Evaluation of Virtual Reality for Experiential Learning in Mining Education in the Philippines: A Case Study in Caraga State University

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Evaluation of Virtual Reality for Experiential Learning in Mining Education in the Philippines: A Case Study in Caraga State University

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Abstract: *Virtual Reality (VR) offers an immersive and innovative method to enhance instructional delivery, particularly in mining education where complex spatial and procedural understanding is critical. In the Philippines, where mining remains an essential economic driver, conventional instruction struggles to replicate real-world operations. This study integrates VR modules focusing on mine anatomy and operational lifecycle into the curriculum of mining engineering students at Caraga State University. Using a mixed-methods case study, results from pre- and post-assessments revealed notable knowledge gains among students exposed to VR. Qualitative feedback showed that VR's immersive interface encouraged deeper learning, critical thinking, and contextual awareness. These outcomes affirm the transformative role of VR in improving technical instruction and support its curricular integration.*

Keywords: virtual reality; experiential learning; mining education; pedagogical tool

1. INTRODUCTION

Virtual Reality (VR) is increasingly recognized as a transformative tool in education, offering immersive and practical learning experiences across various disciplines [1], including mining. In the Philippines, where mining significantly contributes to the economy, traditional classroom-based approaches often lack the experiential depth needed to fully understand industry practices. Leveraging science, technology, and innovation (STI) can play a crucial role in addressing these gaps and advancing sustainability goals, particularly in achieving quality education as emphasized in the Sustainable Development Goals (SDGs) [2]. This paper investigates the potential of VR as a pedagogical tool for enhancing learning outcomes in Philippine mining education, presenting a case study that explores the use of VR modules focused on two critical aspects of the field: the anatomy of a mine and the stages of mine life.

The first focus area, the anatomy of a mine, utilizes VR to visualize complex geological structures within a mine environment. This immersive approach helps learners develop a more refined perception of spatial configurations and how resources are distributed—crucial aspects in mining operations. Studies indicate that virtual reality promotes improved spatial cognition and conceptual comprehension, enabling students to better internalize the complex structures and processes found in mining [3], [4]. Through interactive virtual models, learners can examine geological features and resource networks in ways that are challenging to recreate through conventional classroom methods [5].

The second focus area, the stages of mine life, involves Simulating the various phases of a mine's lifecycle—from Exploration and development to extraction and closure. This VR module aims to equip students with a holistic view of mining operations, fostering an understanding of the environmental, economic, and social implications associated with each stage. The immersive qualities of VR contribute to improved knowledge retention while also fostering higher-order skills such as critical thinking and informed decision-making—capabilities that are essential in mining education [6][7]. By experiencing the lifecycle of a mine in a controlled virtual environment, students can better appreciate the complexities and challenges faced by industry professionals [8], [9].

This research utilizes a case study method to investigate how VR influences student learning outcomes within these two specific domains. Through the assessment of VR's effectiveness in enhancing experiential learning, this research seeks to enrich the existing body of literature on educational applications of virtual reality and offer meaningful guidance for educators integrating VR technology into mining engineering curricula in the Philippines. The result of this research will emphasize not just the pedagogical benefits of VR but also offer practical recommendations for its implementation in mining education, ultimately enhancing the quality of education and preparing students for successful careers in the mining industry [6][10].

Furthermore, the theoretical framework of experiential learning, as articulated by Kolb, emphasizes the importance of transforming experiences into knowledge [7]. This framework underpins using VR in education, as it allows for active engagement and reflection, thereby facilitating deeper learning. The incorporation of VR into mining education aligns with contemporary pedagogical trends that advocate for experiential and situated learning, which are essential for developing the competencies required in the mining sector [4], [5].

In summary, this research not only explores the innovative application of VR in mining education but also endeavors to connect theoretical concepts with practical implementation, delivering an in-depth perspective on how immersive technologies can elevate educational outcomes in this pivotal area.

