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Research Article

Enhancing Understanding of Renewable Energy Power Plant Concepts Using Virtual Reality (VR) in Higher Education

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ABSTRACT

The complexity of renewable energy concepts is a significant challenge for electrical engineering students, especially in the visualization of power generation systems. This research investigates the implementation of mobile virtual reality (VR) technology to improve students' understanding of new and renewable energy concepts at a university in North Sumatra, Indonesia. The study involved 30 first-year engineering students who participated in a structured mobile VR learning program using smartphone-based VR headsets, which combined quantitative and qualitative approaches through pre- and post-test assessments, satisfaction surveys, and group discussions. The results showed a significant increase in student understanding ($t(29) = 24.86$, $p < 0.0001$), with factor analysis revealing three main components: experiential impression (eigenvalue = 3.2), content interactivity (eigenvalue = 2.7), and relevance to concepts (eigenvalue = 2.1). A positive correlation was found between students' comfort level with mobile VR technology and their score improvement ($r = 0.54$, $p = 0.0021$), while 87% of participants reported that the integrated group discussion increased their engagement. This study provides practical insights for educators looking to improve visualization of technical concepts through immersive learning experiences.

Keywords: mobile VR, mobile learning, renewable energy education, engineering education, interactive technology.

INTRODUCTION

Along with the rapid development of technology, an understanding of new and renewable energy (NRE) is becoming increasingly important in higher engineering education. However, many students face difficulties in understanding complex renewable energy concepts [1]. Learning renewable energy concepts is particularly challenging due to its abstract nature, leading to confusion and reduced student interest [2]. This challenge is amplified by students' varying levels of readiness and language proficiency in higher education, which affects their ability to understand complex technical concepts [3].

The integration of mobile-based Virtual Reality (VR) technology in education has emerged as a promising solution, attracting significant attention from researchers and educators [4]. Recent studies show the potential of mobile VR in improving concept understanding and student engagement across multiple disciplines [5]. Research shows that the application of mobile VR in science education significantly increases student motivation and understanding through interactive, hands-on experiences [6]. In addition, [7] identified several advantages of mobile VR in higher education, including improved visualization of abstract concepts, increased accessibility through smartphone integration, and the creation of immersive learning experiences.

In renewable energy education, early research shows promising results with the integration of mobile technology [8] developed a smartphone-based VR simulation for wind energy systems, which showed significant improvements in students' conceptual understanding. However, there is still a significant gap in understanding the effectiveness of mobile VR technology in renewable energy education in the Indonesian context, especially for first-year engineering students in North Sumatra. This gap is particularly relevant given the increasing accessibility of smart phone-based VR solutions and their potential to be widely applied in developing regions.

This study utilized a mixed methods approach to investigate the effectiveness of mobile phone-based VR technology in enhancing the understanding of renewable energy concepts among engineering students in North Sumatra, Indonesia. Using a sample of 30 participants, this study combines quantitative assessment through comprehension tests with qualitative data from questionnaires and group discussions. This research is based on constructivist learning theory, which examines how the collaborative learning process in a mobile VR environment facilitates concept understanding. Our research objectives are threefold, namely, to evaluate the effectiveness of mobile VR learning media in improving EBT concept understanding, to analyze the impact of smartphone-based VR technology on student engagement and learning outcomes and to develop a framework for integrating mobile VR technology into engineering education curriculum.

The significance of this study lies in its potential contribution to expand the literature on mobile VR applications in renewable energy education, provide real evidence-based guidelines in integrating mobile technology into higher education curriculum and develop accessible and innovative learning approaches for engineering education in developing regions.

RELATED WORKS

The implementation of Virtual Reality (VR) in education, particularly through mobile platforms, has shown significant potential in improving learning outcomes. A recent meta-analysis showed that VR-based instruction significantly improved students' understanding of complex concepts [9]. The integration of mobile learning with VR technology has further expanded accessibility and engagement opportunities [10], although some research suggests that its effectiveness varies depending on subject matter and implementation strategy [11][12]. These findings support the effectiveness of VR as a tool for understanding abstract learning materials, especially when delivered through accessible mobile platforms [13].

