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Exploring Virtual Reality's Impact on Math Anxiety: Transforming the Learning Experience

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Abstract

Mathematics learning anxiety negatively impacts students' motivation, comprehension, and academic performance. To address this issue, virtual reality (VR) technology has emerged as an innovative solution that offers a more interactive and immersive learning experience. This study aims to identify how VR integration can help reduce mathematics anxiety by providing a supportive learning environment, as well as to examine the benefits and challenges of using VR as an intervention for mathematics anxiety in students. This qualitative study, with a phenomenological design, involves three elementary school students studying geometry in the 2024 academic year, selected through purposive sampling. Data were collected through observations and in-depth interviews. The results indicate that VR effectively reduces anxiety and enhances students' confidence in mathematics by facilitating concrete visualization of abstract concepts, lowering cognitive load, and encouraging intrinsic motivation. Positive experiences in VR-based environments support the development of students' self-efficacy, which contributes to increased engagement in learning. However, VR implementation faces challenges related to adaptation by students and teachers, infrastructure limitations, and potential increases in cognitive load if not balanced with the reinforcement of foundational concepts. VR is recommended as a supplementary learning tool to achieve optimal concept understanding and practical learning.

Keywords: Mathematics Education, Mathematics Learning, Mathematics Learning Anxiety, Virtual Reality.

Introduction

Mathematics is a fundamental discipline as it cultivates critical thinking skills (Jablonka, 2020), problem-solving abilities (Atteh et al., 2017), logical reasoning (Bass & Ball, 2018), and the capacity to make connections between concepts (Kumar, 2017). Through these competencies, mathematics becomes a crucial tool for understanding and engaging with the world. However, as an abstract science (Mitchelmore & White, 2004), mathematics often presents challenges for students, many of whom struggle to grasp its concepts (Serin, 2023). To address this challenge, educational curricula, and teachers strive to make mathematics more comprehensible by linking abstract mathematical concepts to real-life contexts (Muhaimin & Juandi, 2023). This approach is designed to facilitate meaningful comprehension for students. Nevertheless, many students still find it difficult to understand mathematical concepts, resulting in mathematics learning anxiety (Telaumbanua et al., 2023). This anxiety not only hinders students' engagement and performance in mathematics but also limits the development of essential skills, such as logical

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reasoning and problem-solving (Beilock & Maloney, 2015; J. Zhang et al., 2019; Zhu et al., 2024).

Mathematics learning anxiety is a psychological phenomenon characterized by feelings of tension, worry, and even fear toward tasks involving mathematics (Bjälkebring, 2019). This phenomenon often serves as an obstacle for many students in achieving academic success, particularly in mathematics, which underpins the development of critical thinking, problem-solving, and logical reasoning skills (Beilock & Maloney, 2015; Telaumbanua et al., 2023). Anxiety can manifest in various forms, including discomfort when faced with math problems (Vitasari et al., 2010), low self-esteem that reduces students' confidence in performing math tasks (Abbasi et al., 2013), and a tendency to avoid situations requiring mathematical ability (Grežo & Sarmány-Schuller, 2018).

Research indicates that math anxiety has a significant impact on students' academic achievement, with higher anxiety levels typically correlating with lower academic outcomes (Al Mutawah, 2015; Emily & McLaughlin, 2014). This is of particular concern, as poor academic performance in mathematics can undermine students' confidence and motivation, subsequently affecting their engagement and interest in mathematics (Suren & Ali Kandemir, 2020). Furthermore, math anxiety has long-term consequences that may limit career choices and influence students' life paths, especially in fields related to science, technology, engineering, and mathematics (STEM) (Brewster & Miller, 2020). Students who experience high levels of math anxiety tend to avoid these fields (Levy et al., 2021), thereby restricting their opportunities in careers requiring mathematical skills.

Various factors have been identified as causes of math anxiety, including internal aspects such as students' personality and intellectual abilities, as well as external factors such as parental expectations and pressures from the learning environment (Prahmana et al., 2019). In this context, the involvement of multiple parties—particularly students, parents, and teachers—becomes crucial in helping to alleviate math anxiety (Vukovic et al., 2013). Research suggests effective strategies such as building students' confidence through supportive learning approaches (Sihotang et al., 2017), reducing excessive parental pressure (Retanal et al., 2021), and presenting math material gradually and enjoyably by teachers (Lorenzen & Lipscomb, 2021).

Based on the issues above, reducing math anxiety is an essential component of mathematics education, as high anxiety levels not only impede the development of logical and problem-solving skills but also hinder students' academic and professional potential. As recommended by Noviaristanti et al. (2020), more interactive learning approaches are a viable strategy to help students overcome math anxiety. Active engagement in interactive learning allows students to participate more fully in the learning process, ultimately enhancing their motivation, comprehension, and interest in mathematics.

Developing interactive learning conditions is one of the primary challenges in today's educational landscape. Addressing this challenge requires innovative solutions, one of which can be achieved through the use of educational technology advancements. Modern technology offers various innovative solutions to enhance student engagement, and Virtual Reality (VR) represents a promising development in overcoming learning challenges, including mathematics anxiety (Kamińska et al., 2019). VR is an immersive, computer-based simulation technology that allows users to experience and interact within a three-dimensional space realistically (Gao, 2022). In educational contexts, VR offers unique benefits by providing interactive learning experiences, boosting motivation, and helping students gain a deeper understanding of concepts (Pahmi et al.,

2024). Through an immersive environment, VR can create a non-intimidating atmosphere where students can learn and practice mathematical skills at their own pace, potentially reducing the anxiety associated with mathematics.