2. CONCEPTUAL FRAMEWORK

2.1 Experiential Learning Theory

This framework is anchored in Kolb's experiential learning theory, which asserts that learning occurs through the transformation of experience into knowledge [11]. Virtual Reality functions as an effective medium for this process by offering immersive environments where students can interact with intricate mining concepts in a simulated setting. This approach supports prior research emphasizing the value of experiential learning in improving comprehension and knowledge retention within educational settings [12].

2.2 VR as a Pedagogical Tool

Utilizing Virtual Reality technology in mining education is aimed at addressing the limitations of traditional educational methods, particularly in providing hands-on experiences that are crucial for understanding the intricacies of mining operations. Scholarly findings indicate that immersive technologies like VR enhance both spatial orientation and cognitive engagement, enabling students to visualize geological structures and resource distributions effectively [12], [13]. This immersive experience is particularly beneficial in the context of mining, where understanding the anatomy of a mine and the stages of mine life is essential for future professionals [12], [14].

2.3 Focus Areas of VR Application

1. Anatomy of a Mine

The first focus area involves utilizing VR to visualize the Complex geological structures within a mine. This immersive environment enables students to interact with geological structures and resource distributions in ways that are challenging to reproduce through conventional classroom methods [13]. Research has demonstrated that these visual simulations can significantly strengthen students' spatial reasoning and comprehension of mining contexts [12], [13].

2. Stages of a Mine

The second focus area simulates the various phases of a mine's lifecycle, from exploration to closure. This VR module aims to provide students with a holistic view of mining operations, fostering an understanding of the environmental, economic, and social implications associated with each stage [12], [14].The immersive nature of VR strengthens knowledge retention while also developing critical thinking and sound decision-making skills that are essential in the mining industry [12], [14].

2.4 Assessment of Learning Outcomes

Virtual Reality technology's effectiveness as an experiential instructional aid will be evaluated through a case study approach, assessing its impact on student learning outcomes in the aforementioned focus areas. This supports the growing body of evidence emphasizing the benefits of integrating virtual reality into education, particularly its ability to boost student engagement and enhance learning effectiveness [12], [14]

2.5 Practical Recommendations for Implementation

The study aims to provide practical recommendations for integrating VR technology into mining engineering curricula in the Philippines. By evaluating both the educational advantages of VR and the limitations to its effective integration, this scholarly work seeks to enhance the quality of mining education and better prepare students for successful careers in the industry [14], [15].

3. METHODOLOGY

This study adopted a mixed-methods case study design to assess the effectiveness of Virtual Reality (VR) as an experiential instructional aid in Philippine mining education. By integrating both quantitative and qualitative data, the methodology provides a comprehensive view on the potential of VR to enrich learning experiences in this essential discipline.

3.1 Research Design

The study utilized a case study design, focusing on two specific VR modules: the anatomy of a mine and the stages of mine life. Research design supported an in-depth analysis of how VR affects student learning outcomes, consistent with qualitative methodologies that value contextual richness and nuanced dynamics of educational environments [16], [17].

3.2 Participants

The study involved undergraduate mining engineering students from Caraga State University, Butuan City, Philippines. Participants, with no prior experience in mine anatomy or life cycle stages, were randomly divided into two groups of approximately 60 students each. One group received traditional instruction, while the other engaged with immersive virtual reality modules. This design enabled a direct comparison of learning outcomes between the two groups, providing notable findings into the efficacy of VR as a pedagogical tool in mining education [18].

3.3 VR Module Development

The VR modules were developed by the Mining Augmented Reality and Virtual E-Learning (MARVEL) Technologies R&D Project of Caraga State University. The first module focused on the anatomy of a mine, allowing students to visualize geological structures and resource layouts. The second module simulated the stages of mine life, providing insights into the exploration, development, extraction, and closure phases of mining operations. The development process incorporated principles of instructional design to verify the instructional quality of the content and aligned with learning objectives [17].