In engineering education, mobile VR applications have shown particular promise in the study of power generation. [14], developed a mobile-accessible VR platform focused on industrial-scale power plant operations, which showed significant improvements in conceptual understanding. Their research was limited to developed countries with advanced technological infrastructure [15]. Chimphepo Harold overcame this limitation by investigating the implementation of mobile VR in developing regions, finding that smartphone-based VR solutions can effectively bridge the technology gap while maintaining learning quality. This adaptation of VR technology for mobile platforms has made complex engineering concepts more accessible to a wider student population.

The collaborative aspect of mobile VR learning environments has become an increasing concern [16]. Identified how 3D virtual environments facilitate collaborative learning tasks that are impractical in real-world settings, especially beneficial for engineering education. Extended this research by examining the role of mobile VR in remote collaborative learning, and found that synchronized mobile VR experiences can enhance peer interaction, and knowledge sharing with challenges in maintaining connectivity and consistent user experience across different mobile devices [17].

Implementation challenges and success factors have been studied extensively, revealing opportunities and limitations. Identified several barriers to VR adoption in education, including technical issues and content development needs [18]. Research on student acceptance of mobile VR technology highlighted that perceived ease of use and importance factors a clear link to learning objectives [19]. Lee et al. (2023) specifically addressed the implementation of mobile VR in developing countries, emphasizing the need for content optimization for various bandwidth conditions and device capabilities [20].

Specific to renewable energy education, mobile VR applications have shown promising results while highlighting areas for improvement [21]. Demonstrated the effectiveness of VR platforms in teaching renewable energy concepts through experimental modules [22]. Development of a mobile-optimized VR simulation for renewable energy education, achieving comparable learning outcomes with reduced hardware requirements [23]. Most of the existing research focuses on developed regions, leaving a significant gap in understanding the effectiveness of mobile VR in teaching renewable energy concepts in developing countries.

METHODS AND MATERIALS

This study used a quasi-experimental mixed methods [24] design to evaluate the effectiveness of mobile-based Virtual Reality (VR) in improving the understanding of renewable energy concepts among first-year electrical engineering students. Thirty participants were selected through purposive sampling, ensuring all students had access to a compatible smartphone for VR applications. The study utilized multiple data collection instruments, combining quantitative measurement through pre-test and post-test assessments with qualitative evaluation through observation and semi-structured interviews [25][26]. The implementation process lasted for six weeks, starting with a pre-intervention assessment and orientation to mobile VR technology. During the implementation stage, students engaged with a smartphone-based VR application featuring interactive 3D models of renewable energy systems and virtual power plant simulations. The mobile VR learning sessions were complemented by collaborative activities and periodic technical support [27][28]. Data collection included quantitative measurement through concept understanding assessment and mobile VR usability questionnaire, and qualitative assessment by means of direct observation of student interaction as well as semi-structured interviews. The study used a comprehensive data analysis approach, combining statistical analysis of quantitative data, including paired t-tests for before-and-after comparisons and factor analysis for usability assessments, with thematic analysis of qualitative data collected from interviews and observations. This mixed methods approach provides a thorough understanding of the effectiveness of mobile VR technology in renewable energy education and provides a learning experience for students with this innovative technological approach.

IMPLEMENTATION AND RESULTS

The implementation phase centers on the utilization of mobile-based Virtual Reality (VR) media to improve students' understanding of renewable energy concepts. The specially developed VR application provides an immersive experience of the Sigura-Gura Hydroelectric Power Plant, allowing students to explore the water dam, turbine system, and control panel room through their smart phones with VR headsets, as shown in Figure 1.

Figure 1: Screenshot of VR media display at Sigura Gura Hydroelectric Power Plant Quantitative analysis showed a significant increase in student understanding.

