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The Effectiveness of Using Augmented Reality Media in Mathematics Learning in Primary School: A Systematic Literature Review (SLR)

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ABSTRACT

This study aims to analyse the effectiveness of Augmented Reality (AR) technology in mathematics learning in primary schools through a Systematic Literature Review (SLR) conducted in accordance with the PRISMA guidelines. The review process consists of four main stages, namely identification, screening, eligibility, and inclusion. The data sources were obtained from articles indexed in Scopus published between 2016 and 2025, which used quantitative or mixed-methods approaches and involved primary school students as subjects. Fifteen articles met the inclusion criteria and were analyzed further. Findings confirmed that AR technology is efficacious in improving students' spatial skills, critical thinking, and drive to learn. In addition, AR improves long-term memory retention and makes geometric concepts, such as rotation and spatial orientation, more tangible. From an affective standpoint, using AR makes learning fun and can help children feel less anxious about mathematics. Overall, the effectiveness of AR is multidimensional, covering the cognitive, affective, and psychomotor domains. The limitation of this study lies in the restricted scope of data sources and research types, which may limit the generalizability and contextual depth of the findings. As a recommendation, further research is needed to explore the use of AR in greater depth to strengthen mathematical thinking and reasoning skills.

***Keywords*: augmented reality, mathematics learning, primary school**

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INTRODUCTION

Technological developments have brought about many changes in various aspects of life, including education. In recent years, educational environments have increasingly integrated digital technologies to enhance learning experiences and stimulate cognitive development (Daud et al., 2019; Jamun et al., 2023). The technology used in learning is tailored to its purpose. In mathematics education, technology is used to reduce abstraction in the conveyance of mathematical concepts (Fitriani et al., 2021; Suri et al., 2024). For this purpose, an example of widely used technology is Geogebra, a software tool that can demonstrate the application of geometry, algebra, statistics, and calculus concepts (Majerek, 2014; Tamam & Dasari, 2021; Yohannes & Chen, 2023). Meanwhile, for assignment or assessment purposes, electronic worksheets are widely used as a tool (Wijayanti et al., 2021; N. Sari et al., 2023; R. N. Sari et al., 2024).

One emerging instructional technology is Augmented Reality (AR), which overlays digital elements onto real-world contexts to create interactive learning experiences (Azuma, 1997). AR has been recognised as a tool that facilitates visualisation, increases engagement, and supports conceptual comprehension of abstract mathematical content among young learners (Ibáñez & Delgado-kloos, 2018). AR is a technology that enables the integration of 3D virtual objects into the real environment in real time. This technology enables users to see virtual objects in the real world (Azuma, 1997; Billinghurst et al., 2014), creating an interactive and immersive learning environment. Through AR, students can interact directly with mathematical objects visually and kinesthetically. For example, in learning about spatial figures, students can observe each side of the spatial figure by rotating and enlarging the device that presents the AR.

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Despite the potential of AR, mathematics learning in many primary schools still relies heavily on traditional teaching methods such as direct instruction, rote memorisation, and static visual aids (Dairo et al., 2024). In the context of geometry and spatial figures, for example, the use of conventional media that relies solely on two-dimensional images is not optimal for developing students' spatial visualization (Desai et al., 2021; Fujita et al., 2020; Ponte et al., 2023). The level of abstraction and the difficulty of representing abstract objects are among the obstacles to learning mathematics (Bachtiar & Susanah, 2021; Sumbandari et al., 2022). Students frequently struggle to understand abstract mathematical ideas, which can lead to reduced motivation and achievement (Niyazova et al., 2022; Saha et al., 2024).

Although a growing number of empirical studies have examined the application of AR in mathematics education, the body of evidence remains fragmented. Several studies report improvements in learning attitudes and engagement (Islim et al., 2024), while others highlight enhancements in cognitive outcomes, such as conceptual understanding and spatial reasoning (Yoon et al., 2017). However, existing literature reviews often focus on broader STEM education contexts or secondary and higher education settings (Akçayır & Akçayır, 2016; Ibáñez & Delgado-kloos, 2018), leaving a gap in comprehensive synthesis specifically addressing *primary* school mathematics learning. As a result, the effectiveness of AR for mathematics instruction at the primary level has not yet been clearly established.

Based on the research gaps outlined above, this study aims to conduct a systematic literature review to analyse and synthesise empirical research on the effectiveness of Augmented Reality media in mathematics learning at the primary school level. Specifically, the review identifies the benefits, challenges, and documented learning outcomes associated with AR use. The results of this review are expected to contribute theoretically to the development of technology-based learning models and to provide practical recommendations for teachers on effectively integrating AR into mathematics learning in primary schools.

