

## Utilizing Virtual Reality in Mathematics Education: A Case Study at the High School Level

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**Abstract:** This study presents a systematic literature review aimed at investigating the utilization of Virtual Reality (VR) technology in mathematics education at the high school level. Literature sources were obtained from Scispace and Elicit indexes, as well as data from Google Scholar, DOAJ, and Scopus, covering publications from 2013 to 2024. The findings reveal that the use of VR in mathematics education significantly impacts students' interest, motivation, engagement, and problem-solving abilities at the high school level. Various studies support these findings by demonstrating that VR creates an engaging, interactive, and realistic learning environment for students, thereby enhancing their interest and motivation in learning mathematics. Moreover, the utilization of VR has proven effective in increasing student engagement in learning, facilitating the understanding of mathematical concepts, and enhancing students' problem-solving skills. The integration of VR with innovative pedagogical approaches, such as Project-Based Learning (PBL) or Problem-Based Learning (PBL), also shows potential in improving students' critical thinking skills and mathematical literacy. In conclusion, this research underscores the importance of harnessing VR technology to enhance mathematics education at the high school level, while also highlighting the need for further research to explore the most effective strategies for VR implementation and address implementation challenges in classroom settings.

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**Keywords:** Virtual Reality, Mathematics Education, High School, Student Engagement, Problem-Solving.

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### A. INTRODUCTION

Technology has played a pivotal role in reshaping the landscape of mathematics education globally (Lolang, 2018). In recent decades, there has been significant acceleration in the development and adoption of technology in mathematics classrooms. This phenomenon has led to fundamental changes in learning approaches, where the integration of technology becomes key in enhancing the effectiveness and relevance of mathematics instruction. One major contribution of technology is its ability to enhance students' engagement and understanding of complex mathematical concepts. By utilizing various technological tools and applications such as interactive software, simulations, and online learning platforms, students can access a wider range of resources to actively explore, visualize, and experiment directly with mathematical concepts. This provides them with opportunities to grasp the material in a more enjoyable, interactive, and everyday-life-relevant manner. Beyond mere aids, technology

has become a potent ally for teachers in creating dynamic and stimulating learning environments for students. Thus, the use of technology in mathematics instruction not only opens new avenues for exploration and understanding but also brings about significant positive impacts in enhancing the overall quality of mathematics education.

Virtual reality is a technology that creates a digital environment resembling real-life experiences using specialized hardware and software (Sari et al., 2022). In the realm of education, the use of virtual reality has become a valuable tool in enhancing the learning process. This concept enables students to engage in deep and interactive learning experiences, where they can interact directly with instructional materials through 3D simulations or provided virtual environments. The development of virtual reality in education involves the creation of various applications and platforms specifically designed to present instructional materials in an engaging and easily understandable manner for students. A brief review of previous studies indicates that the utilization of virtual reality in learning has provided significant benefits to students, such as increased engagement, better conceptual understanding, and overall academic performance improvement. By providing interactive and immersive learning experiences, virtual reality has helped enrich traditional teaching approaches and enhance learning effectiveness in various subjects, including mathematics.

Challenges in teaching mathematics at the high school level include transitioning to combined teaching methods as a result of the pandemic (B. PALMA, 2023). Some teachers may resist the concept of inclusive education, which can affect their willingness to accommodate students with visual impairments (Baykaldı et al., 2024). The implementation of distance learning during the pandemic has raised issues related to the delivery of mathematical content, disruptions, curriculum adjustments, and guidance for parents and teachers (Dela Cruz & Hernandez, 2023). Teachers' understanding of engagement in mathematics education research can provide insights into the correlation between engagement goals and engagement dimensions (Jansen et al., 2023). Factors influencing students' attitudes toward mathematics learning include inadequate background knowledge, ineffective teaching methods, and lack of motivation (Olayinka, 2023). To address these challenges and enhance students' understanding, it is important to introduce innovative and engaging teaching approaches, provide support and training for teachers, and involve parents and guardians in the learning process.

Virtual Reality (VR) and Augmented Reality (AR) technologies have emerged as primary choices in implementing mathematics education to enhance interactive learning experiences (Çakıroğlu et al., 2023; Cevikbas et al., 2023; Pahmi et al., 2023; Ridloka et al., 2023). The implementation of these technologies has shown promising results in boosting students' interest, motivation, and problem-solving abilities in the context of mathematics (Cevikbas et al., 2023). VR has been utilized in creating simple mathematical quizzes to generate an engaging learning environment for children. Meanwhile, AR has become an effective pedagogical tool in supporting mathematics learning across various levels, encompassing topics such as geometry, algebra, statistics, and probability. The advantage of AR in mathematics education lies in its ability to overcome learning barriers and cognitive issues. Furthermore, the Virtual Realistic Mathematics Education (VRME) approach, which combines

virtual and realistic approaches, has also been implemented to enhance mathematical literacy skills. However, for the successful implementation of AR/VR in the classroom, challenges such as technological disruptions, costs, and health issues need to be effectively addressed.

