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Augmented Reality Utilization for Mathematical Thinking Skills in Indonesian Junior High Schools

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Abstract

Augmented Reality (AR) is one of the technologies used in Indonesian junior high school mathematics learning. This study aims to conduct a systematic literature review on the use of AR and its influence on mathematical thinking skills at the junior high school level from 2020 to 2024. Mathematical thinking skills in this study are focused on students' problem-solving skills, reasoning skills, creative thinking skills, and critical thinking skills The Systematic Literature Review method is used by reviewing, analyzing, and synthesizing findings from 11 previous empirical studies on augmented reality articles at the junior high school level related to mathematical abilities (problem solving, reasoning, creative thinking, or critical thinking) conducted in Indonesia, sourced from the Google Scholar database (indexed Sinta 1 to Sinta 3) and Scopus (articles and proceedings) published in 2020-2024, in English or Indonesian, and full-text articles are available. This study found that researchers have used various methods to investigate AR in junior high school mathematics education, with quasi-experimental designs, often involving control groups, being the most common. Geometry emerged as the most frequently studied topic. AR-based instruction has been shown to improve junior high school students' mathematical skills in Indonesia, demonstrating a significant impact on academic achievement and critical thinking compared to traditional methods, while also enhancing reasoning and problem-solving abilities. The potential challenges of integrating augmented reality into junior high school mathematics instruction include the need for sufficient technological devices, teachers' technological competencies, and effective learning time management.

Keywords: augmented reality, problem-solving skills, reasoning skills, creative thinking skills, critical thinking skills

INTRODUCTION

Mathematics learning is one of the most important sciences in everyday life. The purpose of mathematics learning in schools is to improve the ability to think systematically, critically and creatively so that students are able to solve problems systematically (Yanti & Fauzan, 2021). Furthermore, the 2013 curriculum states that the aim of learning mathematics in schools is so that students can have good mathematical abilities to be able to solve problems in everyday life (Fauzan & Yerizon, 2013). It is further emphasized in the independent curriculum that in mathematics lessons, students are given the freedom to explore their potential and thinking abilities and are equipped with ways of thinking, reasoning and using logic with continuous mental activity (Nuryanti, 2022). Based on the description, it can be seen that the main objective of learning mathematics in schools is to focus on improving thinking skills. Mathematical thinking skills are mental activities that form the core of thinking in the process of thinking, decision making, and problem solving, where the three processes are interrelated (Marfu'ah et al., 2022). Mathematical thinking skills also include logical and critical reasoning skills in problem solving (Fathani, 2016). Roebyanto stated that The National Council of Teachers of Mathematics (NCTM) issued eight recommendations for mathematics learning in schools, among which the main highlights are problem-solving skills and reasoning skills. Furthermore, Hendriana & Soemarmo also mentioned that higher mathematics skills are critical mathematical thinking skills and creative thinking skills (Dianti, 2017).

Mathematical thinking skills are not instant or automatic abilities possessed by all students (Delima et al., 2021). Therefore, it is important for educators to create learning that not only teaches mathematical concepts in theory, but also encourages students to think logically, creatively, and critically in dealing with various mathematical problems. Effective mathematics learning should be able to stimulate students to develop their thinking skills, so that they can apply mathematical concepts in a broader context. At the junior high school level (SMP), mathematical thinking skills, such as problem-solving skills, reasoning skills, creative thinking, and critical thinking skills, become the foundation for students in understanding more complex mathematical concepts at a higher level (Simanjuntak et al., 2021; Mohammad Albaqawi, 2023; Ferdianto et al., 2022).

However, in practice, many students find it difficult to develop their mathematical thinking skills. Most students still consider mathematics as a difficult, abstract subject, and full of formulas that are difficult to understand (Kuswardi et al., 2020; Zetriuslita & Ariawan, 2021; Ferdianto et al., 2022). They focus more on formulas in solving problems, without really understanding the basic concepts behind them. This results in students being less able to link various mathematical concepts, and less skilled in solving more complex mathematical problems. Many students have difficulty applying mathematical concepts to solve the problems given. This is due to a lack of practice in developing problem-solving and reasoning skills needed to understand the relationships between mathematical concepts (Singh et al., 2024; Tohir et al., 2020; Angraini et al., 2024). In addition, creative and critical thinking skills which are an important part of problem solving are often not well developed, because students are rarely trained to think outside

existing patterns and rely more on existing formulas in solving problems (Noverianto & Munahefi, 2023; Celik & Ozdemir, 2020).