METHOD

This research is a systematic literature review (SLR). The literature review in this study follows the PRISMA framework, comprising four main steps: identification, screening, eligibility, and inclusion (Page et al., 2021). A more detailed description of these four steps is presented in the following subsections.

Identification

The process of identifying literature relevant to the research objectives was carried out by applying a series of systematically designed restrictions. These restrictions included reference sources, article types, publication years, and discussion focus. Reference sources are limited to articles contained in the *Scopus* database. The type of article used is published (final stage*)* articles. The year of publication is limited to the last ten years (2016-2025). The search keywords indicate the focus of the discussion.

Table 1. Source Identification

Aspect	Limitations
Reference Sources	Articles indexed in *Scopus*
Article Type	Published articles (*final stage*)
Publication Year	2016 – 2025
Focus	Searches were conducted using the query: TITLE-ABS-KEY ("augmented reality" AND "mathematics" OR "mathematics education" "elementary school" OR "primary school") AND PUBYEAR > 2015 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (LANGUAGE, "English"))

Screening

During the screening stage, articles identified in the previous stage were selected.Articles were screened according to predetermined criteria. Of the total 95 documents displayed in the identification process in the Scopus database, 36 articles were considered relevant to the research objectives. These 36 articles were

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the result of the first screening stage. The first stage screening criteria were based on the following considerations: (1) the selected articles were research articles, (2) the articles were presented in English. The rejection criteria were: chapter books, review articles (meta-analyses and meta-syntheses), proceedings, and articles not presented in English.

Eligibility

After the screening stage, the 36 collected articles were then assessed for eligibility. To determine the eligibility of articles for use as sources for the study, several exclusion and inclusion criteria were formulated. These criteria are presented in the following table.

Table 2. Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Focus of discussion	Augmented reality media is the independent variable in the study	Augmented reality media is not the primary focus of discussion
Research subjects	Students in primary education	Students in secondary and higher education institutions, university students, prospective teachers, and teachers in primary, secondary and higher education institutions
Type of Research	The research was conducted using a quantitative paradigm or *mixed methods* research	The research was conducted using a qualitative paradigm and developmental research

Of the 36 articles collected, 21 articles were deemed ineligible. The rejection of these 21 articles was based on the focus of discussion for five articles, the research subject for four articles, and the type of research for 12 articles.

Inclusion

The inclusion stage is the final stage. At this stage, the articles to be used as references to achieve the research objectives are determined. The articles designated as references in this study were selected after passing the inclusion and exclusion criteria set in the previous stage. Overall, the stages of selecting reference sources in this study are illustrated in the following flowchart.

After obtaining articles that met the inclusion criteria, a quality assessment was conducted. The evaluation used the CASP (Critical Appraisal Skills Program) checklist to assess the credibility and methodological accuracy of each article. The assessment stages included examining the clarity of the objectives, the appropriateness of the research design and sampling techniques, the clarity of the intervention, the presence of a control group, the validity of the instruments, data analysis, and the reporting of limitations.

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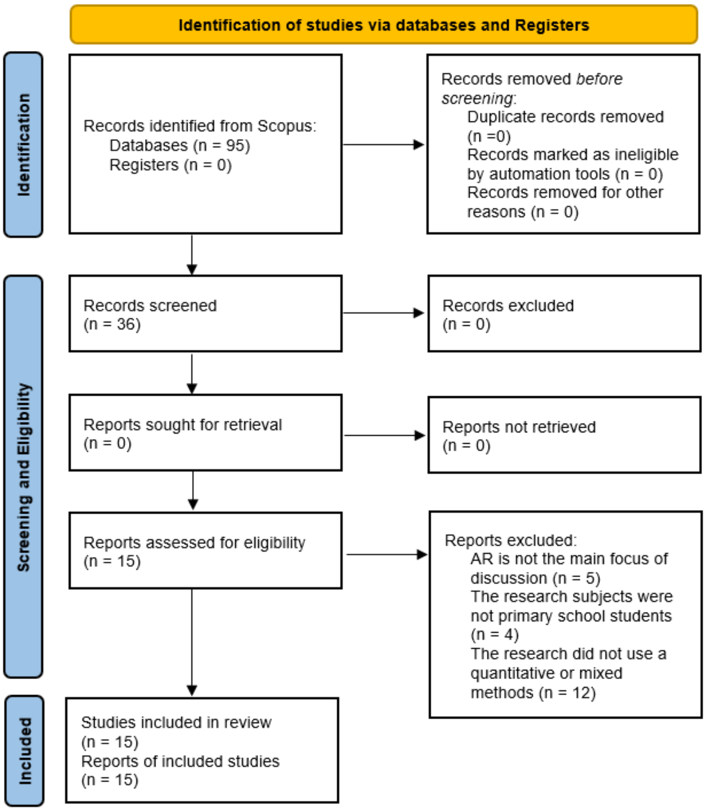

Figure 1. PRISMA Flow Diagram

RESULTS AND DISCUSSION

15 articles met the inclusion criteria for use as review sources in this study. A summary of the characteristics of these articles is presented in the following table.

