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Implementation of Immersive Virtual Reality Games and Learning Engagement for Selected Mathematical Concepts among Middle School Students in Ganzhou City, China

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ABSTRACT: This study investigates the impact of immersive virtual reality (VR) on the learning engagement of students in selected mathematical concepts. A pretest-posttest design was employed to assess the cognitive, behavioral, and affective engagement levels of the respondents before and after the implementation of VR. The pretest results indicated moderate levels of engagement across all dimensions, with notable areas for improvement in attentiveness, collaborative skills, and satisfaction with progress. Following the implementation of immersive VR, significant improvements were observed in all engagement dimensions. Cognitive engagement scores increased, highlighting enhanced attention, understanding, and connection-making skills. Behavioral engagement saw improved participation, focus, and diligence in homework completion, although group collaboration remained an area needing further enhancement. Affective engagement improved as well, with students showing increased enjoyment, excitement, and emotional connection to math. The paired t-test analysis confirmed the statistical significance of these improvements, validating the effectiveness of VR in enhancing overall student engagement in mathematical learning. The study concludes that immersive VR is a powerful educational tool that can transform learning experiences, making them more interactive, engaging, and effective. Recommendations include continuing the use of VR to maintain high engagement levels, improving collaborative activities, and expanding VR integration to other subjects.

KEYWORDS: Virtual reality, Learning engagement, cognitive, behavioural, affective, engagement level

I. INTRODUCTION

The integration of immersive Virtual Reality (VR) games into educational practices has garnered significant interest due to its potential to enhance student engagement and learning outcomes, particularly in challenging subjects such as mathematics. Traditional methods of teaching mathematics often struggle to maintain student interest and engagement, which can lead to suboptimal learning outcomes. VR technology offers a promising solution by providing immersive, interactive, and engaging learning environments that can transform how mathematical concepts are taught and understood.

Research has shown that VR can significantly enhance cognitive, behavioral, and affective engagement in students. Cognitive engagement involves the mental effort and strategies used to comprehend mathematical concepts, while behavioral engagement pertains to participation in learning activities and persistence in task completion (Rafiq et al., 2022; Dunmoye et al., 2023). Affective engagement includes the emotions and attitudes towards learning, which can be significantly influenced by the immersive nature of VR (Lin et al., 2024).

Studies have demonstrated that VR can bring real-life events into the classroom, thereby enhancing active learning and student participation (Rafiq et al., 2022). In collaborative learning settings, VR has been found to effectively capture and analyze body movements, helping to infer engagement levels and improve collaborative knowledge construction (Sung & Nathan, 2024). Additionally, mobile VR technology has shown promise in maintaining learner motivation and engagement in post-pandemic e-learning environments, catering to various learning styles (Manzoor et al., 2022).

The impact of VR on learning engagement is not limited to cognitive aspects. VR has been shown to improve behavioral engagement by making learning more interactive and enjoyable. For instance, serious games and gamified VR environments have been found to increase learning gains, knowledge retention, and engagement in various educational contexts (Menin et al., 2018; Sharmin et al., 2023). Furthermore, the use of VR in K-12 education, particularly during the COVID-19 pandemic, has highlighted its potential to enhance learners' engagement and motivation significantly (Li, 2023).

The versatility of VR technology extends to different educational settings and subjects. In primary education, combining Web3D and WebXR technologies has effectively enhanced engagement and learning outcomes in subjects such as environmental science

(Guo and Mogra, 2022). In higher education, VR has been used to improve learning outcomes and engagement in engineering and technical drawing courses (Bhatia and Hesse, 2023; Huerta et al., 2019). These findings underscore the potential of VR to transform traditional educational practices across various disciplines.

In the context of middle school mathematics, implementing immersive VR games can address the challenges of engaging students with abstract mathematical concepts. By making these concepts tangible and interactive, VR can foster a deeper understanding and appreciation of mathematics among students. This study aims to explore the impact of immersive VR games on the learning engagement of middle school students in selected mathematical concepts, building on the existing body of research that highlights the benefits of VR in education.

Research Question

Is there a significant difference in the level of learning engagement (cognitive, behavioral, and affective) of middle school students in selected mathematical concepts before and after the implementation of immersive virtual reality math games?

II. RESEARCH METHODOLOGY

The research methodology for this study, which examines the impact of Virtual Reality (VR) technology on student engagement with learning fractions, utilizes a quasi-experimental design with pre-test and post-test measures, conducted at the school located in Ganzhou, Jiangxi province, China. This design was selected due to its appropriateness in educational environments where random assignment of participants to groups is not feasible. It facilitates the evaluation of cognitive, behavioural, and affective engagement among 9th-grade students before and after the introduction of a VR intervention. The school, renowned for its advanced facilities and strong emphasis on integrating technology in education, provides an ideal setting for deploying the immersive VR educational tools.