The utilization of virtual reality in mathematics education offers a range of benefits and potential that can be harnessed. (Sundawan, 2014) found that the application of constructivist learning models, which can be facilitated through virtual reality, has a positive impact on students' abilities to solve mathematical problems. This is further supported by (Santri et al., 2018), who demonstrated that the use of mathematical modeling can aid students in understanding algebraic concepts, an approach that can be enhanced through virtual reality simulations. (Mamat & Abdul Wahab, 2022) underscore the importance of understanding basic mathematical concepts, which can be reinforced through interactive and immersive experiences in virtual reality. Lastly, (N.P.D Sinaga et al., 2022) suggest that students' interest in mathematics learning can be enhanced by implementing variations in learning styles during the mathematics learning process. Overall, these studies imply that the implementation of virtual reality can enhance mathematics education by improving problem-solving skills, understanding of complex concepts, and early exposure to mathematical materials.

Existing studies on the utilization of virtual reality in mathematics education have several limitations. (Muh. Ilham Dhani et al., 2022) and (Rustam et al., 2021) emphasize the need for more comprehensive research considering the effectiveness of virtual reality in enhancing mathematics learning outcomes. (Santri et al., 2018) also highlight the importance of incorporating virtual reality into the design of mathematics learning pathways, stating that this approach can improve students' problem-solving abilities and understanding of mathematical concepts. However, these studies have not provided a detailed overview of the specific limitations of previous research in this field. Therefore, future research should focus on addressing these gaps to provide a more comprehensive understanding of the potential of virtual reality in mathematics learning.

Based on the presented research findings, there are gaps that need to be addressed in the context of utilizing virtual reality (VR) in mathematics education. These studies indicate that the use of VR can enhance students' problem-solving abilities, understanding of mathematical concepts, and interest in mathematics learning through interactive and immersive experiences. However, there are limitations in the existing studies regarding the effectiveness and scope of VR utilization in the context of mathematics education. Research by Dhani and Rustam highlights the need for more comprehensive studies to consider the effectiveness of VR in enhancing mathematics learning outcomes. Additionally, the study by Santri demonstrates the importance of integrating VR into the design of mathematics learning pathways, yet there has been no in-depth review regarding the specific limitations of previous research. Therefore, the objective of this research is to address these gaps by providing a more comprehensive understanding of the potential of utilizing VR in mathematics education at the high school level. Using a systematic literature review approach, this research will focus on identifying and addressing the existing limitations to provide a more comprehensive insight into the use of VR in the context of mathematics learning.

## **B. METHOD**

The qualitative research method with a Systematic Literature Review approach employed in this study aims to investigate the utilization of virtual reality in mathematics education at the high school level. The objective of this research is to compile a comprehensive understanding of how virtual reality has been integrated into the context of mathematics learning at this level, with a focus on relevant research outcomes and recent findings. Firstly, literature search will be conducted through leading academic databases such as PubMed, IEEE Xplore, and Google Scholar with the publication timeframe ranging from 2013 to 2024. Relevant keywords such as "virtual reality," "mathematics learning," and "high school level" will be utilized to identify relevant articles. Literature search will focus on journal articles, books, conference proceedings, and other academic sources that have relevance to the research topic. Additionally, reference sources from these articles will also be explored to ensure optimal inclusivity. Literature search will concentrate on journal articles, books, conference proceedings, and other academic sources that are pertinent to the research topic.

The determination of inclusion and exclusion criteria is conducted to ensure that selected articles are relevant to the research focus. Inclusion criteria may include recent publication years, direct relevance to the utilization of virtual reality in mathematics education at the high school level, as well as research methods that support the validity and reliability of findings. Literature selection is carried out by considering the inclusion and exclusion criteria, as well as through stages of reading titles, abstracts, and full-text articles. Articles that meet the criteria will be selected for data extraction. Extracted data include information about the research context, methods used, key findings, and implications of research findings for the utilization of virtual reality in mathematics education at the high school level. With this Systematic Literature Review approach, it is expected that this research will provide a holistic overview of how virtual reality has been implemented in mathematics education at the high school level, making a significant contribution to understanding and further development in this field.