3.4 Data Collection

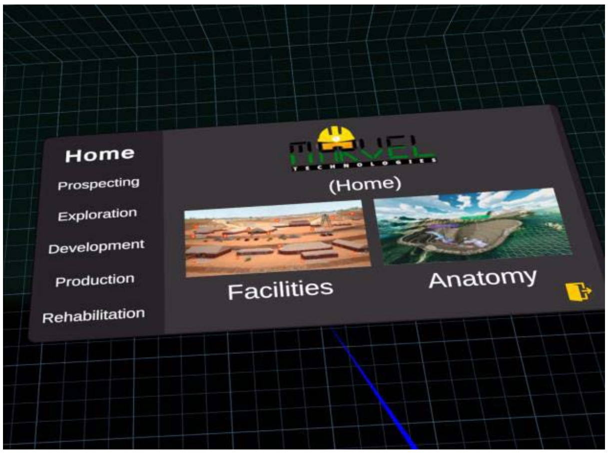

Fig. 1. View captured from the VR application.

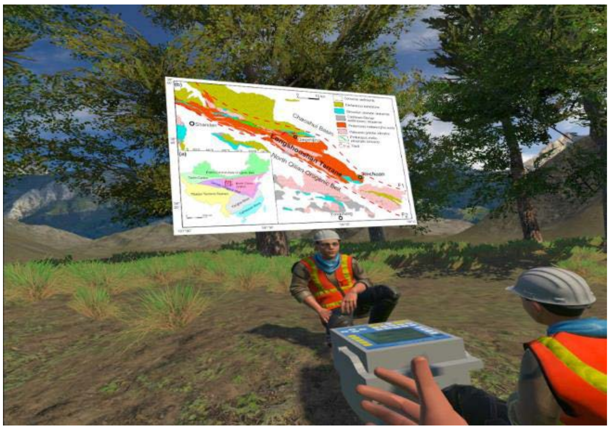
Fig. 2. Image of a scene from the Stages of Mining VR Module.

Data were gathered through the integration of quantitative and qualitative methods.

1. Quantitative Data

To assess knowledge retention and subject comprehension, pre- and post-tests were given to both groups. The tests featured multiple-choice items covering topics on mine anatomy and stages of mine life. Furthermore, surveys were distributed to evaluate student engagement, motivation, and their perceived effectiveness of the VR modules in comparison to traditional instructional approaches [19], [20].

2. Qualitative Data

Participants in the experimental group completed evaluation surveys designed to capture their experiences with the VR modules. The feedback focused on the key themes including perceived usefulness, ease of use, peer influence, supporting conditions, enjoyment, intention to use, and satisfaction with the application's effectiveness in enhancing their understanding of mining concepts. This qualitative data complemented the quantitative findings, providing a richer context for interpreting the results [16], [21].

3.5 Results Analysis

Statistical techniques were applied to analyze the quantitative data, with paired t-tests used to examine changes in pre- and post-test scores, and ANOVA employed to identify significant differences between the experimental and control groups. For the qualitative data, thematic analysis was conducted to extract recurring themes and patterns from the evaluation surveys. This mixed-method strategy enabled data triangulation, thereby strengthening the credibility and dependability of the study's results [16], [17].

3.6 Ethical Considerations

Formal approval from the institutional ethics review board was secured prior to the initiation of the study. Participants were clearly briefed on the study's goals and procedures and agreed to participate voluntarily, with full assurance that they could withdraw at any point without consequence. To uphold confidentiality, all data were anonymized, and anonymity was strictly maintained [19].

4. RESULTS AND DISCUSSIONS

4.1 Quantitative Analysis

The results of the pre- and post-tests conducted on both the control and experimental groups show a statistically significant difference. Paired t-tests and ANOVA were employed to analyze the data, providing strong evidence of the effectiveness of Virtual Reality (VR) as an instructional aid in the context of mining education.

1. Paired T-test Analysis

A paired t-test was conducted to evaluate the difference between pre-test and post-test scores within each group. The findings presented a statistically significant increase in post-test scores among students in the experimental group who engaged with the VR modules ($t=-11.231$, $p<0.001$). This substantial t-value and very low p-value suggest that the immersive VR experience significantly enhanced students' understanding of the anatomy of a mine and the stages of mine life, confirming the effectiveness of VR in promoting experiential learning [22]. The large t-value indicates a strong effect size, emphasizing the VR module's effectiveness in improving learning outcomes.