The sampling strategy involved purposefully selecting 90 students for the study. The research instruments include a specifically designed survey questionnaire to measure different dimensions of student engagement and a comprehensive VR program tailored for learning fractions. This program comprises high-resolution VR headsets and controllers, and a VR software platform loaded with educational content, which together facilitate a rich, interactive learning environment.

The curriculum developed for this study spans eight weeks and is meticulously crafted to cover different aspects of understanding and applying fractions, from basic concepts to complex applications in real-world scenarios. Data gathering involves a clear process of obtaining necessary approvals, administering pre- and post-intervention surveys, and diligent follow-ups to ensure comprehensive data collection.

Statistical analysis of the collected data is conducted using weighted means to assess the level of engagement and paired t-tests to compare the pre- and post-intervention results. This analysis helps determine the effectiveness of the VR intervention in enhancing learning outcomes.

Ethical considerations are rigorously maintained throughout the research process. Participants are fully informed about the study's objectives, their rights as participants, and the confidentiality of their responses. Voluntary participation is emphasized, and participants are allowed to withdraw at any time without consequence.

III. RESULTS AND DISCUSSION

Table 1. Differences in the Level of Learning Engagement of the Respondents Prior and After the Implementation of Immersive Virtual Reality in Selected Mathematical Concepts

Indicator	Category	Mean	t	Sig.	Decision on Ho	Interpretation
1. Cognitive	Prior After	2.771 3.191	.181	.010	Rejected	Significant
2. Behavioral	Prior After	2.864 3.144	.207	.003	Rejected	Significant
3. Affective	Prior After	2.895 3.050	.358	.000	Rejected	Significant
Overall	**Prior After**	**2.710 3.050**	**.254**	**.000**	**Rejected**	**Significant**

The data presented in Table 1 highlights the differences in the level of learning engagement of respondents before and after the implementation of immersive virtual reality (VR) in teaching selected mathematical concepts. This comprehensive analysis encompasses cognitive, behavioral, and affective dimensions of engagement, demonstrating the overall effectiveness of VR in enhancing students' learning experiences.

Prior to the implementation of immersive VR, the mean cognitive engagement score was 2.771, which increased significantly to 3.191 post-implementation. The correlation coefficient of .181 and a significance level of .010 indicate that this improvement is statistically significant. The null hypothesis, which posited no difference in cognitive engagement levels before and after the intervention, was rejected. This suggests that the immersive VR environment significantly enhanced the students' cognitive engagement. Students became more attentive, better at understanding mathematical problems, and more capable of making connections between class content and real-life applications. The data underscores the role of immersive VR in fostering a deeper understanding and greater interest in mathematical concepts, leading to improved cognitive engagement.

Behavioural engagement also saw a notable increase, with the mean score rising from 2.864 prior to the implementation of VR to 3.144 afterward. The correlation coefficient was 0.207, with a significance level of 0.003, leading to the rejection of the null hypothesis. This indicates a significant difference in behavioral engagement due to the VR intervention. The findings suggest that students were more diligent in their behaviors related to learning math, such as completing homework on time, actively participating in class activities, and maintaining focus during lessons. The immersive nature of VR likely made math lessons more interactive and engaging, thereby encouraging students to be more involved and attentive in their learning processes.

In terms of affective engagement, the mean score improved from 2.895 before the VR implementation to 3.050 afterward. The correlation coefficient of 0.358 and a significance level of .000 indicate a strong and significant improvement in affective engagement. The null hypothesis was rejected, confirming a significant difference in the emotional and attitudinal aspects of learning engagement. Students reported enjoying math more, feeling excited about math classes, and being more satisfied with their progress and achievements in math. The immersive VR environment likely contributed to these positive feelings by making learning more enjoyable and emotionally rewarding.

The overall mean engagement score increased from 2.710 to 3.050, with a correlation coefficient of 0.254 and a significance level of 0.000, leading to the rejection of the null hypothesis. This comprehensive result indicates a significant overall improvement in learning engagement across all three dimensions—cognitive, behavioral, and affective—following the implementation of immersive VR. The consistent improvement across all areas suggests that VR is an effective educational tool for enhancing student engagement. The interactive and immersive nature of VR likely plays a crucial role in making learning more engaging and effective, resulting in better academic outcomes and a more positive learning experience for students.