## **C. RESULTS AND DISCUSSION**

### **1. The Influence of Virtual Reality Usage on Students' Understanding of Complex Mathematical Concepts**

The utilization of virtual reality has been proven to deepen students' understanding of complex mathematical concepts (Çakıroğlu et al., 2023; Dini Rahmawati et al., 2022; Rahmawati et al., 2022; Su et al., 2022). The use of virtual reality-based mathematics learning media, coupled with innovative approaches such as ethnomathematics, has been effective in improving students' learning outcomes in mathematics (Rahmawati et al., 2022). Immersive learning systems through virtual reality have been developed to teach mathematical geometry concepts, leading to increased learning motivation and student performance (Pobokin & Selivanov, 2022). Additionally, virtual reality-based mathematics learning media has proven beneficial in enhancing students' understanding of trigonometry concepts. Empirical research indicates that the use of virtual reality programs can positively influence students' reflection and the formation of mathematical knowledge. Overall, the integration of virtual reality into

mathematics learning promises an improvement in students' understanding of complex mathematical concepts.

The implementation of Virtual Reality (VR) in mathematics education has been demonstrated to significantly influence students' understanding of complex mathematical concepts (Nabilah et al., 2021). However, the effectiveness of this approach may be hindered by students' anxiety in virtual learning situations (Nabilah et al., 2021). To address this challenge, the use of the Indonesian Realistic Mathematics Education (PMRI) approach is suggested as a potential solution, aiming to make mathematics learning more engaging and less intimidating (Yuniawatika et al., 2018). It has been proven that this approach successfully enhances students' mathematical communication skills (Yundayati & Suyoto, 2020).

The research findings indicate that the utilization of virtual reality in mathematics education has a positive impact on students' understanding of complex mathematical concepts. The integration of virtual reality technology opens up new opportunities to create a more interactive, immersive, and engaging learning environment for students. By utilizing virtual reality-based learning media, students can have a deeper and more practical learning experience in understanding abstract mathematical concepts. Although the research results demonstrate the effectiveness of using virtual reality in enhancing students' understanding of mathematics, there are still some aspects that need further evaluation. Most of these studies may have limitations in terms of sample size, research methods, or generalizability of results. Additionally, technical aspects such as the availability of technology infrastructure, implementation costs, and teacher training also need to be considered in the overall evaluation of the effectiveness of using virtual reality in the context of mathematics education.

## **2. Concrete Benefits Offered by the Utilization of Virtual Reality in Mathematics Education at the High School Level**

The use of virtual reality (VR) technology demonstrates significant benefits in the process of mathematics learning at the high school level. It has been proven to enhance students' interest and motivation in learning mathematics, as well as improve their problem-solving abilities and understanding of mathematical concepts (Dini Rahmawati et al., 2022; Predescu et al., 2023; Ridloka et al., 2023). VR learning media with an ethnomathematics approach has been effective in enhancing students' learning outcomes, achieving higher learning outcomes compared to conventional teaching methods (Campos et al., 2022). The use of VR in education contexts creates captivating, immersive, and interactive learning experiences, fostering active and in-depth learning (Cuka & Bufasi, 2022). Students using VR technology have demonstrated superior performance in visualization tasks and reported positive learning experiences. Additionally, the utilization of hypermedia, including VR, has been shown to improve students' achievement in mathematics. These findings affirm the potential of VR to enhance mathematics learning and achieve better outcomes for high school students.

The utilization of virtual reality in mathematics education at the high school level has been found beneficial in several aspects, yet it also poses challenges. (Nabilah et al., 2021) discovered that students experience high levels of anxiety in virtual mathematics classes due to environmental factors and boredom from prolonged screen time. This highlights the

necessity for virtual learning environments to prioritize student comfort and engagement. On the other hand, (Maslihah, 2016) and (Mulyati, 2016) both underscore the potential of realistic mathematics education in enhancing problem-solving skills and making mathematics more engaging. This approach, viewing mathematics as a process constructed by students, can be effectively integrated into virtual reality-based mathematics education. Lastly, (Idhayani et al., 2020) emphasize the importance of effective learning management in creating a enjoyable learning environment, which can be particularly crucial in virtual settings.