Studies indicate that VR-based learning promotes a deeper understanding of complex concepts through an experiential learning approach (Asad et al., 2021), making it an effective solution for alleviating stress and anxiety often associated with mathematics (Kamińska et al., 2019). By providing a safe and non-intimidating learning environment, VR supports cognitive processes in mathematics comprehension while also boosting students' confidence (Li et al., 2021). VR-based learning experiences are also known to help students develop visualization and problem-solving skills related to geometry (Ruijia et al., 2023). Research by Mikropoulos & Natsis (2011) reveals that VR enables students to visualize the solar system, manipulate geometric shapes, or simulate scientific experiments—all aimed at simplifying the understanding of challenging materials. Through direct interaction in a virtual world, students can explore and manipulate objects within a three-dimensional space, which is challenging to achieve with conventional learning media (Muhaimin et al., 2023). Additionally, elementary students, who are generally more inclined toward exploratory and play-based learning (Hsieh et al., 2015, 2016; Pellas et al., 2019), make VR a highly suitable medium for primary education. This indicates that VR application in mathematics education can contribute to creating more interactive mathematics learning experiences and have a positive impact on students' mathematics anxiety.

Previous studies show that VR technology can enhance students' cognitive abilities, including spatial skills (Di & Zheng, 2022) and problem-solving skills (Araiza-Alba et al., 2021). However, studies exploring the impact of VR on affective aspects, such as mathematics learning anxiety, are still limited. Mathematics anxiety is a significant challenge in mathematics education, as it can impede the development of students' logical and critical reasoning skills and negatively impact academic performance. Therefore, this study is relevant and urgent as it seeks to fill the gap in the literature regarding the role of VR in reducing students' mathematics anxiety. The main objective of this research is to identify how VR integration can help mitigate mathematics anxiety by providing an interactive learning environment. This study also aims to highlight the benefits and challenges of using VR as an intervention for mathematics anxiety experienced by students. The findings of this research are expected to serve as a foundation for innovation in mathematics learning, specifically in creating more inclusive and effective interactive approaches to address affective barriers such as learning anxiety.

Literature Review

Theoretical Framework of Learning Anxiety

The cognitive theory of anxiety suggests that an individual's thoughts and perceptions greatly influence their emotional responses and behavior. According to Beck's Cognitive Theory (1976), anxiety is triggered by distorted thinking patterns that lead individuals to overestimate threats in a situation. In mathematics education, prospective teachers may experience anxiety due to negative perceptions of their mathematical abilities. This condition, often referred to as 'math anxiety,' can manifest as a fear of failure or a belief that they are not competent in mathematics (Hembree, 1990). Research indicates that such distorted thinking patterns may trigger avoidance behaviors, causing individuals to shy away from engaging with mathematical material, which ultimately exacerbates their anxiety (Ashcraft & Ridley, 2005).

On the other hand, cognitive load theory posits that individuals have a limited capacity for processing information, and when this capacity is exceeded, their performance decreases (Sweller, 1988). In mathematics education, especially when students are confronted with complex problems, their cognitive load may increase, thereby heightening anxiety. This is a concern in elementary education programs, where teachers are expected to teach mathematical concepts to students effectively. Research has shown that high anxiety can impair working memory function, reducing the ability to solve mathematical problems (Ashcraft, 2002). Thus, understanding the cognitive foundations of anxiety is essential for designing effective strategies to mitigate its impact on students.

Math anxiety is a complex issue that affects students' ability to interact positively with the subject. Sheila Tobias first introduced the concept of math anxiety in her book "Overcoming Math Anxiety" (Tobias, 1993), where she described this anxiety as a deep, sudden fear that leaves students feeling helpless to overcome it. Over time, the understanding of math anxiety has broadened to include several indicators, such as low confidence in math ability, fear of failing to grasp mathematical concepts, negative attitudes toward math, and a general fear of the subject (Bursal & Paznokas, 2006). These indicators provide deeper insights into how math anxiety can take root and develop among students.

Low Confidence in Math Ability

Low confidence is often a critical factor in math anxiety. Students who feel inadequately skilled frequently need more confidence in tackling math problems, especially those that require a deeper understanding of the application of more complex concepts. This lack of confidence can lead to decreased motivation and interest in learning mathematics because students tend to think that the difficulties they encounter reflect their insufficient abilities. The result is an avoidance of the subject and a reliance on external help, hindering their ability to grow independently.

Fear of Failing to Understand Mathematical Concepts

Fear of failing to understand mathematical concepts is another significant indicator of anxiety. Students who experience this fear often feel burdened by the thought that they might not be able to solve problems or understand topics adequately. This fear may stem from previous experiences, such as poor grades or negative comments, which make them feel that failure in mathematics is inevitable. Additionally, academic demands and the pressure to achieve good results can exacerbate this fear, leading to high levels of anxiety when faced with math lessons.

Negative Attitudes Toward Mathematics

A negative attitude toward mathematics can worsen learning anxiety. Students who have negative perceptions of math tend to view the subject as unpleasant or even intimidating. This perception may be shaped by the belief that math is difficult, time-consuming, or requires high-level skills. Such a negative attitude results in a lack of motivation to learn, causing students to avoid challenges in mathematics and feel unmotivated to improve their understanding. Consequently, this negative attitude forms a cycle that reinforces anxiety, as students lack the interest to attempt and understand math effectively.

General Fear of Mathematics

A general fear of mathematics often makes students reluctant or even excessively anxious when faced with the subject. This fear is not limited to tests or exams but also arises during learning situations involving math, such as class discussions or presentations. This general fear can be

influenced by the environment, such as peer pressure or expectations from teachers demanding high performance. In some cases, this fear can lead to physical reactions, such as sweating or a rapid heartbeat, demonstrating the profound psychological impact of this anxiety. This fear indicates a need to create a more supportive learning environment so that students feel more comfortable learning mathematics.