Therefore, to overcome this problem, a better understanding is needed of the aspects contained in mathematical thinking skills, as well as how to develop and hone these skills (Yasinta et al., 2020). Innovation is needed in the approach to learning mathematics that can improve students' mathematical thinking skills, such as problem-solving skills, reasoning skills, creative thinking, and critical thinking skills. One technology that is beginning to be recognized as having great potential in improving mathematics learning is Augmented Reality (AR) (Hanggara et al., 2024; Richardo et al., 2023; Maulida et al., 2024; Ivana et al., 2023). AR technology offers an interactive experience that allows students to interact with virtual objects that are integrated with the real world, thus providing more interesting and enjoyable learning. With AR, students not only learn through text and images in textbooks, but can see and interact directly with mathematical concepts in three dimensions (Lainufar et al., 2021; (Yunianto & Cahyono, 2021).

Many research in mathematics learning show that technology, such as AR, has the potential to increase student's problem solving abilities. The use of AR in mathematics provides students with the opportunity to interact directly with learning objects in a more real and easy-to-understand form (Rohendi & Wihardi, 2020). This is very important in the context of mathematics learning which often relies on understanding abstract concepts that are difficult to visualize (Safitri et al., 2024). With the visualization of these concepts, students can more easily understand the material being taught, as well as improve their problem-solving skills (Muwahiddah et al., 2021).

In addition, AR can also improve students' creative thinking skills, as it gives them the opportunity to explore various solutions to the problems they face (Richardo et al., 2023; Salinas & Pulido, 2017). AR allows students to conduct virtual experiments and simulations that were previously difficult to do in the real world (Radu et al., 2023; Arulanand et al., 2020). In the context of mathematics, this allows students to experiment with mathematical concepts and visualize the results directly. This stimulates their creativity in finding alternative solutions to existing problems, as well as helping them develop critical thinking skills that are important for facing more complex challenges (Suryanti et al., 2020).

The application of AR in mathematics learning can also improve students' reasoning skills (Angraini et al., 2024). With AR, students can see the relationship between previously separate mathematical concepts, as well as connect mathematical theories with real applications (Sudirman et al., 2024). This can help students develop their critical thinking skills, which are essential in solving complex mathematical problems (Dewi et al., 2024). AR allows students to develop spatial reasoning skills, especially in geometry and algebra concepts, which are often difficult for junior high school students to understand (Isharyadi & Herman, 2022).

Previous studies have widely demonstrated the potential of using AR in mathematics learning (Tamur et al., 2024). However, there are still few studies that systematically examine the impact and challenges of using AR on mathematical thinking skills, such as problem solving, reasoning, creative thinking, and critical thinking skills,

especially in junior high school students. Most studies on AR focus more on the application of technology. Therefore, it is important to conduct more in-depth research on the use of AR in mathematics learning and how this technology can improve students' mathematical thinking skills at the junior high school level.

Systematic Literature Review (SLR) is an effective method to review previous studies on a particular topic. By conducting SLR, researchers can identify key findings, trends, and gaps in the literature on the use of AR in mathematics learning. Several SLR studies related to AR have been conducted, such as SLR research on the use of AR in mathematics learning (Nurfaidah et al., 2023; Hermawan & Hadi, 2024). Other research related to SLR is the influence of AR on creative thinking skills (Rohmaini & Fathurrohman, 2024; Hidajat, 2023) (rohmaini dan scopus). These studies focus on the use of AR in mathematics learning and its influence on creative thinking skills. While this study provides a clearer picture of the effectiveness of using AR in improving problem-solving skills, reasoning skills, creative thinking, and critical thinking skills in junior high school students.