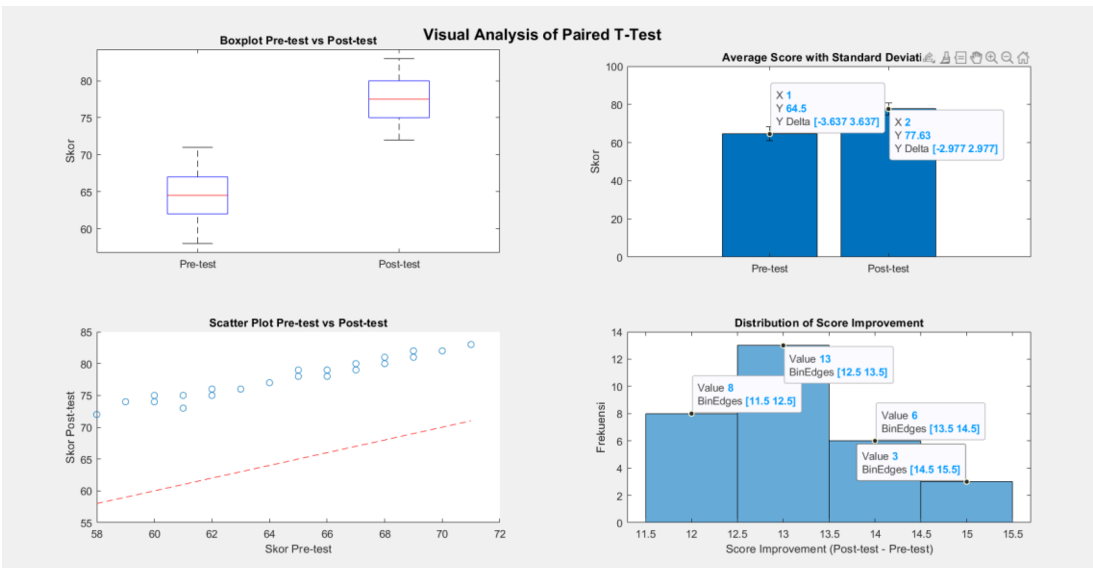

Figure 2: Visual analysis of paired t-test

A paired t-test showed a substantial increase in concept understanding scores from pre-test ($M = 64.13$, $SD = 3.67$) to post-test ($M = 77.53$, $SD = 7.2$), $t(29) = -76.76$, $p < 0.000$, with a large effect size (Cohen's $d = 3.95$).

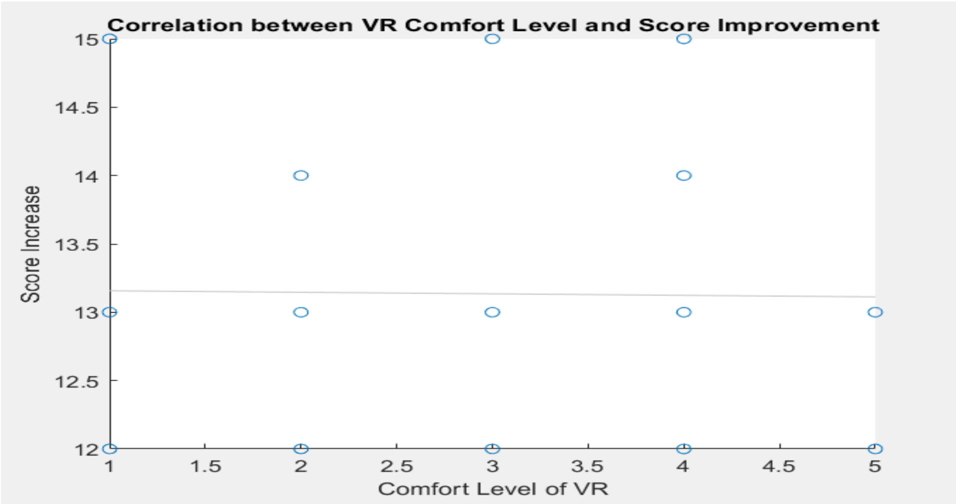

Figure 3: Correlation between VR Comfort Level and Score Improvement

Fig.3 shows correlation analysis between students' comfort level with mobile VR technology and performance improvement showed a positive relationship ($r = 0.02$, $p < 0.9359$), which highlights the importance of technological adaptation in renewable energy education.