Each of the above indicators shows that math anxiety is not solely about academic difficulties but also involves emotional and social factors that need to be managed comprehensively. A deep understanding of these indicators is essential for educators to design instructional strategies that can reduce student anxiety and enhance their confidence, motivation, and interest in learning mathematics.

Theoretical Framework on VR in Education

Virtual Reality (VR) has emerged as an innovative tool in the field of education, providing immersive experiences that enhance learning outcomes by allowing users to interact within a computer-generated three-dimensional environment. This capability is highly beneficial for developing spatial reasoning skills, which are critical cognitive skills across various academic domains. A study by Mikropoulos & Natsis (2011) shows that VR can create an engaging and interactive learning space where students can gain a deeper understanding of spatial concepts, making it a valuable addition to teaching methods.

Compared to traditional teaching methods, VR offers unique advantages in facilitating spatial comprehension. Conventional approaches often rely on two-dimensional representations, such as diagrams or static images, to explain spatial concepts. While these methods are effective, the lack of immersive aspects can reduce student engagement and hinder a deep understanding of complex spatial relationships. In contrast, VR provides a dynamic three-dimensional learning experience where students can manipulate objects and observe spatial relationships directly. Research by Dunleavy et al. (2009) found that students using VR for spatial tasks performed better than those using traditional methods, highlighting VR's potential to bridge the limitations of conventional spatial learning with a more interactive experience.

One of the primary strengths of VR in education is its ability to increase student engagement and motivation. A learning environment that stimulates curiosity and enjoyment has the potential to improve retention and understanding of spatial concepts. Beck (2019) found that students engaged in VR-based learning reported higher levels of interest and enjoyment compared to those studying in conventional classroom settings. The immersive quality of VR promotes an active learning environment, where this increased engagement leads to better outcomes, affirming VR's value as a motivational tool in spatial reasoning education.

Furthermore, VR opens opportunities for collaborative learning, which is essential for cognitive development according to Vygotsky's sociocultural theory. VR environments allow students to work together in a virtual space, promoting teamwork and enabling them to solve spatial problems collectively. Collaborative VR-based activities, as indicated by Molina-Carmona et al. (2018), significantly enhance spatial reasoning skills, showing VR's role as a medium for compelling shared learning experiences. This aligns with the importance of collaborative skills in modern education, where shared learning experiences can deepen the understanding and application of knowledge.

Methodology

Research Design

This study employs a qualitative method with a phenomenological approach. According to Creswell (2015), phenomenology is a research design that aims to understand individual experiences and behaviors in facing a specific phenomenon. In this context, the phenomenological approach is used to analyze the impact of VR technology integration on students' math anxiety. This approach allows the researcher to deeply explore the subjective experiences of students when interacting with math learning materials using VR, which the researcher previously designed.

Additionally, the phenomenological approach provides space for students to express their perceptions and feelings regarding VR-based math learning. Thus, this study not only focuses on identifying changes in anxiety levels but also explores the benefits and challenges arising from the use of VR as an intervention to address math anxiety. Considering the complexity of anxiety in the context of math learning, the phenomenological method is deemed suitable for delving into the emotional dynamics, perceptions, and responses of students to the VR tool applied in the learning process.

Participants

Participant selection in this study was conducted carefully to ensure that the results obtained were reliable and relevant. The participants involved are elementary school students in 2024 studying geometry, focusing on the perimeter and area of flat shapes. The sampling technique used is purposive sampling, a technique for selecting subjects based on specific objectives determined by the researcher (Creswell, 2015). The main criteria for selecting participants include: (1) participants must be enrolled as elementary school students, (2) participants will be engaged in geometry learning, and (3) participants are willing to participate in the entire research process, including VR training sessions and math anxiety analysis.

In addition, participants are also required to have access to the necessary technology to follow the VR intervention. This criterion is essential as not all elementary school students have adequate skills or access to technology, especially VR. By setting clear criteria, the researcher can ensure that the participants involved have the potential to gain maximum benefit from the intervention provided. As explained by Wilson et al. (2007), active participation in the learning process significantly influences learning outcomes, making appropriate participant selection a critical factor in this study. Through purposive sampling, this study involves three elementary school students as subjects labeled S1 to S3 for identification purposes.

Data Collection

To gather the necessary data in this study, we used two main data collection techniques: direct observation and in-depth interviews. These methods were selected to obtain a comprehensive picture of students' math anxiety and the role of VR technology as a potential intervention. Direct observation was conducted during math learning sessions integrating VR, allowing the researcher to directly observe students' responses to the use of this technology in the learning context. This observation technique aims to obtain information related to student behaviors that reflect their levels of anxiety toward math material. Meanwhile, in-depth interviews were conducted to confirm the findings from the observations and to delve deeper into students' subjective perceptions and experiences regarding VR use in learning. These interviews aim to

enrich the data and provide a deeper understanding of how students perceive the impact of VR intervention on their math anxiety. Both techniques, observation, and interviews, work synergistically to identify key themes related to math anxiety and explore VR's potential in addressing this issue.

Data Analysis

In this study, data analysis was conducted following the procedures described by Creswell (2015). The data analysis process begins with collecting all relevant information from observations and in-depth interviews. The collected data is then analyzed through the reduction stage, where the researcher filters and organizes information to identify aspects related to math anxiety and the impact of VR use in learning. The next stage is data presentation, where the analysis results are systematically organized to facilitate understanding and interpretation. At this stage, data is presented in narrative form that clearly illustrates the relationship between VR use and changes in students' math anxiety levels. After that, the researcher draws conclusions based on the findings, which are subsequently used to answer the research questions and provide insights into the effectiveness of VR as a tool to address math anxiety.

