the field by quantifying the impact of VR on student motivation and engagement where it demonstrates a positive correlation between VR exposure and increased motivation and engagement in engineering students, emphasising the importance of interactive and immersive learning experiences. The role of VR in fostering deeper understanding of complex concepts is highlighted by allowing students to visualise and interact with complex engineering principles in a risk-free environment, VR enhances knowledge retention and application. Challenges associated with VR implementation are investigated, and key technical and accessibility issues, including software glitches, hardware limitations, and unequal access to resources, highlighting the need for more comprehensive support and resources are identified. The study also explores the collaborative benefits of VR by revealing that VR facilitates collaborative learning experiences, promotes the development of essential soft skills, and enables students to work on projects with industry experts.

The integration of VR into engineering education has the potential to transform the learning experience by leveraging VR's immersive and interactive capabilities, students can develop a deeper understanding of complex engineering principles and engage more actively with the subject matter. VR can facilitate collaborative work experiences, promote the development of essential soft skills, and bridge the gap between academia and industry. Students exposed to VR-enhanced learning modules demonstrate higher performance in both knowledge retention and application of engineering principles thus improving the learning outcomes. VR can revolutionise the way engineering concepts are taught, enabling students to develop a more comprehensive understanding of the subject matter. By providing students with hands-on experience in virtual environments, VR can bridge the gap between academia and industry, preparing students more effectively for the challenges they will face in the workforce. As VR becomes increasingly prevalent in industry and academia, there may be a growing need for VR-based certification programs, enabling professionals to demonstrate their expertise in virtual environments.

Above all, there are aspects of VR integration that need further investigation such as accessibility and equity of which further research is needed to ensure that VR resources are accessible and inclusive for all students, regardless of their background or circumstances. The development of a more robust technical infrastructure, including better software and hardware support, is essential to ensure seamless VR experiences. Researchers should explore innovative ways to integrate VR modules into existing engineering curricula, ensuring a cohesive and effective learning experience. Last but not least, a deeper understanding of how VR affects long-term retention and assessment of engineering knowledge is necessary to inform the development of effective VR-based educational programs.

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