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ANALYSIS OF THE USE OF AUGMENTED REALITY IN LEARNING MATHEMATICS

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ABSTRACT

The use of textbooks or LKPD as learning media has several limitations, such as students' difficulties in reading and understanding content and a lack of interactivity, which may lead to boredom during the learning process. One promising technological solution to address these challenges is Augmented Reality (AR). This study aims to identify the common mathematical topics, learning models, and objectives frequently examined in research on AR-based mathematics education. The research methodology employed is a literature study, analyzing previous studies related to the integration of AR in mathematics learning. The findings indicate that the most frequently studied mathematical topic in AR-based research is geometry, particularly three-dimensional (3D) shapes, as AR allows students to observe and interact with geometric models more realistically. Additionally, the most commonly implemented learning models in AR-based mathematics education include inquiry-based learning and game-based learning. The impact of AR in mathematics learning includes enhancing student interest and motivation, deepening conceptual understanding, and increasing student engagement in the learning process.

Keywords: Augmented Reality, Mathematics, Geometry

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PRELIMINARY

Mathematics is a fundamental subject taught at all levels of education, playing a crucial role in the advancement of science and technology (Nurlaela & Imami, 2022). It serves as the foundation for technological and scientific developments worldwide. Through mathematics education, students are expected to develop logical, precise, critical, and innovative thinking skills, making it a vital aspect of knowledge advancement (Hasibuan, 2018). However, mathematics is often perceived as a challenging subject by students due to its abstract nature and traditional teaching methods that may not effectively engage learners (Mulyati & Evendi, 2020). The reliance on static materials, such as textbooks and worksheets, often fails to provide interactive and visual representations, making it harder for students to grasp complex mathematical concepts (Fatimatuzzahro et al., 2021). To address

these challenges, educators must adopt more engaging learning approaches that foster active participation, creativity, and innovation in mathematics education.

One promising approach is the use of Augmented Reality (AR) as an interactive learning tool. AR enhances the learning experience by integrating digital elements into the real world in real-time, making abstract concepts more tangible and engaging. Unlike conventional teaching methods that rely on static images and text, AR provides immersive and interactive environments, allowing students to explore and manipulate three-dimensional (3D) objects dynamically.

In mathematics education, particularly in geometry, AR has proven to be an effective tool for visualizing complex structures. A study by Nurvitasari & Sulisworo (2023) demonstrated that AR-based student worksheets (LKPD) significantly improved students' comprehension of three-dimensional shapes, especially cubes. Through AR, students can observe and interact with geometric models from multiple perspectives, which enhances their spatial reasoning and conceptual understanding. Recent research by Volioti et al. (2023) and Prasetya et al. (2024) supports the idea that Augmented Reality (AR) not only fosters student engagement and motivation but also helps them grasp complex mathematical concepts more effectively than traditional teaching methods. By bridging the gap between theoretical knowledge and real-world application, AR provides a more interactive and immersive learning experience, enriching students' understanding of mathematical principles.

With its potential to transform the learning experience, AR serves as a powerful educational tool that not only enhances visualization but also creates an interactive and stimulating environment for students. Its integration into mathematics education offers a promising approach to making learning more engaging, efficient, and conceptually accessible.

The rapid advancement of technology has significantly influenced education, particularly in the development of digital learning tools that enhance student engagement and understanding (Nurfaidah et al., 2023). One of the most significant technological advancements in education is the growing use of mobile devices for learning. Research shows that most students today have access to smartphones, making mobile-based learning solutions, such as Augmented Reality (AR), more practical and accessible (Khairunnisa & Aziz, 2021). With AR technology integrated into mobile applications, students can visualize mathematical concepts more interactively, turning abstract ideas into tangible experiences. Despite technological advancements, many educators still rely on conventional learning

media, such as textbooks and worksheets, which may not adequately address students' difficulties in understanding mathematical concepts. These static resources often fail to provide interactive and visual representations, making it harder for students to grasp abstract mathematical ideas. Obstacles in reading and understanding mathematical content in textbooks often cause students to feel bored during the learning process (Suganda & Fahmi, 2022). Therefore, there is a need for learning media that can support students in understanding the material and visualizing various mathematical figures.