Based on this background, this study aims to conduct a systematic literature review on the use of Augmented Reality (AR) and its influence on mathematical thinking skills at the junior high school level from 2020 to 2024. Mathematical thinking skills are focused on students' problem-solving skills, reasoning skills, creative thinking, and critical thinking skills. To achieve this goal, the research questions (RQ) in this study are as follows:

1. What are the characteristics of Studies on the Use of Augmented Reality in Relation to Junior High School Students' Mathematical Thinking Skills in Indonesia?
2. How does AR affect junior high school students' mathematical thinking?
3. What are the potential challenges of integrating augmented reality into middle school mathematics instruction?

METHODS

Design of Study

This study employed a systematic literature review method by examining, analyzing, and synthesizing findings from previous research. A systematic literature review is a review of existing research employing explicit, accountable, and rigorous research methods (Newman & Gough, 2020). The systematic literature review in this study was conducted to explore the use of augmented reality (AR) as an instructional medium in relation to the mathematical thinking skills of junior high school students in Indonesia.

Data Collection and Elibility Criteria

Data collection was carried out by searching for articles in the Google Scholar and Scopus databases. According to Newman and Gough (Newman & Gough, 2020), a systematic review in education should draw upon a variety of sources, encompassing online resources such as Google Scholar and general bibliographic databases like Scopus.

In addition, the article search within the databases was conducted using the search strings, as presented in Table 1.

Table 1. Search Strings

Topic	Terms
Educational Level	SMP OR MTs OR "sekolah menengah pertama" OR "madrasah tsanawiyah" OR "secondary school" OR "middle school" OR "junior high school"
Intervention	"augmented reality" OR "mobile augmented reality"
Focus	mathematics OR matematika OR math
Outcome	"mathematical skills" OR "critical thinking" OR "creative thinking" OR reasoning OR "problem solving" OR "keterampilan matematis" OR "berpikir kritis" OR "berpikir kreatif" OR penalaran OR "pemecahan masalah"

Subsequently, eligibility criteria were established to assess the suitability of the retrieved articles for inclusion in the systematic literature review. The eligibility criteria include the following: 1) empirical research; 2) focus on AR; 3) related to junior high school students' mathematical thinking skills; 4) conducted in Indonesia; 5) published in international journal indexed by Scopus or national journal indexed by Sinta 1 to Sinta 3, or in Scopus-indexed conference proceeding; 6) published between 2020 – 2024; 7) written in either Indonesian or English; 8) full text available.

The article collection process followed the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) flow diagram (Page et al., 2021) as shown in Figure 1. The PRISMA consisted of three phases: identification, screening, and inclusion. During identification phase, 161 articles were identified from selected databases. Eligibility criteria were employed in the screening phase after duplicate records removed. At the inclusion phase, 11 articles were included in the literature review.