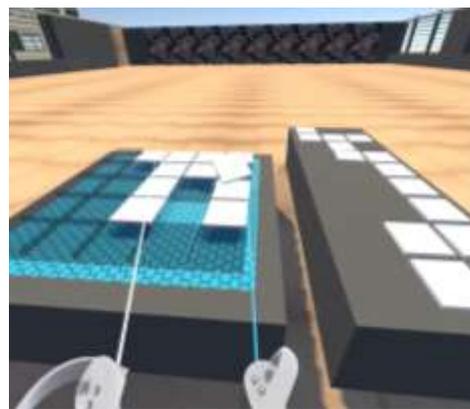
Research Ethics

This study was conducted in accordance with applicable research ethics standards. Before data collection, ethical approval was obtained from the university's research ethics committee. Respondents were provided with an information sheet and a consent form explaining the purpose of the study, procedures to be conducted, their rights as participants, and data confidentiality assurances.

Result

The Role of VR in Student Math Anxiety

A VR-based learning medium was previously developed for elementary-level education, focusing on the perimeter and area of shapes. In the perimeter activity, students are guided to move from one green-colored point to another within the VR space (Figure 1a). Each time students pass through these points, a line is formed until they eventually return to the starting point. In the area activity, students engage in an exploration involving picking up and placing unit squares onto provided flat or three-dimensional shapes (Figure 1b). In some cases, students also need to cut certain parts of the shapes before placing the unit squares correctly.



(a) (b)

Figure 1. Exploration activities of the material (circumference) and area (b) in VR space.

After completing the exploration activities, students are presented with a series of questions designed to confirm their understanding (Figure 2). If a student cannot answer the question correctly, the VR medium automatically directs them back to the exploration activity to reinforce their understanding. This structure ensures effective repetition, where in-depth exploration is supported by continuous practice, thereby strengthening the learned concepts.



Figure 2. Questions in VR space

Following the implementation of the VR-based learning medium, we analyzed to determine students' levels of math anxiety after using the medium. In this regard, we used observation and interviews as data collection tools. The implementation process took place over two sessions, with each session covering one topic—either perimeter or area. Each topic was delivered in one day. Initially, we observed all students in the class participating in VR-assisted learning. From these observations, we then selected three students who appeared most active and fully engaged with the VR medium during the learning process to serve as research subjects for further study. These three students were subsequently interviewed to explore their experiences in-depth following their use of the VR medium.

Initial observations indicated that students were highly enthusiastic about this VR-based learning. Based on preliminary interviews with the teacher, it was revealed that there had previously been no learning involving technological tools like VR. The teacher generally used PowerPoint (PPT) as a teaching aid in addition to the conventional blackboard. The presence of VR in this learning environment introduced a fresh atmosphere that captivated students' interest. However, this enthusiasm only partially aligned with their initial ability to operate the VR equipment. In the initial stage, most students encountered difficulties using the device and required time for instructions on its usage. However, after a brief guide, students began to operate VR smoothly and felt more comfortable using it.

To facilitate understanding of the analysis results regarding students' anxiety, we categorized the findings according to each anxiety sub-indicator, thus providing a more detailed picture of the medium's

Confidence in Mathematical Ability

Confidence in mathematical ability is a critical factor influencing students' performance in understanding and solving mathematical problems. Low confidence often leads to feelings of anxiety and fear when facing math problems, which can hinder their ability to grasp concepts optimally. In this context, using VR learning media aims to create an interactive and immersive learning experience that can reduce students' anxiety, strengthen concept understanding, and ultimately increase their confidence.

During the VR-based learning, students showed a heightened interest and apparent enthusiasm in understanding the presented mathematical concepts. Initially, some students appeared awkward and hesitant when wearing the VR equipment and beginning the simulation. This hesitation indicated that most were unfamiliar with the technology and perhaps needed more confidence in understanding the material. However, over time, students appeared more comfortable and began exploring the material with greater confidence. VR enabled students to visualize mathematical concepts, such as perimeter and area, in a more concrete and interactive form. This visualization provided students with the opportunity to comprehend abstract concepts more tangibly, making it easier for them to internalize and understand the material. This positively impacted their confidence, with some students who previously seemed passive or hesitant now showing increased engagement and participation.

Some students who typically exhibited anxiety when solving problems began to try tackling problems without fearing mistakes. They asked questions more frequently and expressed their understanding of the concepts being learned, indicating increased confidence in their abilities. Other signs of improved confidence included more relaxed facial expressions and verbal responses that suggested greater satisfaction and comprehension of the material. Additionally, students appeared more motivated to repeat simulations and attempt practice problems within VR. This exploratory behavior suggested increased confidence, as they felt more comfortable practicing and learning from mistakes.

Subsequent findings from observation were confirmed through post-implementation interviews following the VR-based media use. Three students, referred to as S1, S2, and S3, were selected for these interviews. Each subject had unique responses, but where responses were similar, only one response was presented. All three subjects were interviewed using this indicator and provided differing responses.