The utilization of VR in mathematics education creates a more engaging, immersive, and interactive learning experience for students. This enhances the appeal of mathematics learning and triggers students' interest and motivation towards the subject. Additionally, the positive learning experience gained by students from using VR can also enhance their understanding of mathematical concepts. The cited studies demonstrate that the utilization of virtual reality technology in mathematics education at the high school level yields significant concrete benefits. These include increased student interest and motivation, improved problem-solving abilities in mathematics, and enhanced understanding of mathematical concepts. However, there are also challenges that need to be addressed, such as the high level of anxiety among students in virtual mathematics classes, as found by Nabilah.

### **3. The Primary Constraints or Challenges Encountered in Implementing Virtual Reality Technology in Mathematics Education at the High School Level**

The implementation of virtual reality (VR) technology in mathematics education at the high school level faces various challenges. These challenges include technical disruptions, high costs, difficulties in initiation, health issues, and a lack of familiarity with VR technology (Zydney & Hord, 2023). Additionally, issues arise concerning flexible scheduling, difficulties in monitoring student work, and inconsistent use of collaborative communication tools (Cevikbas et al., 2023). Technical barriers and time constraints for teachers also hinder the implementation of technology in mathematics education in high schools (Tian, 2023). Furthermore, adapting mathematical content to online formats poses limitations for educators and students (Saucedo James et al., 2023). Amidst the pandemic, teachers face challenges in managing and designing flipped learning models, especially for those accustomed to traditional teaching methods (Permatasari, 2022). To address these challenges, addressing technical issues, providing training and support to teachers, and finding effective ways to integrate VR technology into mathematics education at the high school level are necessary.

The implementation of virtual reality (VR) technology in mathematics education at the high school level faces several key challenges. Both (Nabilah et al., 2021) and (Febryliani et al., 2021) highlight the high level of anxiety among students in virtual classrooms, which can be caused by factors such as an unsupportive learning environment and prolonged screen time. These challenges underscore the need for educators to prioritize students' psychological well-being and create a comfortable learning environment. (Dahlan et al., 2019) emphasizes the importance of pedagogical competence in integrating character values into mathematics education, suggesting that additional training and support for teachers are necessary. Lastly, (Putri et al., 2018) emphasizes the importance of students' mathematical understanding, which can be hindered by challenges in virtual learning. Collectively, these findings underscore the

need for a holistic approach to address challenges in implementing virtual reality technology in mathematics education at the high school level.

The main challenges in implementing virtual reality technology in mathematics education at the high school level encompass technical, financial, health, and educational aspects. Factors such as technical difficulties, high costs, and lack of familiarity with VR technology can hinder its effective use. Additionally, other challenges include difficulties in planning flexible learning schedules, monitoring student work, and using collaborative communication tools consistently. Teachers also face challenges in adapting mathematical content to online formats and designing flipped learning models, especially amidst the COVID-19 pandemic. The challenges encountered in implementing virtual reality technology in mathematics education at the high school level have significant implications for the effectiveness of learning. These constraints can hinder teachers' ability to provide optimal learning experiences for students and affect the quality of students' understanding and academic achievement in mathematics.

#### **4. Mathematics Teaching Approaches Can Be Developed or Adapted to Incorporate the Use of Virtual Reality**

The teaching approach in mathematics can be enriched through the utilization of virtual reality. Virtual Realistic Mathematics Education (VRME) represents a fusion of virtual and realistic approaches aimed at enhancing mathematical literacy skills, such as application, interpretation, and formulation (Çakiroğlu et al., 2023). Virtual reality technology has been widely applied in educational contexts, including mathematics learning, to enhance students' interest, motivation, and problem-solving skills (Ridloka et al., 2023). Furthermore, VR also offers a promising approach in teaching geometry, as evidenced by research evaluating the use of VR-based geometry instruction (Thomsen et al., 2023). Moreover, game-based learning media supported by virtual reality and artificial intelligence technology have been developed to provide adaptive feedback and recommendations for students in mathematics learning (Nurhayati & Arif, 2023). The conclusions drawn from these findings indicate that virtual reality can be a valuable tool in the development and adaptation of mathematics teaching approaches.

The development of teaching materials using a realistic mathematics approach has been proven successful in facilitating the learning process for students (Haryonik & Bhakti, 2018). However, the use of virtual classrooms may increase students' levels of anxiety, particularly in mathematics lessons (Febryliani et al., 2021; Nabilah et al., 2021). To address this issue, the development and implementation of self-paced learning curricula in mathematics education programs can provide a more enjoyable and effective learning environment (Wulandari et al., 2021). Therefore, the utilization of virtual reality technology in mathematics learning needs to consider these factors to ensure a beneficial and successful learning experience.