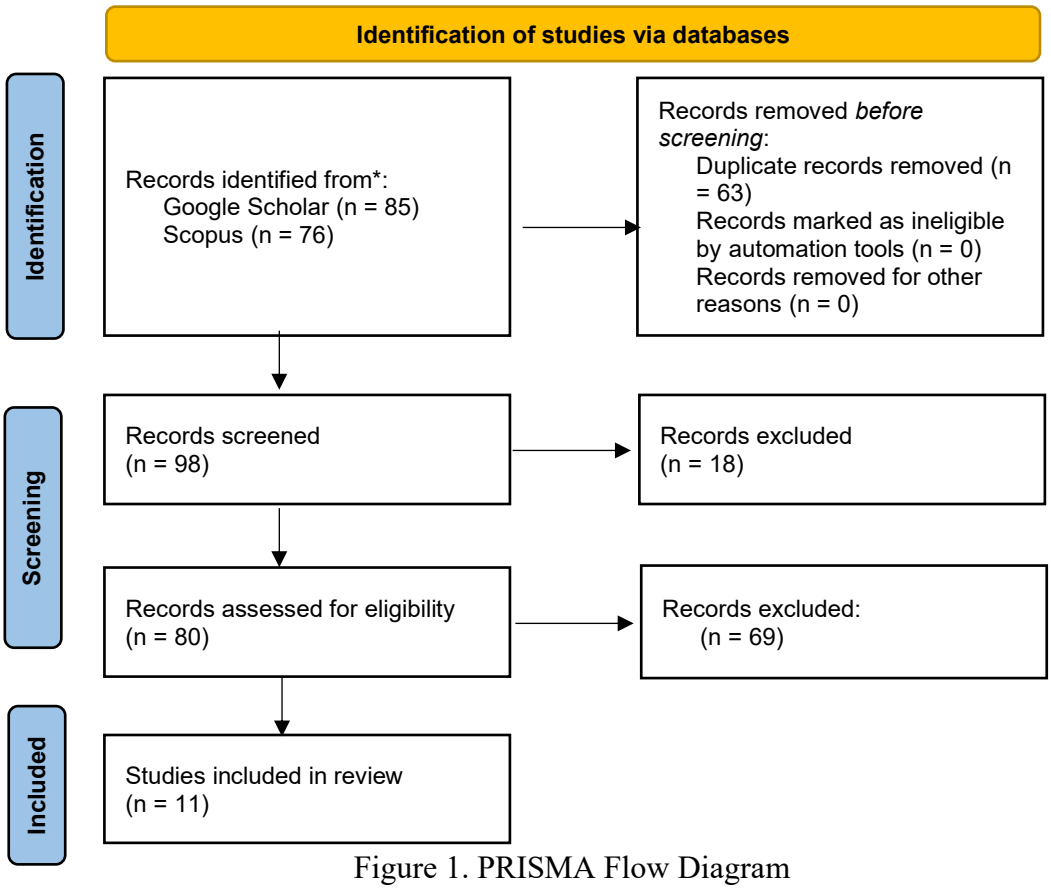

Figure 1. PRISMA Flow Diagram

Data Analysis

The data analysis process was conducted using eligibility criteria to determine the inclusion and exclusion of the retrieved research articles. Articles that met the eligibility criteria were included in the analysis. The analysis was guided by the objectives of the study, namely: (1) to examine the characteristics of studies on the use of augmented reality (AR) in relation to junior high school students' mathematical thinking skills in Indonesia; (2) to explore the effects of AR integration on students' mathematical thinking skills; and (3) to identify the challenges of integrating AR into junior high school mathematics instruction. To achieve these objectives, a categorization process was developed to extract and group the studies based on specific themes. The categories used for data extraction include:

(1) research characteristics: study design, participants, and sample size;
(2) the effect of AR integration in mathematics learning: learning content and mathematical learning outcomes in the form of mathematical skills;
(3) challenges in integrating AR into mathematics education.

RESULTS AND DISCUSSION

This study was conducted to identify the use of augmented reality (AR) in relation to the mathematical thinking skills of junior high school students in Indonesia. The literature review focuses on the findings of previous studies concerning the impact of AR integration on students' mathematical thinking skills and the challenges of incorporating AR into junior high school mathematics instruction.

Based on the search results on Scopus and Google Scholar regarding articles on augmented reality in junior high schools related to mathematical abilities (problem solving, reasoning, creative thinking, or critical thinking) published in 2020-2024, written in Indonesian or English, Scopus or national journal indexed by Sinta 1 to Sinta 3, or in Scopus-indexed conference proceedings, 85 articles were obtained from Google Scholar and 76 articles from Scopus, with 63 duplicate articles, leaving 98 articles. Next, screening was carried out with the criteria that the research was conducted in Indonesia, 69 articles were obtained. The next screening was that the article was the result of empirical research, the research subjects used were junior high school students, and the content of the article must contain problem solving, reasoning, creative thinking, or critical thinking with the results of 11 articles.

Based on the data collection process, a total of 11 studies met the eligibility criteria and were included in the analysis. The studies included comprised one conference proceeding article and ten journal articles. Further analysis revealed that five of the eleven articles were published in national journals accredited by Sinta, while the other six were published in international journals indexed in Scopus. The overview of the included studies in this systematic literature review is presented in Table 2.