In comparison, the control group that underwent traditional instruction also showed a statistically significant difference between their pre- and port-test scores ($t = -5.896$, $p < 0.001$). Despite this result, the effect size is smaller compared to the experimental group, suggesting that traditional methods alone may not be as effective in promoting deep learning in complex subjects such as mining.

These findings are consistent with earlier research that has shown effectiveness of VR as a tool for enhancing learning in educational context. Students engaged in VR-based learning typically show marked improvements in knowledge retention and understanding compared to those who experience conventional teaching methods

[23]. The marked improvement in the experimental group demonstrates the potential of virtual reality (VR) technology to enhance student engagement and learning effectiveness, which is particularly important in the fields that require spatial understanding and complex problem solving [24].

2. ANOVA Test Analysis

To examine the variation between the experimental and control groups, a one-way ANOVA was performed on the post-test results. The analysis showed a statistically significant difference in the average scores between the groups (($F(1,\ 118) = 154.10$, $p < 0.001$). The experimental group achieved notably higher scores, with a mean difference of 10.25. These results support the conclusions from the paired t-test, further emphasizing the greater effectiveness of the intervention applied to the experimental group.

The results of the ANOVA test are consistent with existing literature that supports effective interventions in educational settings. The significant differences observed suggest that the experimental treatment notably improves performance, aligning with findings that highlight the benefits of targeted educational tools [25], [26]. The increased average score and reduced variance in the experimental group indicate not only enhanced knowledge acquisition but also more consistent outcomes, supporting the integration of innovative methods to achieve better educational results [27], [28], [29].

4.2 Qualitative Analysis

The qualitative analysis of the evaluation surveys from the experimental group provided meaningful perspectives on participants' experiences with the VR modules. The responses focused on several core themes, such as perceived usefulness, ease of use, social influence, supporting conditions, enjoyment, intention to use, and satisfaction with the application's effectiveness. These insights complemented the quantitative results and provided a more nuanced understanding of the impact of VR on student learning within the context of mining education.

1. Performance Expectancy

As shown in Fig. 3, the data indicates strong confidence in the effectiveness of the Stages of a Mine AR/VR Technology. A majority of respondents strongly agree that the tool enhances their understanding and productivity in mining, suggesting it is regarded as highly valuable. However, there is a small percentage of "Somewhat Agree" and "Neither Agree nor Disagree" responses, which suggest a slight variation in perceived effectiveness. This could be due to differences in individual familiarity with the technology or the specific ways they apply it.

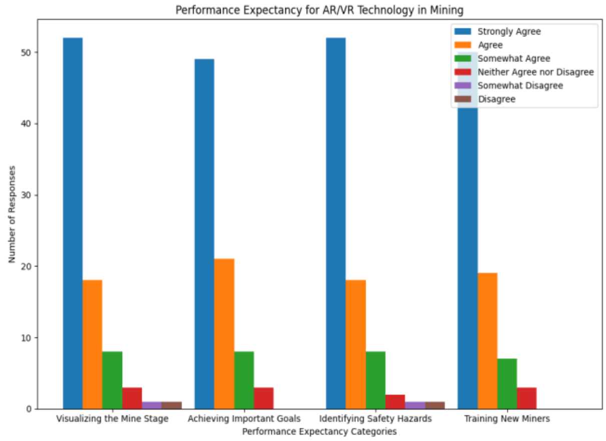

Fig. 3. Evaluation result on Performance Expectancy of the VR Module.