Table 3. List of Articles Declared Eligible

No	Author /Year	Country	AR Type	Participants	Learning Topics	Findings
1	(Akbar et al., 2025)	Indonesia	Marker-based AR	Students aged between 10 and 12 years old.	Simple spatial shapes	Students who used AR in mathematics learning demonstrated significantly higher CTS (Critical Thinking Skills) than those in conventional classes.
2	(Zhengtao & Hidayat, 2025)	Malaysia	Marker-based AR	Third-grade primary school student. The experimental group: n = 30 The control group: n = 30	Graphs and Geometry	This research demonstrates that integrating AR tools can positively impact students' academic performance, particularly by facilitating the comprehension of complex concepts through immersive and interactive environments.
3	(Wang et al., 2025)	Eastern China	Marker-based AR	86 sixth graders	Geometry	Augmented Reality integrated Mathematics Curriculum (ARiMC) did not significantly improve overall spatial skills. A significant

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No	Author /Year	Country	AR Type	Participants	Learning Topics	Findings
						positive impact on the graphic movement dimension, especially among female students. AR-based learning is a potentially effective teaching strategy that can improve specific spatial abilities, especially for female students, though it did not yield significant improvements across all spatial skills compared to traditional methods.
4	(Hunhui Na, K. Bret Staudt Willet, 2025)	USA	Marker and marker-less-based AR	43 sixth-grade students	Geometry	The results show that both AR technologies effectively improve geometry comprehension. This study highlights the technical advantages of each AR technology, which can produce unique pedagogical advantages.
5	(Wu et al., 2024)	China	AR Picture Book (Mobile AR)	83 fourth-grade students	Geometry	Students who interacted with AR materials showed the most significant improvement in geometric thinking, reported higher flow, and experienced lower cognitive load.
6	(Tarng et al., 2024)	Taiwan	Mobile AR	66 fifth-grade students	Geometry	Augmented Reality Learning Management System (ARMLS) significantly improves learning outcomes for low- and medium-achieving students compared to traditional learning methods. However, there was no significant difference in learning motivation between the two methods, possibly because ARMLS lacked gamification elements.
7	(Nadzeri et al., 2024)	Malaysia	GeoAR Aplica-tion	61 second grade students	Geometry	This study found that AR technology significantly improved students' spatial visualization abilities, as reflected in the increase in average SVAT scores from pre-test to post-test. Although this study targeted lower primary school students, it is recommended that AR also be used in upper grades, especially for abstract topics such as perimeter, area, and volume, as it helps in visualizing 3D objects.
8	(Nadzri et al., 2023)	Malaysia	Mobile AR	59 fourth grade students	Geometry	The results showed a significant difference in the overall average scores of the post-test and delayed post-test, with the experimental group showing a significant improvement compared to the control group. In conclusion, the use of modules with integrated AR technology was proven to improve student performance in geometry compared to traditional methods. AR technology can help students master Geometry concepts through visualization, strengthen long-term memory, and gain conceptual understanding through experiences.

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No	Author /Year	Country	AR Type	Participants	Learning Topics	Findings
9	(Cadillo León et al., 2023)	Peru	Games with AR	19 first grade students	Mathema-tical skills	Using neutrosophic statistics data, there was a significant increase in students' mathematical skills.
10	(Hwang et al., 2023)	China	Authentic Geometry Go App (AGG) with AR	82 fifth grade students	Geometry	Measuring authentic geometric shapes using the application can improve students' estimation skills. Furthermore, meaningful peer assessment with visual representations in authentic contexts can facilitate the evaluation of peers' work and improve students' understanding of geometry. Therefore, we encourage educators to use AR with appropriate learning activities to enhance the quality of students' measurements and visual representations by having students measure real geometric shapes and apply mathematical knowledge in authentic contexts.
11	(Amir et al., 2020)	Indonesia	3Dmetrics (AR based 3D space material)	36 fourth-grade students	Geometry	This study shows no correlation between students' perceptions and their spatial abilities. Furthermore, 3Dmetric has been proven to improve cognitive performance in understanding geometry, offering a better learning experience through enhanced visualization and interaction. Overall, primary school students in Indonesia show positive perceptions of 3Dmetric, regardless of their spatial ability levels.
12	(Demitriadou et al., 2020)	Cyprus	VR and AR applica-tion	30 fourth, fifth, and sixth-grade students	Geometry	VR significantly enhances student engagement and performance. Additionally, AR also had a positive effect on student motivation and knowledge retention. Although no significant differences in knowledge acquisition were found between groups, VR and AR applications created a more engaging learning experience compared to traditional methods. These results reinforce the potential of VR/AR technology to motivate students and improve learning outcomes.
13	(Wangid et al., 2020)	Indonesia	Mobile AR	348 fourth grade students	Geometry	The use of augmented reality storybooks can have a positive, significant effect on fourth-grade students' anxiety during mathematics learning. There was a difference between the group that received treatment (experimental group) and the group that did not (control group) using AR-assisted storybooks.
14	(Hanafi et al., 2019)	Malaysia	Mobile AR	75 elementary school students with an average	Fraction, percent,	The study's results indicate that males tend to excel in mobile applications, possibly due to their familiarity with technology. These