Based on the opinion of Al Ikhsan et al. (2022), one of the technologies that has experienced rapid development to date is the smartphone. Almost all levels of society, including students, have at least one smartphone unit, and some even have more than one. The increase in the number of students who own and use smartphones opens up greater opportunities for the use of technology in education. Among a number of technological applications that can support learning mathematics using smartphones is Augmented Reality (AR). AR technology offers various advantages in learning media, including helping teachers with material delivery, saving time, and forming an interactive learning atmosphere and being able to build positive energy (Saputra et al., 2023).

Augmented Reality has a characteristic as an educational media that is not only interactive but also gives a real impression that can be directly experienced by students (Nurhaliza et al., 2022). The appearance of virtual objects in Augmented Reality (AR) can facilitate direct interaction between users, especially students, and the objects they are studying. This AR technology is easily accessible through smartphones, making it highly practical for students. In addition, AR functions as a bridge between the digital world and the physical world, allowing significant interaction between the two, and providing a display of objects in a three-dimensional format (Kartini et al., 2020; Setiawan et al., 2023). According to Afifi et al. (2021), effective use of learning media is expected to reduce the level of abstraction of material, increase students' motivation to learn, and improve their learning outcomes. This is supported by research by Khoirunnisya et al. (2024), which explains that the use of learning media is one technique to help students understand mathematical concepts. The use of media in mathematics education is very important because it can make abstract mathematical concepts more concrete.

While previous studies have explored the implementation of Augmented Reality (AR) in mathematics education, many have primarily focused on technical development and usability rather than its direct impact on student comprehension and learning effectiveness. For instance, research by Meilindawati et al. (2023) investigated AR applications in

classroom settings but did not assess measurable improvements in students' conceptual understanding. Similarly, Kartini et al. (2020) examined AR-based teaching tools but focused more on student engagement rather than knowledge retention. These gaps indicate the need for more empirical studies analyzing how AR specifically enhances students' mathematical comprehension and problem-solving abilities.

Therefore, this study aims to address this gap by examining the impact of AR on students' conceptual understanding of mathematics, particularly in visualizing abstract concepts and improving problem-solving skills. By focusing on both engagement and learning outcomes, this research will contribute to a deeper understanding of AR's role as an effective educational tool in mathematics instruction

METHODS

This study employs a qualitative research method using a library research approach. Library research is a series of activities carried out to collect, read, record, and analyze various scientific literature relevant to the research topic. In this study, library research is used to examine the application of Augmented Reality (AR) in mathematics learning, particularly in enhancing student motivation and conceptual understanding. Research on library studies based on the opinion of Assyakurrohim et al. (2022) is characterized by the main characteristic in which researchers directly interact with existing sources, such as journals.

The subject of this study consists of scientific literature, including research journals, academic books, conference proceedings, and scientific articles discussing the implementation of Augmented Reality in education, specifically in mathematics learning. To ensure that the sources used are relevant to recent developments, this study limits the literature reviewed to those published between 2020-2024.

The data collection technique involves identifying, selecting, and analyzing literature discussing the use of AR in mathematics learning. Literature sources are gathered from various scientific databases using specific keywords, such as "Augmented Reality in mathematics learning," "student motivation through AR," and "conceptual understanding with AR."

The data analysis technique used in this study is content analysis, which is conducted systematically, objectively, and critically on the reviewed literature. The analysis is carried out in several stages. First, data organization, which involves searching for and collecting literature relevant to the research problem and objectives by reviewing abstracts,

introductions, methodologies, findings, and conclusions from various sources. Second, literature classification, which involves reading and recording key information from various literature discussing Augmented Reality in mathematics learning, particularly concerning student motivation and conceptual understanding. Third, information synthesis, which integrates the findings from the literature review into a unified whole by identifying relationships between the various studies analyzed. Fourth, identification of key findings, which involves analyzing patterns or trends emerging from previous studies to determine the effectiveness of AR in improving students' understanding and motivation in mathematics.