Table 2. Overview of Included Studies

Article Code	Author(s)	Title	Article Type	Indexation
A01	Angraini et al. (2022)	Improving Mathematical Critical Thinking Ability Through Augmented Reality-Based Learning	Journal	Sinta
A02	Hanggara et al. (2024)	The Impact of Augmented Reality-Based Mathematics Learning Games on Students' Critical Thinking Skills	Journal	Scopus
A03	Suryanti et al. (2020)	Augmented Reality for Integer Learning: Investigating its potential on students' critical thinking	Conference Proceedings	Scopus
A04	Noverianto & Muhanefi (2023)	Analisis Kemampuan Berpikir Kreatif Matematis Ditinjau dari Motivasi Belajar Siswa pada Scientific Problem Based Learning Berbantuan Javanese Culture Augmented Reality	Journal	Sinta
A05	Richardo et al. (2023)	Ethnomathematics Augmented Reality: Android-Based Learning Multimedia to Improve Creative Thinking Skills on Geometry	Journal	Scopus
A06	Angraini et al. (2024)	Improving Students' Mathematical Reasoning Ability Through Augmented Reality Learning Media	Journal	Scopus
A07	Maulida et al. (2024)	The Effect of Experiential Learning and Directed Instructions Assisted by Augmented Reality on Students' Self-Regulated Learning	Journal	Scopus & Sinta
A08	Hakim et al. (2021)	The Development of Learning Module with Mobile Augmented Reality Based on 9E Learning Cycle to Improve Problem Solving Skills	Journal	Sinta
A09	Hakim et al. (2024)	Developing MoAR-Integrated Printed Learning Modules to Improve Mathematical Problem-Solving Abilities in Geometry Learning	Journal	Sinta
A10	Ivana et al. (2023)	The Effectiveness of Comic Illustrated Augmented Reality Learning Media to Improve Mathematical Problem-Solving Ability	Journal	Scopus
A11	Muwahiddah et al. (2021)	The Ability Solve Geometry Problems in Spatial Intelligence Through Project Based Learning-Ethnomathematics Assisted by Augmented Reality Apk	Journal	Sinta

Characteristics of Studies on the Use of Augmented Reality in Relation to Junior High School Students' Mathematical Thinking Skills in Indonesia

Methodologically, as shown in Table 3, researchers employed a variety of research methods in studying the use of augmented reality (AR) in junior high school mathematics education. The most commonly used research design was quasi-experimental (n = 6), with nearly all of them utilizing a control group design (n = 5), and only one study employing a single-group design. In addition, four studies adopted a developmental research design (n = 4), while three studies employed a mixed methods design (n = 2). Furthermore, all studies that used a developmental design implemented the ADDIE

development model. Likewise, all studies with a mixed methods design followed the explanatory sequential design. Similar trends have been observed in other systematic literature reviews, which report that the development of AR-based instructional media for mathematics learning is the most frequently conducted type of study (Ahmad & Junaini, 2020).

Table 3. The Summary of Included Studies

Article Code	Study Design	Grade	Sample	Topics	Mathematical Skills
A01	Quasi Experimental	7^{th}	30	Geometry	Critical Thinking
A02	Quasi Experimental	8^{th}	77	Geometry	Critical Thinking
A03	Quasi Experimental	7^{th}	95	Number	Critical Thinking
A04	Mixed Method	8^{th}	32	Geometry	Creative Thinking
A05	Development	N/A	18	Geometry	Creative Thinking
A06	Quasi Experimental	7^{th}	60	Geometry	Reasoning
A07	Quasi Experimental	8^{th}	50	Number	Reasoning
A08	Development	9^{th}	68	Geometry	Problem Solving
A09	Development	9^{th}	68	Geometry	Problem Solving
A10	Development	8^{th}	61	Geometry	Problem Solving
A11	Mixed Method	8^{th}	30	Geometry	Problem Solving

In terms of participants, eighth-grade junior high school students were the most frequently involved in studies on the use of AR in mathematics learning (n = 5), followed by ninth-grade students (n = 4) and seventh-grade students (n = 3). One study did not provide detailed information about the specific grade level of the participating students. Regarding sample size, three studies involved fewer than 50 participants, while eight studies included more than 50 participants. In general, according to other systematic literature reviews, the junior high school level is the most commonly targeted educational level for the use of AR in mathematics instruction (Pahmi et al., 2023). Another review from Bulut & Borromeo Ferri (2023) also found that the majority of the studies appears to focus on secondary school students.