Approaches to teaching mathematics can be developed or tailored to the use of virtual reality by leveraging VRME. Through VRME, teaching approaches can become more immersive and interactive, engaging students in understanding and applying mathematical concepts. The use of VR technology can enhance students' interest and motivation in learning

mathematics, as well as help them develop problem-solving skills. Additionally, VR provides opportunities for more engaging and effective geometry teaching by allowing students to interact with mathematical models in a realistic virtual environment. The use of virtual reality in mathematics education holds great potential for improving the quality of learning and students' achievements. However, it is important to remember that the use of VR technology can also pose challenges, such as students' anxiety levels in virtual classrooms. Therefore, strategies to address these issues need to be considered to ensure that the use of VR in mathematics education provides a positive and effective learning experience for all students.

### **5. Prospects for the Development and Implementation of Virtual Reality in Mathematics Education in the Future, Particularly at the High School Level**

The utilization of virtual reality (VR) has shown potential in enhancing students' problem-solving skills in mathematics (Çakıroğlu et al., 2023; Huang et al., 2023; Ridloka et al., 2023; Yonwilad et al., 2022). Studies have found that the implementation of VR in math quizzes can increase children's interest and motivation in learning mathematics, as well as improve their problem-solving skills (Pramuditya et al., 2022). Virtual Realistic Mathematics Education (VRME), which combines virtual and realistic approaches, has been effective in enhancing mathematical literacy skills, including the ability to use, interpret, and formulate mathematical problems. Additionally, the virtual 5E instructional organization has been successful in improving mathematical problem-solving abilities among mathematics students. Collaborative problem-solving in a VR environment has also been shown to enhance the formation of geometric knowledge among participants. Through the use of question-based virtual reality games, students have demonstrated improved problem-solving abilities in both mathematical and non-mathematical contexts. Overall, these findings suggest that the use of virtual reality can be a valuable tool in enhancing students' problem-solving skills in mathematics.

The utilization of virtual reality in mathematics education holds promise for enhancing students' problem-solving abilities. However, it is essential to consider the psychological aspects of students within the context of virtual learning environments (Nabilah et al., 2021). Realistic approaches in teaching specific mathematical concepts, such as circles, have proven effective in improving students' understanding and engagement. Meanwhile, the integration of real-world problems into mathematics learning can also enhance students' problem-solving abilities (Mulyati, 2016). The development of learning materials with environmental themes can also have a positive impact on students' learning outcomes in specific mathematical topics (Ulfa & Firdausi, 2020).

The research findings indicate that the utilization of virtual reality (VR) in mathematics education can provide a more engaging and interactive learning experience for students. This can foster students' interest and motivation in mathematics, which, in turn, can help enhance their problem-solving skills. The VRME approach, in particular, offers a combination of virtual and realistic approaches that can assist students in better understanding mathematical concepts and improving their problem-solving abilities. Studies conducted on the use of virtual reality in mathematics learning have shown positive outcomes. However, it is important to note that there are still several factors to consider, including the psychological



aspects of students in the virtual learning environment. Additionally, while the use of VR has been proven effective in enhancing students' problem-solving skills, further research is needed to gain a deeper understanding of how VR technology can be optimally utilized in the context of mathematics education.

#### **D. CONCLUSIONS AND SUGGESTIONS**

Based on the evaluation of various studies examining the use of virtual reality in mathematics education at the high school level, it can be concluded that this technology holds significant potential for enhancing students' problem-solving skills and their understanding of complex mathematical concepts. However, there are still several challenges that need to be addressed, including students' anxiety levels in virtual classrooms, technical barriers, implementation costs, and the lack of technological infrastructure availability. Additionally, the psychological aspects of students in the virtual learning environment need to be considered, and further research is needed to gain a deeper understanding of the impact and effectiveness of virtual reality use in mathematics education.

The gap identified in this evaluation lies in the insufficient research focused on the development of strategies to address these challenges. These strategies could include methods for reducing student anxiety in virtual classrooms, improving accessibility and utilization of VR technology in schools, and devising approaches to effectively integrate this technology into existing mathematics curricula. Therefore, a pressing research topic for future investigation is "Development and Implementation of Strategies for Using Virtual Reality in Mathematics Education at the High School Level: Enhancing Students' Problem-Solving Skills and Addressing Implementation Challenges." This research could concentrate on the development of specific and practical strategies to overcome the challenges encountered in implementing virtual reality technology in mathematics education. Additionally, it could evaluate the effectiveness and impact of these strategies in improving student learning outcomes. Thus, this research would provide valuable insights into optimizing the utilization of virtual reality technology in the context of mathematics education at the high school level.

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