Through this approach, this study aims to provide a comprehensive overview of the application of Augmented Reality in mathematics learning and to contribute to the scientific understanding of AR's effectiveness in enhancing student motivation and conceptual comprehension. The findings of this study are expected to serve as a reference for educators and researchers in developing more interactive and innovative technology-based learning methods.

RESULTS AND DISCUSSION

1. Augmented Reality (AR)

Augmented Reality (AR) is a technology that integrates digital elements into real-world environments, enabling interactive and real-time experiences (Hernita, 2023). Unlike Virtual Reality (VR), which fully immerses users in a digital environment, AR enhances the real world by overlaying digital objects that can interact with users. The concept of AR was first introduced by Thomas P. Caudell in 1990, where it was described as a system capable of dynamically and interactively merging the physical and virtual worlds.

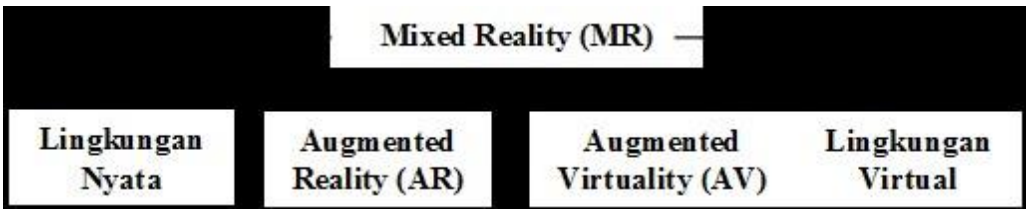

Figure 1. Real environment - virtual environment sequence

The AR system possesses several key characteristics that distinguish it from other technologies. First, AR integrates the physical environment with digital objects, allowing users to interact with the real world while receiving additional information in the form of visuals, sound, or animation. Second, this technology enables real-time interaction, where digital information can change or respond instantly to user actions, creating a more

immersive experience. Additionally, AR has the capability to display objects in a three-dimensional format, providing a more realistic visual perspective and helping users comprehend concepts that are otherwise difficult to visualize conventionally (Hernita, 2023).

In the context of education, the implementation of AR has brought significant changes to interactive learning methods. According to research by Indahsaria and Sumirat (2024), the use of AR in academic settings allows students to engage with learning materials more deeply, particularly in subjects that require complex visual understanding, such as mathematics, physics, and biology. This technology helps students grasp abstract concepts more effectively through realistic visual simulations. For example, in geometry learning, AR enables students to observe and manipulate three-dimensional shapes directly, which would not be possible using only two-dimensional textbook images. Additionally, in science subjects, AR can simulate laboratory experiments virtually, allowing students to conduct experiments without safety risks or equipment limitations.

Despite offering numerous advantages in education, the implementation of AR still faces several challenges. One of the primary obstacles is the need for adequate infrastructure, such as AR-compatible devices and a sufficiently powerful computing system to run AR-based applications optimally. Furthermore, integrating AR into the learning process requires proper training for educators to ensure they can effectively incorporate this technology into their teaching methods. Without sufficient understanding from educators, AR risks becoming merely an additional tool without significantly impacting the learning process. Another challenge is the relatively high cost of developing AR-based content, making it difficult for all educational institutions to adopt this technology on a broad scale.

With the various benefits it offers, AR has the potential to become one of the leading technologies in digital-era education. Studies by Chen et al. (2021) and Lee and Chung (2021) indicate that AR use in education can significantly enhance student motivation and comprehension. However, to ensure its effective utilization, a well-planned implementation strategy is required, including investments in technological infrastructure, teacher training, and the development of a curriculum that integrates AR technology. With these measures in place, AR can truly revolutionize the way students learn and create a more interactive, engaging, and effective educational experience in the future.

2. Augmented Reality (AR) technology system in improving learner motivation and the quality of learning.

Augmented Reality (AR) technology has been widely studied as an effective tool in education due to its ability to enhance students' learning experiences by improving their skills and knowledge efficiently (Alenezi, 2023). This aligns with the Sustainable Development Goal (SDG) 4, which emphasizes quality education. The integration of AR in the learning environment serves as an innovative strategy to enhance student motivation and engagement, leading to a deeper and more effective understanding of the subject matter (Alenezi, 2023; Carolina, 2022). In the context of mathematics education, AR has the potential to bridge the gap between abstract concepts and their real-world applications, facilitating both technical and conceptual comprehension while increasing student motivation.