Specifically, only a few studies reported using alternative instructional media as a comparison to AR as the treatment in the control group (n = 3). The alternative instructional media mentioned included PowerPoint-based media (Angraini et al., 2024), worksheet (Angraini et al., 2022) and text book (Ivana et al., 2023). Furthermore, AR interventions were also compared with other instructional approaches, such as conventional teaching methods (Angraini et al., 2024; Hakim et al., 2021; Hanggara et al., 2024; Maulida et al., 2024) and discovery learning model (Muwahiddah et al., 2021). Unfortunately, this findings showed that only a limited number of studies have compared AR with well-designed alternative learning media. The majority of comparisons have been made against conventional teaching methods or other pedagogical models. While these comparisons can highlight AR's potential for significant pedagogical shifts, future research should also contrast AR with other media possessing similar interactive and visual features.

The Impact of Augmented Reality Utilization on Junior High School Students' Mathematical Abilities in Indonesia

The use of augmented reality (AR) in mathematics instruction has demonstrated its effectiveness in teaching various mathematical topics. Such evidence is apparent in the studies included in the present systematic literature review. This review found that geometry was the most frequently studied topic (n = 9), both in experimental and developmental research designs (Angraini et al., 2022, 2024; Hakim et al., 2021, 2024; Hanggara et al., 2024; Ivana et al., 2023; Muwahiddah et al., 2021; Noverianto & Munahefi, 2023; Richardo et al., 2023). Only two studies focused on mathematical topics other than geometry, namely number concepts (Maulida et al., 2024; Suryanti et al., 2020). Another reviews also found that geometry is the most frequently selected mathematical topic for AR-based instructional media (Ahmad & Junaini, 2020; Bulut & Borromeo Ferri, 2023). This finding aligns with the notion that three-dimensional constructs in mathematics education can be virtually developed through the use of Augmented Reality (AR) applications (Kaufmann & Schmalstieg, 2003).

The use of AR in mathematics instruction has also demonstrated its effectiveness in enhancing junior high school students' mathematical skills in Indonesia. This aligns with a meta-analysis studies which found that AR-based learning has a relatively high effect size in influencing students' academic achievement (Flavin et al., 2025; Tamur et al., 2024). Three studies indicated that students who received instruction through AR showed improved critical thinking skills compared to those who were taught using conventional approaches (Angraini et al., 2022; Hanggara et al., 2024; Suryanti et al., 2020). The use of AR media in learning supports the delivery of knowledge and skills while also enhancing students' attention and interest, thereby promoting more focused and regulated learning processes (Angraini et al., 2022). By integrating digital content with real-world environments, AR-based learning offers unique opportunities to enhance critical thinking skills through active engagement and contextual problem-solving (Hanggara et al., 2024).

In addition, studies on the use of AR have also proven its potential to enhance junior high school students' creative thinking skills (Noverianto & Munahefi, 2023; Richardo et al., 2023). Based on their study, Noverianto & Muhanefi (2023) indicated that the use of AR as an instructional medium also increased students' motivation to learn. Furthermore, they reported that students with a high level of creative thinking skills also tended to exhibit high learning motivation. Meanwhile, Richardo et al (2023) in their study, developed an Android-based AR application incorporating ethnomathematics content, which was shown to be effective in enhancing students' creative thinking skills in practice. According to Giannopulu et al. (2022), AR functions by merging abstract physical elements with the real-world environment to enhance students' cognitive and imaginative capacities. AR media facilitates students' understanding of abstract mathematical concepts, particularly in geometry, by enhancing visualization and supporting discovery-based learning that fosters the development of mathematical creative thinking skills (Richardo et al., 2023).

Furthermore, two studies on the use of AR in mathematics instruction also demonstrated its potential to enhance students' reasoning skills (Angraini et al., 2024; Maulida et al., 2024). Specifically, Angraini et al. (2024) found that instruction incorporating AR was more effective in improving students' reasoning skills compared to conventional teaching methods. AR offers a high level of interactivity, allowing virtual objects to engage directly with users. In contrast, students who engage in conventional learning typically receive material through PowerPoint presentations, which may enhance interest but offer a lower degree of interactivity (Angraini et al., 2024). On the other hand, Maulida et al. (2024) compared the use of AR in Direct Instruction (DI) and Experiential Learning (EL) approaches. Instruction using Augmented Reality-supported Direct Instruction (DI-AR) had a greater impact on students' mathematical reasoning skills than Augmented Reality-supported Experiential Learning (EL-AR). This is attributed to students' greater familiarity with the structured and clear nature of DI, which is also effective for diverse groups of learners, including those with special needs. DI-AR outperformed EL-AR in enhancing mathematical reasoning due to advantages such as immediate feedback and its effectiveness across various student backgrounds. In contrast, EL presents limitations such as requiring more time and resources, as well as producing more varied outcomes among students. (Maulida et al., 2024).