The results indicate a significant overall improvement in learning engagement across all three dimensions—cognitive, behavioral, and affective—after the implementation of immersive virtual reality (VR) in teaching mathematical concepts. This means that students demonstrated better attention and understanding (cognitive engagement), more active participation and adherence to tasks (behavioral engagement), and greater enjoyment and emotional connection to the subject (affective engagement).

The consistent improvement across these areas suggests that VR is a highly effective educational tool for enhancing student engagement. By providing interactive and immersive experiences, VR likely plays a crucial role in making learning more captivating and effective. This interactive nature of VR allows students to engage with mathematical concepts in a more hands-on and visually stimulating way, which can help to maintain their interest and motivation.

The immersive aspect of VR can simulate real-world applications of mathematical concepts, making lessons more relevant and understandable for students. This relevance can enhance cognitive engagement by helping students see the importance of what they are learning and how it applies to real life. Moreover, the engaging and fun aspects of VR can make students look forward to their math lessons, thus improving their emotional connection to the subject.

Thus, the data implies that VR not only helps in better understanding and applying mathematical concepts but also increases students' overall enthusiasm and participation in the learning process. This leads to better academic outcomes and a more positive and engaging learning experience for students. Additionally, VR technology allows for a more interactive and immersive learning environment, which can cater to different learning styles and preferences. Students are able to engage with the material in a hands-on way, making abstract concepts more concrete and easier to grasp. As a result, students are more likely to retain the information and apply it to real-world scenarios, further enhancing their understanding and skills in mathematics.

In conclusion, the implementation of immersive virtual reality in teaching selected mathematical concepts significantly improved the learning engagement of students in cognitive, behavioral, and affective dimensions. These findings underscore the potential of VR as a transformative educational tool that can enhance student engagement, making learning more interactive, enjoyable, and effective. The significant improvements across all dimensions of engagement highlight the importance of integrating innovative technologies like VR into educational practices to foster better learning outcomes and a more engaging educational experience. By utilizing VR technology in the classroom, educators have the opportunity to cater to different learning styles and create a more personalized learning experience for each student. This not only enhances their understanding of complex mathematical concepts

but also boosts their overall motivation to learn. As VR continues to advance and become more accessible, its integration into education will likely become more widespread, revolutionizing the way students engage with and absorb information in the classroom. Ultimately, the benefits of incorporating VR into educational practices are clear, paving the way for a more immersive and effective learning experience for students of all ages.

According to Filer and Holmes (2020), The integration of VR with gamification elements can foster affective engagement by making learning enjoyable and motivating students to participate actively. For example, VR-based taxation exercises have been found to improve student understanding and make learning more fun, thus enhancing engagement. In addition, the interactive nature of VR simulations allows students to apply their knowledge in a practical setting, reinforcing their learning and promoting a deeper understanding of complex concepts. By incorporating gamification elements such as rewards, challenges, and leaderboards, educators can further enhance student motivation and engagement in the learning process. Overall, the combination of VR technology and gamification has the potential to revolutionize education by creating immersive and engaging learning experiences for students of all ages.

In fact, learning engagement in mathematics through Virtual Reality (VR) technology involves multiple facets, including cognitive, behavioral, and affective engagement. Cognitive engagement refers to the mental effort and strategies students use to understand mathematical concepts (Dunmoye et al., 2023; Chen et al., 2023). Behavioral engagement pertains to students' participation in learning activities and their persistence in completing tasks (Teoh et al., 2022; Retnanto et al., 2019). Affective engagement encompasses students' emotions and attitudes towards learning mathematics (Lin et al., 2024; Filer and Holmes, 2020). Research has shown that when students are cognitively engaged in learning math through VR technology, they are more likely to retain and apply the concepts they have learned. Additionally, behavioral engagement in VR math activities can lead to increased motivation and confidence in tackling challenging problems. Affective engagement is also crucial, as students who have positive emotions and attitudes towards math are more likely to persevere through difficulties and ultimately succeed in the subject. Overall, incorporating VR technology in math education can enhance students' overall engagement and learning outcomes.

IV. CONCLUSION

Every word in the comparison between pretest and posttest results confirmed that immersive VR significantly enhanced students' engagement in all areas—cognitive, behavioral, and affective. This validates VR as a powerful tool in education, capable of transforming learning experiences and boosting overall student engagement in mathematical concepts. Therefore, it is recommended to conduct long-term studies to monitor and evaluate the sustained impact of VR on student engagement and academic performance. This will help in understanding the broader implications of VR in education and provide insights for further innovations and improvements in teaching and learning practices.

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