- Researcher : *"How did you feel about your mathematical ability before using the VR media?"*
- S1 : *"Previously, I felt very scared and lacked confidence when working on math problems. I often felt confused and worried that I couldn't understand the material, which made me feel inadequate"*
- S2 : *"Before using VR, I was actually quite able to understand basic material, but when the problems got harder, I immediately felt doubtful and afraid of making mistakes. Sometimes I felt that my ability wasn't strong enough to solve difficult problems"*
- S3 : *"I wasn't too confident, but I wasn't too anxious either. I felt my ability was average, but when the problems looked complex, I tended to guess rather than truly understand the concept"*

- Researcher : *"After using VR in learning, did you feel any change in your confidence?"*
- S1 : *"Yes, there was a significant change. With VR, I felt I could understand the material better because I could see the concept directly and interact with the simulation. It made me more confident and less afraid to make mistakes when trying the problems"*
- S2 : *"There was a change. I felt more confident when working on problems after learning with VR. Although there's still some doubt, at least my understanding of certain concepts improved. It helped reduce my fear"*
- S3 : *"There was a bit of change, though not very much. VR helped me understand the material better, but I still need more practice to really build confidence. At least now I'm not too afraid when facing somewhat difficult problems"*

Based on the interview excerpts above, S1 showed a change in confidence in mathematics after using VR media. Previously, this subject felt very afraid and lacked confidence in solving math problems, mainly because they felt they could not adequately understand the material. VR implementation appeared effective for this subject, as VR offered a visual and interactive learning method that helped alleviate anxiety and made them more confident in understanding and applying mathematical concepts. These results indicate that VR implementation has a strong potential to build confidence in students who previously felt unsure of their math abilities, suggesting that VR-based learning could be an effective tool for students with high levels of math anxiety.

In contrast, S2 experienced moderate anxiety before using VR, feeling quite confident with primary material but becoming anxious when problems became more complex. After using VR, this subject felt an increase in confidence, although the change was not as significant as the first respondent. The respondent felt more confident in understanding certain concepts, which helped reduce the fear of facing problems. However, some aspects still caused doubt. VR implementation helped S2 increase confidence in mathematical ability, though the impact did not eliminate the anxiety when facing complex problems. This shows that VR can be a supportive tool for reducing anxiety but may require additional approaches, such as intensive practice or further guidance for students with moderate anxiety.

Differing from the previous responses, S3 had relatively low anxiety and perceived their math ability as "average." Although they felt somewhat supported by VR, the subject found the change not particularly significant. The respondent felt that VR helped them understand the material, but it only partially increased their confidence. This may be because the respondent still felt the need for more practice to build confidence truly. VR implementation had minimal impact on this subject's confidence. While VR facilitated understanding, the need for more practice suggests that VR alone may not be sufficient to boost confidence for students with low anxiety but limited confidence in math. For students like this, VR can serve as a supplementary tool, while practice-based learning methods may be more effective in genuinely building confidence.

Fear of Failing to Understand Mathematical Concepts

The fear of failing to understand mathematical concepts is a form of anxiety that arises when students feel worried about not being able to comprehend or apply the material being taught. This anxiety often leads students to avoid activities related to mathematics due to the fear of making mistakes or failing in the learning process. This indicator aims to observe how students respond to visualizations of mathematical concepts using VR-based media.

During the implementation of VR-based learning media, students are encouraged to explore various concepts of area and perimeter of plane figures through interactive visual simulations. The VR media allows students to interact directly with models of plane figures, which they can rotate, enlarge, and examine from multiple perspectives. Each student experimented with various simulations provided, such as calculating the perimeter or area by following virtual instructions integrated into the VR application. Initially, some students appeared anxious and hesitant when entering the VR learning session, especially those who previously struggled with mathematical concepts. They displayed cautious behavior, often pausing or pondering before continuing their exploration. However, over time and after a brief explanation of using VR, students began engaging more actively in exploring the provided features.

During observations, positive indicators of students' confidence began to emerge. As they visualized the concepts of area and perimeter firsthand, their anxiety appeared to decrease. Previously, passive students became more willing to attempt to understand these concepts without fearing mistakes. They became more enthusiastic about completing the instructions in VR and independently performing calculations using the available plane figure simulations. Students' verbal responses also reflected increased confidence. Those who usually felt anxious when faced with math problems appeared calmer and more enthusiastic during VR activities. They were heard discussing their calculations and the workings of VR with each other, and they seemed more comfortable asking questions to teachers or peers if they encountered difficulties without fear of appearing "wrong" or failing.

From their expressions and behaviors, it was evident that the learning experience through VR media provided comfort and reduced their fear of understanding mathematical concepts. Some students even repeated the simulations to ensure their understanding, indicating that the fear of failure was gradually replaced by curiosity and self-confidence in learning concepts of area and perimeter.

These findings were further confirmed through interviews with S1, S2, and S3. For this math anxiety indicator, we obtained three interview responses per subject, but only two responses were shown as two of them (S2 and S3) were identical.

- Researcher : *“How did you feel before using VR media to understand mathematical concepts, especially the more complex ones?”*
- S1 : *“I often felt afraid of failing to understand the material, especially concepts that seemed complex. It felt like, no matter what I did, I always made mistakes, which made me feel insecure”*
- S2 : *“Before using VR, I was worried about complex material. I usually avoided it because I was afraid I would not understand. It felt easier to observe from a distance”*

- Researcher : *“After using VR media in learning, did you notice any changes in your understanding of previously complex mathematical concepts?”*
- S1 : *“Yes, VR helped a lot! I could see how the concept worked directly. For example, when learning about perimeter and area, the VR visualization made me understand better. My fear decreased, and I felt more confident when trying to solve problems”*
- S2 : *“With VR, I felt more encouraged to try to understand the more complex concepts. Now, I can see the concept more clearly, so I am not as afraid of failing anymore because I can see how to apply it directly”*

The interviews demonstrate the positive impact of using VR media in helping students overcome their fear of failing to understand complex mathematical concepts. The fear of failure often stems from past unsuccessful experiences, limited concept comprehension, or even academic pressure that causes students to hesitate to engage with new concepts.