Furthermore, four studies indicated that the use of AR in mathematics instruction can enhance junior high school students' problem-solving skills in Indonesia (Hakim et al., 2021, 2024; Ivana et al., 2023; Muwahiddah et al., 2021). Two studies conducted developmental research: Hakim et al. (2021, 2024) developed AR-based learning modules, and Ivana et al. (2023) developed comic-illustrated AR media. Both studies indicated that their respective AR media effectively enhanced junior high school students' problem-solving skills. Meanwhile, Muwahiddah et al. (2021) conducted an analytical study comparing students' geometry problem-solving skills through project-based learning assisted by an AR application versus discovery learning. The findings revealed that students who participated in project-based learning assisted by AR demonstrated better problem-solving skills than those who engaged in discovery learning.

The potential challenges of integrating augmented reality into middle school mathematics instruction

The use of AR in junior high school mathematics learning requires smartphones or tablets that have cameras and are able to install software that can display virtual objects into the real environment (Maulida et al., 2024). Some AR applications consume quite a lot of CPU and memory when it is running (Angraini et al., 2024). This means that one of the challenges of using AR in mathematics learning is the need for devices that have sufficient memory so that AR can be used smoothly. In addition, there is the challenge of limited use for students or schools that do not use Android devices.

Meanwhile, teachers who develop AR also need devices that can install software to create AR media (Guntur et al., 2019). Teachers must also be technology literate in order to develop AR learning media. This means that teachers must have good technological skills in order to develop AR. Many AR applications only focus on visualization without integrating instructional steps that support students' thinking or

problem-solving processes (Hakim et al., 2024). Therefore, in developing AR media, teachers need to pay attention to instructional steps that support students' thinking processes. In addition, the effectiveness of AR still depends on the learning method (Maulida et al., 2024). Therefore, teachers must be able to choose the right learning method when using AR media.

The use of using learning media Android smartphones in schools was still lacking, so that before the learning was the teacher conducted carried out, socialization about the use of learning using AR-based android media smartphones (Angraini et al., 2024). By using AR, Students can manipulate the shapes in the missions by rotating, enlarging, and shrinking them. Additionally, students can listen to explanations related to the material being studied while playing the game (Hanggara et al., 2024). Therefore, the use of AR in mathematics learning requires a lot of time than regular learning.

CONCLUSION

Based on the research finding, it can be concluded that 1) The characteristics of Studies on the Use of Augmented Reality in Relation to Junior High School Students' Mathematical Thinking Skills in Indonesia are the most common design used was quasi-experimental, often with a control group. Many studies also used developmental and mixed methods designs. Eighth-grade students were the most often involved, followed by ninth and seventh graders. Few studies compared AR with other instructional media. Comparisons included PowerPoint, worksheets, textbooks, and traditional teaching methods. Geometry is the most studied 2) AR instruction has improved junior high school students' math skills in Indonesia, showing high impact on academic achievement and critical thinking compared to traditional methods. Furthermore, AR also enhances students' creative thinking and motivation. Studies indicate that AR helps students visualize abstract math concepts, particularly in geometry, promoting discovery-based learning. Additionally, AR instruction boosts reasoning skills, demonstrating more effectiveness in structured teaching compared to experiential approaches. Lastly, four studies found that AR can improve problem-solving skills among junior high school students, confirming that AR-based learning modules are beneficial for enhancing these skills over other learning methods. 3) The potential challenges of integrating augmented reality into middle school mathematics instruction are the need for devices that have sufficient to ensure smooth operation, particularly for teachers who are responsible for developing AR content, teachers must possess strong technological competencies to create AR media as well as sound pedagogical skills to select appropriate teaching strategies and design instructional steps that effectively support students' cognitive development when utilizing AR and implementing AR in mathematics learning is time-intensive and demands extensive familiarization efforts to introduce and promote the use of AR-based learning through Android smartphones.

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