Recent technological advancements have made AR more accessible in educational settings. One of the widely used approaches in AR-based learning is the interactive print system, which utilizes markers such as QR codes to connect physical learning materials with digital AR content (Alenezi, 2023). These markers serve as intermediaries, enabling students to visualize and interact with virtual objects through their devices. However, as AR technology evolves, it is no longer limited to QR code-based activation. Modern AR systems can recognize image-based content, such as diagrams and illustrations in textbooks, allowing for a more seamless and intuitive learning experience (see Figure 2). For instance, a student studying geometry can scan an image of a cube from a textbook, prompting an interactive 3D model to appear on their device screen.

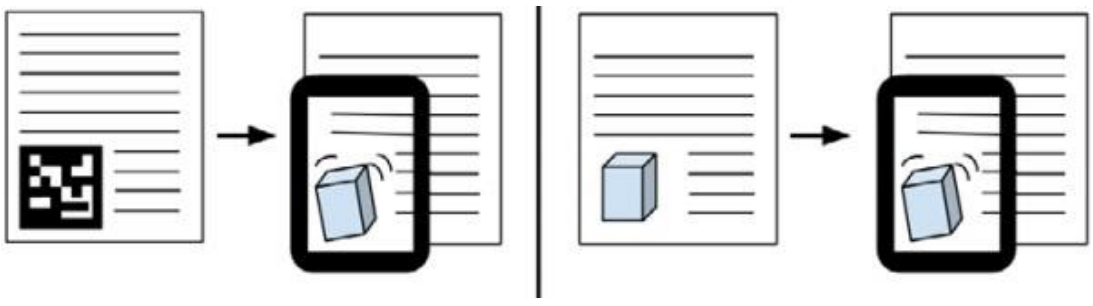

Figure 2 a) AR using QR Codes, b) AR using images.

Various studies indicate that AR technology can support and improve different learning approaches, making the learning process more engaging and effective. Several key approaches that benefit from AR implementation include:

a) Constructivist Learning

AR facilitates student engagement by allowing them to explore and construct relationships between prior knowledge and new concepts (Ropawandi et al., 2022). This approach fosters deeper learning by enabling students to interact directly with virtual objects, enhancing their cognitive development.

b) Situated Learning

Learning in real-world contexts becomes more effective when AR integrates real-life elements into the classroom setting (Wen & Looi, 2019; Zhao et al., 2020). This method helps students understand abstract concepts by linking them to familiar, everyday experiences.

c) Game-Based Learning

AR enhances game-based learning by enabling students to engage with digital narratives, assume various roles, and apply knowledge to practical situations (Brom, Sisler, & Slavik, 2020). This immersive experience increases motivation and allows for more interactive problem-solving activities.

d) Inquiry-Based Learning

AR enables students to manipulate virtual models in real-world environments, fostering curiosity and critical thinking (Pedaste et al., 2020). Through interactive exploration, students can conduct investigations and analyze contextual information more effectively.

Despite numerous discussions on the benefits of AR in education, it is essential to highlight its specific advantages in mathematics learning. Mathematics is often perceived as an abstract subject, making it challenging for students to visualize and comprehend complex concepts. AR addresses this issue by providing interactive 3D representations of geometric shapes, algebraic graphs, and mathematical models, enabling students to manipulate and analyze these objects dynamically.

For instance, AR can aid in teaching geometry by allowing students to explore spatial structures through augmented 3D objects. This interactive approach helps bridge the gap between theoretical knowledge and practical application, making abstract concepts more tangible. Additionally, studies show that AR-based mathematics education significantly improves student engagement, problem-solving skills, and conceptual understanding (Alenezi, 2023; Carolina, 2022).

Moreover, the integration of AR aligns with the goals of the Industry 4.0 era, which emphasizes digital transformation in education. By incorporating AR into the curriculum,

educational institutions can enhance student motivation, interest, and learning outcomes, ultimately fostering a more innovative and technology-driven learning environment.