S1 expressed feeling afraid of failing and lacking confidence when faced with complex mathematical concepts. S1 felt that every effort often ended in mistakes, which ultimately reduced their confidence. This suggests a negative mindset that traps S1 in a cycle of failure—efforts seem never to be enough, and each mistake reinforces their fear. After using VR, S1 experienced a significant change, particularly in understanding and confidence. S1 mentioned that the interactive visualization helped them "see how the concept works directly." When abstract concepts like perimeter and area are presented through VR media, students can better understand the relationships between elements in a plane figure. VR allows them to interact with concepts visually, reducing ambiguity and addressing anxiety caused by fear of mistakes. This suggests that VR-based learning not only adds clarity but also instills courage and confidence in S1 to attempt math problems independently.

In the following responses by subjects 2 and 3, before VR-based learning, there was apprehension about complex material, leading them to need help understanding those concepts. S2 preferred to "observe from a distance" rather than engage actively, reflecting an avoidance strategy as a form of protection from the fear of failure. This tendency to avoid risks may stem from past experiences of failure or the perception that mistakes could result in negative consequences, such as lowered confidence or judgment from others. After VR-based learning, these subjects experienced a positive change in their attitude toward challenging mathematical concepts. With VR, the subjects felt more encouraged to try to understand complex concepts because they could see the concepts more clearly and directly. Interactive visualization provided a more profound understanding, thereby reducing the fear of failure. The subject is now more motivated to try applying the learned concepts, something they previously avoided.

Negative Attitude Towards Mathematics

In this indicator, we conducted interviews with each subject before and after the implementation of VR-based learning media in mathematics education. Before using this VR learning media, all three subjects expressed a negative perception of mathematics. They felt that mathematics was a complex subject and tended to cause stress. One subject said, "I've never liked mathematics, it seems too complicated to understand." This response represents the view of all three subjects,

who felt that mathematics was one of the subjects they struggled to master. As further explained by the subjects, this perception arose for several fundamental reasons.

One of the main reasons was their limited basic understanding, which made it increasingly difficult for them to follow mathematical concepts as the material became more complex. Additionally, their experience with learning mathematics in the classroom could have been more enjoyable and varied. They felt that the teaching methods used by the teacher were not varied, and the learning tools needed to be more diverse, which caused them to become bored quickly and struggle to focus. One subject expressed, “When learning mathematics in class, it feels boring, just writing down formulas. Sometimes I don’t even understand why the formulas are like that.” Furthermore, all three subjects mentioned a lack of confidence when faced with math problems. They were afraid of making mistakes and worried about failing, which led them to be reluctant to participate in class actively. There was also a common belief that mathematics was only relevant to brilliant students, which further strengthened their negative perceptions.

However, after the implementation of VR-based learning media, a significant change in their attitude towards mathematics was observed. The subjects showed increased interest and motivation in learning mathematics. This was because, previously, the teacher had never introduced innovative learning tools like VR. The VR media, with visualizations of mathematical concepts in three dimensions, made them more interested and made learning feel more enjoyable. One subject said, “With VR, I can see the shapes directly from the problems. So, I’m not just imagining it, I can actually see how it works.” This interactive learning experience helped them reduce the anxiety they previously felt. They felt more comfortable learning mathematics and more confident in solving problems. Additionally, their understanding of mathematical concepts also improved. By using VR, the subjects could visualize abstract concepts and interact directly with the material, making complex concepts easier to understand. The subjects began to see that mathematics has concrete applications and is not just about calculations on paper. One of them stated, “I didn’t expect that mathematics could be seen like this. This is the first time I feel like I understand.” The implementation of VR-based learning media showed a positive impact in changing students’ negative perceptions. It also helped improve their understanding of mathematics. These findings suggest that technology, especially VR, can be an effective tool to help students overcome negative perceptions and learning difficulties in subjects considered challenging.

General Fear of Mathematics

Before the implementation of VR-based learning media, it was identified that all three subjects showed a general fear of mathematics. This fear included feelings of anxiety, lack of confidence, and the perception that mathematics was a difficult or even frightening subject, which had been formed early on. This led to ongoing fear, even affecting the students psychologically. The following is an excerpt from in-depth interviews with the students.

- Researcher : *“What do you think is the source of this fear or difficulty?”*
- S1 : *“I feel anxious when asked to go to the front of the class because I am worried that my answer will be wrong. Mathematics is a subject for students who are good at it, not for me”*
- S2 : *“Yes, I have experienced that, but sometimes the explanation from the teacher is complicated for me to understand. Seeing my classmates*

understand the material better, I end up feeling more inferior. Eventually, I chose to stay quiet rather than try”

- S3 : *“Yes, every time I have a complex problem, I am afraid my answer will be wrong. In the end, I became more insecure and felt that I would never be able to master mathematics”*

Based on the interviews above, S1 explained that anxiety arises when asked to go to the front of the class, as they are afraid their answer will be wrong. The subject feels that mathematics is more suited for students who are better at it, so they judge themselves as lacking the necessary ability in this subject. A different response was given by S2, who had tried asking the teacher but found the explanations challenging to understand. This only added to feelings of inferiority and lack of self-confidence, leading them to choose not to try rather than risk making a mistake. Finally, S3 explained that the fear of making a mistake made them increasingly insecure, and they felt they would never be able to master mathematics.

After the implementation of VR media in mathematics learning, interviews were conducted again to assess the students' responses post-implementation of this media.