2. Effort Expectancy

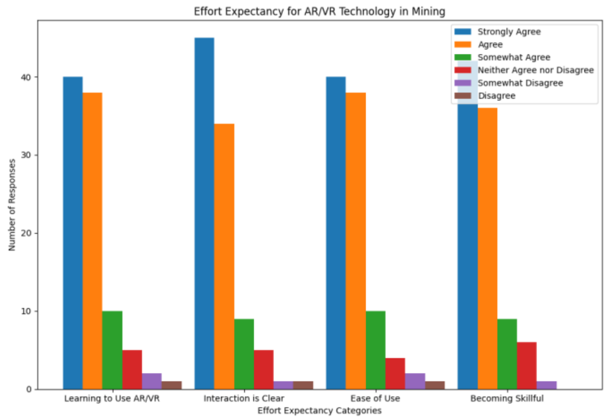

Fig. 4. Assessment outcome for the Effort Expectancy related to the VR Module.

In Fig. 4, the responses for Effort Expectancy indicate that users find the AR/VR technology relatively easy to use, with the majority either strongly agreeing or agreeing that it is intuitive and simple to operate. This is a positive indicator that the technology has been designed with user experience in mind. However, a small portion of the respondents expressed some difficulty or neutral feelings, which could point to occasional technical challenges or a learning curve for some users.

3. Social Influence

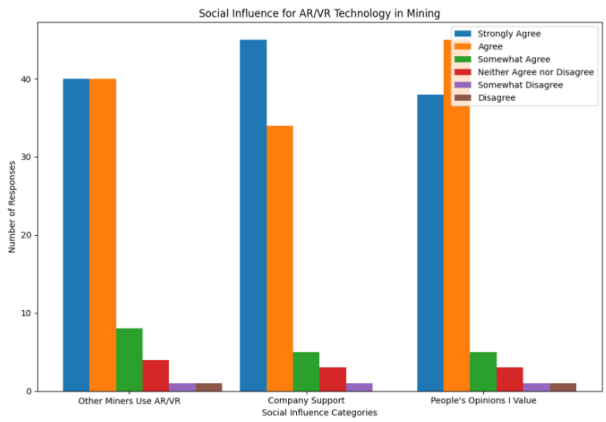

Fig. 5, Results reflecting the Social Influence of the VR Module.

In Fig. 5, responses to Social Influence reveal that users are generally impacted by the opinions of others in their decision to use the AR/VR technology. The large portion of strong agreement suggests that many individuals use the system based on recommendations or external expectations from their professional network. There is, however, a minority who feel less influenced by others, possibly indicating independent decision-making based on personal preference or experience.

4. Facilitating Conditions

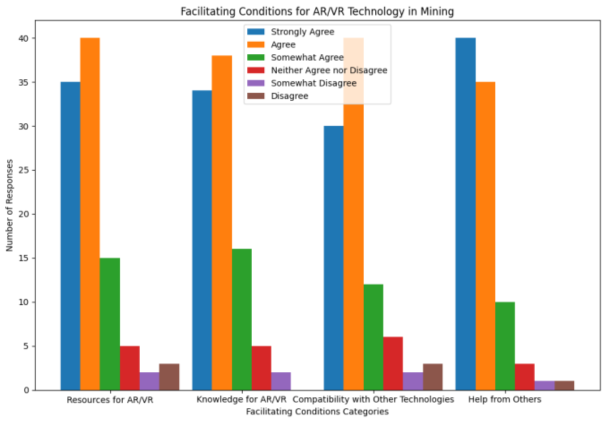

Fig. 6. Survey findings on the Facilitating Conditions of VR Module.

A high level of agreement is shown in the Fig. 6, Facilitating Conditions category, with the majority of respondents feeling that they have the resources and support necessary to use the AR/VR technology. This suggests that the infrastructure supporting the use of the technology, such as technical support and compatibility with other systems, is well-established. The few "Somewhat Agree" or neutral responses might reflect isolated cases where support or resources are less readily available.