3. The use of Augmented Reality (AR) in maths learning

Augmented Reality (AR) has emerged as an effective tool in enhancing student engagement and motivation in mathematics education. Various studies have highlighted AR's positive impact on learning outcomes, particularly in improving students' conceptual understanding, interest, and academic performance. One of the most prominent applications of AR in mathematics education is the visualization of three-dimensional (3D) geometric shapes, which can be challenging to grasp through conventional teaching methods. By integrating AR technology, students can interact with mathematical objects in a more immersive and tangible manner, facilitating better spatial reasoning and conceptual comprehension.

A study conducted by Al-Omari and Loum (2023) examined the effectiveness of guided discovery learning supported by AR in teaching mathematical concepts to fourth-grade students. The findings revealed that AR-based instruction significantly enhanced students' understanding compared to traditional methods. Moreover, the study emphasized that AR's interactive and engaging nature increases students' interest in learning mathematics, making the subject more accessible and enjoyable.

Similarly, Di Paola et al. (2024) explored the impact of AR on pre-service teachers' approaches to teaching geometry. Their research found that AR significantly improved students' comprehension of geometric transformations and spatial relationships. By providing a dynamic, hands-on learning experience, AR helped bridge the gap between abstract mathematical theories and real-world applications. Beyond geometry, AR has also been applied in algebraic learning. Solfitri et al. (2024) investigated the use of AR in visual-based algebra instruction, demonstrating that AR-assisted learning enhances students' understanding of complex mathematical operations. The study also found that AR reduced students' anxiety levels, making abstract mathematical concepts more approachable.

A broader perspective on AR's role in mathematics education is presented by Sulak and Koklu (2024), who conducted a bibliometric analysis of AR-related research in mathematics over the past two decades. Their findings indicate a growing body of literature supporting AR's effectiveness in enhancing mathematical comprehension and engagement, further validating its significance as an instructional tool. Moreover, Nazarenko (2025) investigated the role of digital technologies in STEM education and found that AR has

substantial potential to improve the quality of mathematics instruction. By offering interactive models and visualizations, AR helps students develop a deeper conceptual understanding compared to traditional instructional methods.

A comprehensive meta-analysis by Feijoo-Garcia et al. (2024) further supports these findings, concluding that AR not only enhances mathematical learning but also fosters problem-solving skills and critical thinking. The study suggests that AR-based learning environments contribute to long-term improvements in student performance. Additionally, Auliya (2024) conducted a systematic review on various strategies for improving student motivation in mathematics education. The study identified AR as one of the most effective approaches, transforming how students perceive and engage with complex mathematical concepts. Sianturi (2025) analyzed multiple studies on AR applications in mathematics learning and concluded that AR enhances students' mathematical skills, conceptual understanding, and overall academic achievement. The findings suggest that AR's benefits extend beyond visualization, positively influencing students' active participation in learning.

The research by Indahsari and Sumirat (2024) further emphasizes the role of AR in interactive learning environments. Their study highlights how AR integrates real-world elements with digital content, creating immersive educational experiences that improve students' conceptual understanding and engagement. Their findings align with meta-analyses by Chen, Looi, and Wu (2021) and Lee and Chung (2021), which confirm that AR enhances learning outcomes by making abstract concepts more tangible and interactive. By extending traditional classroom learning through real-time interactive simulations, AR allows students to explore mathematical concepts in a way that enhances retention and problem-solving abilities. However, the study also identifies challenges in AR implementation, including the need for adequate technological infrastructure, teacher training, and cost-effective solutions to maximize its potential in educational settings.

4. The impact of using Augmented Reality technology (AR)

Technological advancements have significantly transformed education, with Augmented Reality (AR) emerging as a powerful tool to enhance learning experiences. AR provides an immersive and interactive environment, which is particularly beneficial in subjects like mathematics, where abstract concepts often challenge students' understanding. Research by Yu-ching Chen (2019) highlights that AR not only enriches the learning environment and increases motivation but also reduces anxiety commonly associated with

mathematics. Since motivation is a key factor in academic success, AR's ability to engage students actively contributes to better learning effectiveness and performance.