- Researcher : *“How do you feel about mathematics now after using VR media?”*
- S1 : *“In the media, I was faced with interactive exploration activities, and the interactive problems made me more engaged in the learning process”*
- S2 : *“I can manipulate objects directly, so the concepts are more precise. If I need help understanding, I can try again until I do, and that really helps”*
- S3 : *“Yes, with VR, I do not feel as tense as I do in regular classes. If I make a mistake, I can try again without fear”*

The results of the interviews after the implementation of VR media in mathematics learning showed a change in the subjects' attitudes toward the subject. All three subjects reported a positive experience after using the VR media, which contributed to overcoming their fear and difficulties in learning mathematics. S1 felt that the use of VR in mathematics learning provided them with the opportunity to engage in interactive exploration activities. This experience not only made them more active in learning but also reduced their fear, as they felt more directly involved with the material being taught. This indicates that with VR media, fear of mathematics can be reduced, as students can interact with math problems in a more enjoyable and non-intimidating way.

For S2, the ability to directly manipulate objects in VR made mathematical concepts more transparent and easier to understand. The trial-and-error process, without the pressure of time or external evaluation, allowed students to learn in a more accessible manner, reducing the fear of making mistakes. For S3, they stated that with VR, they felt more relaxed and not as tense as in regular classes. The ability to try again without fear of mistakes made them more confident. This shows that VR helps create a safer emotional learning environment, where fear and anxiety towards mathematics are reduced, and students can learn more freely.

Benefits and Challenges of Using VR

In this study, we identified the benefits and challenges of using VR-based learning media through direct observation and interviews with students. Observations showed that the use of VR media can increase student enthusiasm for learning mathematics. The learning process became more interactive, with students actively trying and exploring activities provided by VR to deepen their understanding of mathematical concepts. Additionally, the interview results showed a positive shift in perceptions towards VR media, especially for students who previously had negative views of mathematics. Students who felt afraid or anxious about learning mathematics were motivated to learn after interacting with the VR media. Those who were initially afraid of facing math problems were instead challenged to solve the problems presented in VR, which in turn improved their understanding of the material and reduced learning anxiety.

Although VR media offers significant learning benefits, its implementation also faces several challenges that need to be addressed. One of the main challenges is the initial adjustment required for students and teachers who need to become more familiar with VR technology. Since this technology is still relatively new, both students and teachers often experience difficulties during the initial phase of use. Time and effort are needed to introduce this media in a way that allows students to fully maximize the potential of VR in the mathematics learning process. This adjustment is crucial for the effective use of VR and for achieving optimal results.

Moreover, limitations in access and infrastructure present significant challenges. VR media requires specific hardware, such as VR headsets and high-spec computers, which may only be available in some schools, particularly those with limited budgets. The relatively high cost of the equipment can be an obstacle for educational institutions to provide this technology evenly, thus limiting the reach of VR media in the broader educational environment.

VR media also has limitations in terms of the content or material that can be integrated. Not all subjects can be easily adapted into VR format, especially abstract material or content that lacks solid visual elements. This can limit the effectiveness of VR as a comprehensive learning aid. Another challenge is the dependency on technology. There is concern that students may become overly reliant on VR technology, believing that they can only understand the material with its assistance. However, VR media should function as an extension or supplement to existing learning, helping to deepen student understanding rather than as the sole method. This challenge requires educators to convey that VR is merely a tool to enhance an already solid understanding so that, even in the absence of VR media, students are still able to grasp the concepts well.

Additionally, technical issues and the need for adequate infrastructure support also present barriers. Using VR requires a stable internet connection, reliable hardware, and competent technical support to address any disruptions that may occur. These barriers can impede smooth learning and require considerable resources. With these various challenges, while VR has great potential to enhance the quality of learning, its success depends on infrastructure support, user training, and practical strategies to avoid over-reliance on technology. The readiness of institutions, educators, and students to integrate VR in a balanced way is essential for this media to have an optimal and sustainable impact on learning.

Discussion

The research results indicate that VR-based learning media helps students reduce their anxiety toward mathematics. These findings suggest that the use of VR-based learning media has the potential to increase student's confidence in learning mathematics by providing a more

interactive and immersive learning experience. VR allows students to experience the visualization of abstract concepts, which helps them understand the material more concretely and reduces learning anxiety. However, VR's impact appears to be limited, indicating that this technology may be more effective when combined with other learning methods, such as intensive practice. In terms of learning theory, these findings align with cognitive load theory (Sweller, 2011), which states that concrete visualization can reduce students' cognitive load, allowing them to focus more on achieving a deeper understanding of concepts. The use of VR in mathematics learning serves as a tool to reduce the mental burden typically experienced by students when faced with abstract concepts such as geometry or calculus. According to previous research by Cheng & Tsai (2020), immersive media like VR is effective in increasing students' interest and reducing anxiety, as it provides a direct experience that can change their perceptions of subjects previously deemed difficult. This finding strengthens the research results, especially in the context of mathematics, where VR helps create a safer and more enjoyable learning environment for students who often hold negative perceptions of mathematics.

These findings also support the Self-Efficacy Theory (Bandura & Watts, 1996), which asserts that direct experience of successfully performing an activity can enhance individuals' belief in their abilities. The interactive VR learning experience allows students to overcome their fears and feel successful in solving mathematics tasks, thereby boosting their confidence. In line with the study by Huang et al. (2020), VR media that provides direct simulations has proven effective in improving students' self-efficacy, particularly in subjects that often provoke high anxiety, such as mathematics.

However, challenges in implementing VR media must also be considered. For students who still require additional practice or further guidance, more than VR is required. This supports the view of Zhang et al. (2020) that innovative learning media like VR should be combined with traditional methods to achieve optimal results, especially in learning contexts that require deep understanding and persistence, such as mathematics.