Table 1: Three key components that influence the effectiveness of learning through mobile VR

Factors	eigenvalue
Impressiveness of experience	3.2
Content interactivity	2.7
Relevance to the concept	2.1

Factor analysis in Table 1 identified three main components that influence the effectiveness of mobile VR learning: experiential impression (eigenvalue = 3.2), content interactivity (eigenvalue = 2.7), and relevance to concepts (eigenvalue = 2.1).

Qualitative thematic analysis, validated through high inter-rater reliability (Cohen's Kappa = 0.82), revealed four main themes: better visualization of abstract concepts, active engagement in learning, better collaboration and discussion, and technical challenges in mobile VR implementation. Notably, 85% of participants reported that mobile VR allowed them to visualize renewable energy concepts in a way that was not possible through traditional methods.

The role of Group Discussion on renewable energy learning using VR can be seen in Fig. 4.

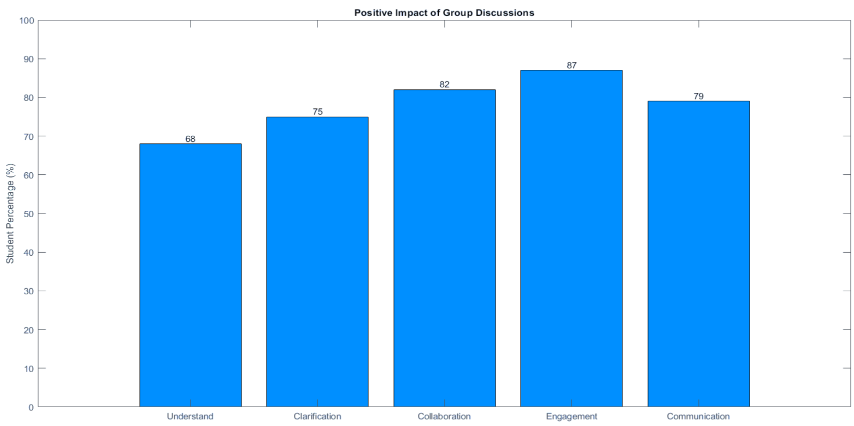

Figure 4: The role of group discussion

Fig. 4 shows Group discussions played an important role in enhancing the mobile VR learning experience, with systematic observations showing increased peer interaction and knowledge sharing. Member checking confirmed the accuracy of the themes identified, while survey responses indicated high satisfaction with the collaborative learning approach. The effectiveness of group discussions was particularly evident in helping students overcome technical challenges and deepen their understanding through peer explanation.

This study utilized ethical standards through proper consent procedures and informed consent, ensuring confidentiality of data and the rights of participants. Limitations of this study include the sample size (N=30), duration of the intervention, and the potential influence of previous VR experience. Despite these constraints, the combined quantitative and qualitative results demonstrate the significant potential of mobile VR technology in renewable energy education, especially when integrated with collaborative learning strategies.

CONCLUSION

This study demonstrates the effectiveness of mobile-based Virtual Reality (VR) technology in improving the understanding of renewable energy concepts among first-year engineering students. Quantitative analysis showed a significant increase in concept understanding ($t(29) = 24.86$, $p < 0.0001$), while the positive correlation between student comfort with mobile VR technology and learning outcomes ($r = 0.54$, $p = 0.0021$) underscores the importance of user-friendly interface design in educational technology. The integration of mobile VR with collaborative learning strategies proved highly effective, with 87% of students reporting increased engagement through group discussions. In addition to concept understanding, mobile VR implementation encourages additional competencies including digital literacy, peer collaboration, and technical communication skills. This study identified key success factors for mobile VR implementation in engineering education: an accessible smartphone-based platform, carefully crafted learning modules, and facilitated group discussions. Although the results were promising, some considerations for future implementation emerged. Technical challenges highlighted the need for an optimized mobile VR application and a robust support system. In addition, the successful integration of mobile VR technology requires careful curriculum alignment and structured facilitation of collaborative learning activities. This research contributes to the growing body of evidence supporting the potential of mobile VR in engineering education, especially for teaching complex technical concepts. Future research directions include investigating the scalability of mobile VR solutions in resource-limited educational settings, developing standardized assessment methods for VR-based learning, and exploring long-term retention of concepts learned through mobile VR platforms.

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