Mathematics is often perceived as a difficult subject due to its abstract nature and reliance on spatial reasoning. Many students struggle with visualizing geometric figures and understanding their properties, which can lead to frustration and disengagement. AR addresses this challenge by providing real-time 3D visualizations that allow students to manipulate and explore mathematical objects in an interactive way. Through the Keller's ARCS model (Attention, Relevance, Confidence, and Satisfaction), AR enhances students' learning experiences by:

a) Attention: using the right design, learning materials or media can captivate students' attention and encourage them to explore and understand the learning material more deeply.
b) Relevance: Students will feel more encouraged if the learning materials presented are aligned with their goals, needs and experiences.
c) Confidence : the more effective a learning experience is, the higher the motivation of students to improve their performance in the learning process
d) Satisfaction: Students tend to be more motivated if they feel that the learning experience is successful and satisfying.

A study conducted by Abdullah Alanezi (2023) reinforces these findings, demonstrating that AR-based mathematics learning enhances motivation and academic achievement. His research utilized three assessment indicators:

1. Achievement tests, where students using AR showed significant improvement in post-test scores compared to a control group.
2. Motivation surveys, where students reported higher engagement and curiosity when AR was integrated into the learning process.
3. Open-ended feedback, where learners expressed greater satisfaction when interacting with mathematical concepts through AR-based tools.

Further supporting evidence comes from research by Evi Syahida, Suprakarti, and Aris Hadiyan (2020), who developed an Android-based AR learning media for the coordinate system. Their study found that AR effectively bridges the gap between 2D representations and real-world spatial understanding, allowing students to visualize and manipulate coordinate planes in a more intuitive way. The validity of this AR-based media was tested in different settings, with small-scale trials achieving a 79.6% success rate and

large-scale trials improving to 81.2%, indicating a significant positive impact on students' understanding and engagement.

The research by Indahsari and Sumirat (2024) highlights the broader role of AR in interactive learning environments. Their findings emphasize that AR enhances conceptual understanding, fosters critical thinking, and promotes hands-on learning. The study aligns with meta-analyses by Chen, Looi, and Wu (2021) and Lee and Chung (2021), which confirm that AR significantly improves mathematical comprehension, engagement, and motivation.

Moreover, a study by Jannah and Oktaviani (2022) focused on the impact of AR on digital numeracy literacy in mathematics learning. Their findings indicate that AR enhances students' abilities to interpret and manage mathematical data, particularly in real-life applications. By providing an interactive approach to data representation, AR allows students to engage in problem-solving and mathematical reasoning more effectively. Their quasi-experimental study using a Pretest-Posttest Control Group Design showed that students who learned with AR performed significantly better in numeracy-related tasks compared to those using conventional methods.

By enabling students to visualize and interact with complex mathematical structures, AR not only makes learning more engaging and intuitive but also addresses fundamental challenges in understanding mathematical concepts. However, successful implementation of AR in mathematics education requires adequate technological infrastructure, teacher training, and cost-effective solutions to maximize its potential in diverse educational settings.

CONCLUSION

The integration of Augmented Reality (AR) in mathematics education presents a transformative approach to addressing the challenges of visualizing abstract mathematical concepts. This study highlights that AR provides interactive and immersive learning experiences, enabling students to engage more deeply with mathematical structures such as geometric shapes, algebraic models, and data representations. The findings suggest that AR enhances student motivation, fosters problem-solving skills, and improves conceptual understanding, making it a valuable tool in modern education. Despite its benefits, several challenges must be addressed for the successful implementation of AR in classrooms. These include technological infrastructure, the need for teacher training, and the cost of content development. Additionally, while AR improves student engagement, further research is

needed to assess its long-term impact on mathematical proficiency and knowledge retention. As digital education continues to evolve, AR holds great potential to revolutionize mathematics learning, bridging the gap between theoretical knowledge and real-world applications. By integrating AR-based tools with well-structured instructional strategies, educators can create a more interactive, effective, and engaging learning environment, ultimately enhancing students' overall academic performance in mathematics.

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