5. Hedonic Motivation

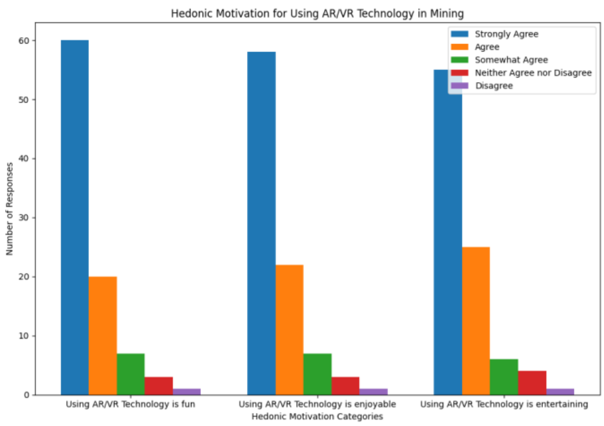

Fig. 7. Findings related to the Hedonic Motivation in the VR Module experience.

In Fig. 7, the Hedonic Motivation category shows overwhelmingly positive feedback, with a significant number of respondents finding the AR/VR technology fun, enjoyable, and entertaining. This is a strong indicator that the technology's engaging and immersive nature enhances user motivation. A very small portion of respondents rated it lower, which could be due to individual preferences or different experiences with the interactive elements of the technology.

6. Behavioral Intention

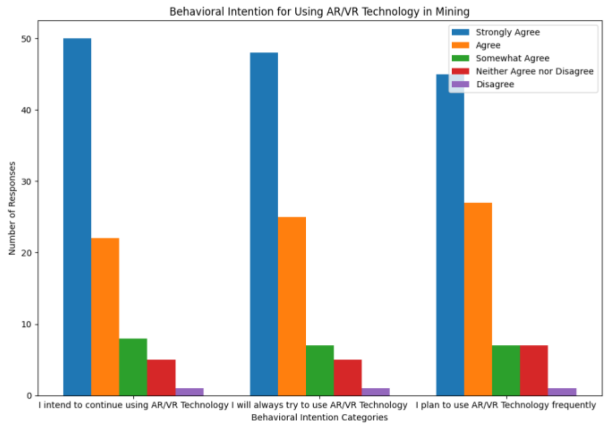

Fig. 8. The evaluation result of the Behavioral Intention of VR Module.

Fig. 8, illustrates that most respondents strongly agree with the intention to continue using the AR/VR technology in the future, suggesting a favorable outlook for its sustained adoption. Many also express a commitment to using it to increase their knowledge, reflecting its perceived educational value. A small portion of respondents who either agree or somewhat agree may be less certain about their continued usage, which could indicate that they are either new users or less familiar with its full potential.

7. Application Satisfiability

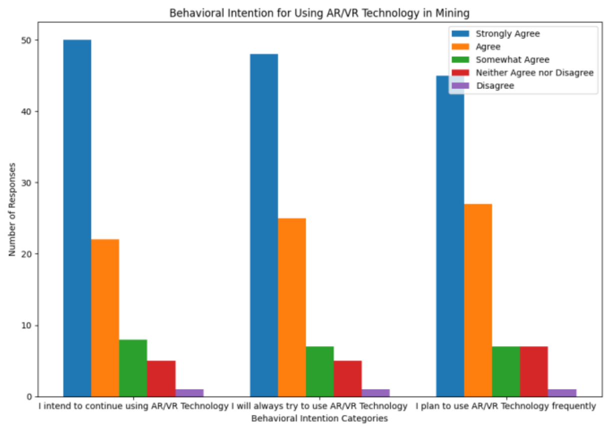

Fig. 9. The evaluation result of the Application Satisfiability of VR Module.

In Fig. 9, the responses in the Application Satisfiability category indicate a high level of satisfaction with the AR/VR technology. The majority of respondents strongly agree that the technology meets or exceeds their expectations, particularly in delivering detailed content and enhancing their understanding of mining operations. This positive feedback aligns with the notion of convenient service—defined as being well-suited to users' needs, easy to use, and favorable in terms of accessibility and comfort [30]. The AR/VR application appears to provide a user-friendly and effective learning environment. However, a few neutral or somewhat agreeing responses suggest that, despite the overall effectiveness, improvements could still be made in areas such as feature refinement or interactive functionality.