Furthermore, the findings indicate that the use of VR-based learning media can reduce students' fear of understanding mathematical concepts, particularly the area and perimeter of flat shapes. Initially, many students felt anxious and lacked confidence when faced with what they considered complicated material. However, after interacting with concept visualizations through VR, this anxiety decreased, and students appeared more enthusiastic and willing to explore mathematical concepts. VR media helps students see the practical applications of concepts, providing a more interactive and realistic learning experience, which, in turn, enhances their confidence. According to Ashcraft & Krause (2007), mathematics anxiety arises when students feel incapable of understanding the material, which can negatively impact their performance and participation. This anxiety can trigger avoidance mindsets, as seen in students S2 and S3, who tend to "follow from a distance" to avoid the risk of failure. This aligns with Bandura & Watts' (1996) self-efficacy theory, which suggests that the fear of failure can be exacerbated when students have low confidence in their ability to complete specific tasks.

With interactive visualizations like VR, the learning experience becomes more concrete and more accessible to comprehend, allowing students to overcome the fear of making mistakes. Studies by Merchant et al. (2014) also show that VR can improve students' motivation and confidence by providing an immersive learning environment where abstract concepts become more accessible to understand. Interactive visualization allows students to directly engage with concepts, helping to address any unclear ideas that may lead to anxiety.

Before using VR media, students exhibited negative attitudes toward mathematics, viewing it as difficult, tedious, and stressful. A lack of basic understanding, monotonous teaching methods, and fear of making mistakes were the primary factors reinforcing this perception. After implementing VR, a positive change occurred. Students became more motivated and confident and found it easier to understand abstract concepts due to 3D visualization. VR created an interactive learning experience, making mathematics feel more concrete and engaging for students. Typical fears of mathematics included anxiety, lack of self-confidence, and the feeling that mathematics was only suitable for "smart" students. After using VR, students felt calmer, more willing to try without fear of mistakes, and more confident. VR provides a more emotionally secure learning environment, helping to reduce students' anxiety and fear.

These findings align with learning motivation theory and perceptions of mathematics. According to motivation theory, engaging and interactive learning experiences like VR can enhance students' intrinsic motivation (Arayaphan et al., 2022). In the context of mathematics learning, enjoyable experiences and active student engagement can reduce anxiety and fear, which plays a role in increasing motivation to learn mathematics (Ashcraft & Moore, 2009). Furthermore, negative perceptions of mathematics are often caused by inadequate and unengaging teaching, as explained by educational perception theory, which emphasizes the importance of relevant and engaging learning approaches (Skemp, 2020). Previous research has shown that technology such as VR is effective in addressing negative perceptions and anxiety in learning mathematics. Xin (2022) found that VR can increase student engagement and understanding of abstract material. Another study by Keller et al. (2018) also showed that VR can provide visual representations that help reduce cognitive difficulties in learning mathematical concepts, thereby improving student learning outcomes.

This study also shows that the use of VR media in mathematics learning brings benefits such as increased enthusiasm, interactivity, and motivation among students. Students who were previously anxious or fearful of mathematics tend to show positive changes in their perceptions, becoming more motivated and challenged to solve mathematics problems in the VR environment. However, the implementation of this media also faces significant challenges, such as initial adaptation for students and teachers, limited infrastructure and access, and dependency on technology. From a constructivist learning theory perspective, the benefits of VR align with Piaget and Vygotsky's views that active and interactive learning can improve student understanding as they build knowledge through direct experiences (Vygotsky, 1978). According to research by Merchant et al. (2014), VR technology allows students to interact directly with content, which can enhance their engagement and understanding compared to traditional methods. On the other hand, challenges related to infrastructure and access limitations are consistent with findings by Jowallah et al. (2018), who revealed that technological barriers in education are often caused by a lack of adequate infrastructure and sufficient teacher training.

Additionally, the issue of VR technology dependency identified in this research can be linked to Sweller's (1988) cognitive load theory. Relying on VR without a solid foundational understanding may increase cognitive load, where students depend on technological assistance without deeply understanding the concepts. The solution suggested in this theory is to use technology as a support for learning, not as the sole source of understanding, so that students are still able to master concepts without the aid of VR.

Conclusion

VR-based learning media shows great potential in reducing anxiety and increasing students' confidence in learning mathematics. VR makes the learning experience more interactive and immersive, allowing students to visualize abstract concepts concretely, which reduces fear and motivates them to engage more deeply with the material. This reduction in anxiety is related to the decreased cognitive load, which makes it easier for students to focus on a deeper understanding of concepts. VR also strengthens students' self-confidence, supporting the development of their self-efficacy through positive learning experiences. The VR-based learning environment provides students with opportunities to experiment without fear of making mistakes, creating a safe atmosphere that supports intrinsic motivation toward mathematics.

However, the implementation of VR faces several challenges. The adaptation to this technology requires time for both students and teachers, as it is still relatively new. On the other hand, limitations in infrastructure and access in schools with limited budgets also pose obstacles to the widespread application of VR. Total dependence on VR without reinforcing basic concepts can also increase students' cognitive load, leading to difficulties in understanding the material if not accompanied by other teaching methods. Therefore, VR should be positioned as a supportive tool, not the sole source of understanding, so that students can achieve a deep understanding of concepts with the support of this technology.

Overall, VR-based learning media positively contributes to creating an interactive learning experience, enhancing student motivation, and reducing anxiety in learning mathematics. To achieve optimal results, the use of VR should be combined with other teaching methods, such as intensive practice and additional guidance, so that students gain a deep understanding and do not rely solely on technology. In the future, the integration of VR in education requires infrastructure readiness, teacher training, and practical strategies to maximize the positive impact of VR in sustainable learning processes.

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