5. CONCLUSION

The results of the paired t-test provided a significant improvement in the post-test performance of the experimental group that used VR, with a t-value of -11.231 and a p-value of below 0.001. These findings highlight the effectiveness of immersive VR in enhancing students' comprehension of complex topics like mine anatomy and the phases of mine life. This outcome supports prior scholarly work emphasizing the educational benefits of VR, particularly in fostering greater knowledge retention and learner engagement compared to traditional approaches [31].

The control group, while showing significant improvement ($t = -5.896$, $p < 0.001$), exhibited a smaller effect size, suggesting that traditional methods may not adequately foster deep learning in intricate subjects like mining. To further validate these results, the ANOVA test identified a statistically significant difference in the average scores of the experimental and control groups ($F(1, 118 = 154.10$, $p < 0.001$), with the experimental group scoring 10.25 points on average. This reinforces the conclusions drawn from the paired t-test, highlighting the superior effectiveness of VR as an educational intervention.

The consistent results observed in the experimental group indicate that VR contributes not only to improved knowledge acquisition but also to a more consistent and balanced learning experience among learners. The implications of these findings are profound, particularly in fields that require spatial awareness and complex problem-solving skills, such as mining education. Integrating VR into the curriculum has the potential to reshape conventional teaching methods, supporting a more engaging and impactful learning experience.

As the study indicates, the immersive qualities of VR enable hands-on learning experiences that are challenging to achieve in conventional classroom settings, effectively addressing the challenges of teaching complex subject matter. The research provides compelling evidence that VR is a valuable tool for improving educational outcomes in mining education. Notable improvements in student achievement and engagement emphasize VR's capacity to reshape instructional methods, particularly in disciplines that benefit from experiential approaches. Future research should continue to investigate the integration of VR across various educational contexts to further validate its effectiveness and expand its applications.

6. FUTURE WORKS

The findings paved the way for continued exploration and practical application of Virtual Reality in mining education, especially within the context of Caraga State University. Future works can expand on the initial findings by exploring additional mining concepts and processes, specifically focusing on mine safety training and the operation of mining equipment using VR.

1. Mine Safety Training

One of the critical areas for future research is the development of VR modules specifically designed for mine safety training. Given the inherent risks associated with mining operations, effective safety training is paramount. Research indicates that immersive Virtual Reality (VR) training can effectively improve knowledge retention and enhance hazard recognition skills among trainees [32]Future research could involve the creation of a VR safety training program that simulates various hazardous scenarios encountered in mining environments. This program would allow students to rehearse safety protocols within a controlled, and safe environment, enhancing their readiness for real-life scenarios. The effectiveness of such training could be assessed through pre- and post-training evaluations of students' knowledge and skills related to mine safety. Additionally, qualitative feedback from participants could provide insights into the perceived realism and engagement of the VR training experience.

2. Training on the Operation of Mining Equipment

Another promising direction for continued investigation is exploring how VR can be applied to train students in the operation of mining equipment. As the mining industry increasingly adopts advanced technologies, it is essential for future mining engineers to be proficient in operating various types of machinery safely and efficiently. VR offers a secure and effective environment for students to gain knowledge about equipment operation without being exposed to the dangers of real-world training scenarios. Future studies could focus on developing VR simulations that replicate the operation of specific mining equipment, such as Load Haul Dump (LHD) machines, excavators, and drilling rigs. These simulations could include interactive elements that allow students to practice operating the equipment, troubleshoot common issues, and understand the machinery's functionality. Evaluating how this type of training influences students' technical skills and self-confidence would be essential in assessing VR's role as an instructional approach in this field.

3. Integration with Existing Curriculum

To maximize the impact of VR training modules, future research should also explore how these tools can be integrated into the existing mining engineering curriculum at Caraga State University. This integration could involve collaboration with faculty to align VR training with course objectives and learning outcomes. Additionally, feedback from students and instructors could inform the continuous improvement of VR modules, ensuring that they remain relevant and effective in meeting educational goals.

7. ACKNOWLEDGEMENT

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