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No	Author /Year	Country	AR Type	Participants	Learning Topics	Findings
				age of 13.5 years old	volume of liquid	findings highlight the importance of integrating mobile learning devices into mathematics education while addressing gender performance gaps by encouraging female students' engagement with mobile technology.
15	(Gün & Atasoy, 2017)	Turkey	Mobile AR	88 sixth grade students	Geometry	This study revealed significant differences between the pre-test and post-test average spatial ability scores for the experimental group (AR application) and the control group, indicating that both methods had a positive impact on students' spatial abilities.

The methodological quality of the included studies was assessed using the Critical Appraisal Skills Programme (CASP) checklist for experimental and quasi-experimental research designs. Overall, the studies reviewed clearly stated their research objectives: to evaluate the effectiveness of Augmented Reality (AR) in enhancing mathematical understanding, spatial thinking, critical thinking, and learning experiences among elementary school students. However, randomisation procedures were not clearly reported in most studies, as participants were generally assigned to experimental and control groups according to existing classroom structures. This condition may introduce selection bias. Although baseline equivalence between groups was commonly ensured through pre-test administration, not all studies provided statistical evidence of group homogeneity.

Furthermore, blinding procedures were not implemented due to the visible and interactive nature of AR interventions, which may lead to performance and observer bias. Most studies employed validated and reliable assessment instruments, and the descriptions of the intervention procedures were sufficiently detailed to allow replication. Statistical analyses were generally appropriate to the research design and objectives, although not all studies reported effect sizes or addressed missing-data handling and intent-to-treat analyses. In summary, the methodological quality of the included studies is adequate, and the findings are considered credible, although interpretations should remain cautious given the limited transparency of randomisation and the absence of blinding procedures.

Table 4. Summary of Quality Appraisal of Included Studies

Author/Year	Design	Grouping	Intervention Clarity	Instrument Validity	Key Limitation	Quality
Akbar et al. (2025)	Quasi experimental	Non random	Clear	Valid CTS rubrics	No. blinding	Good
Zhengtao & Hidayat (2025)	Quasi experimental	Non random	Clear	Standard math test	No. long term retention	Good
Wang et al. (2025)	Quasi experimental	Non random	Clear	Valid spatial test	Gain limited to specific subskills	Moderate-Good
Hunhui Na & Willet (2025)	Mix method	Non random	Clear comparison	Multiple validated tools	Limited motivation analysis	Good

Author/Year	Design	Grouping	Intervention Clarity	Instrument Validity	Key Limitation	Quality
Wu et al. (2024)	Quasi experimental	Non random	Clear	Valid geometric thinking scale	Short duration	Good
Tarng et al. (2024)	Quasi experimental	Non random	Clear	Valid learning assessment	Motivation not significantly improved	Good
Nadzeri et al. (2024)	Pre-Post	No control	Clear	Valid SVAT	No comparison group	Moderate
Nadzri et al. (2023)	Quasi experimental	Non random	Clear	Valid perfor-mance test	Topic limited to geometry	Good
Cadillo León et al. (2023)	Experi-mental	Single small sample	Clear	Specialized scoring	Very small sample	Moderate
Hwang et al. (2023)	Quasi experimental	Non random	Clear	Valid estimation and peer assessment scales	Limited generaliza-bility	Good
Amir et al. (2020)	Cross-sectional	No control	Clear	Valid perception and spatial test	No causal inference	Moderate
Demitriadou et al. (2020)	Comparative	Non random	Clear	Valid engagement measures	No significant knowledge gain difference	Good
Wangid et al. (2020)	Quasi experimental	Non random	Clear	Valid anxiety scale	No follow-up test	Good
Hanafi et al. (2019)	Quasi experimental	Non random	Clear	Valid perfor-mance test	Gender effect no theorized	Moderate-Good
Gün & Atasoy (2017)	Quasi experimental	Non random	Clear	Valid spatial test	Improvement not statistically significant	Moderate

Discussion

The findings of the reviewed studies consistently indicate that AR contributes positively to students' mathematics learning outcomes, particularly in geometry and spatial topics. AR enables students to interact directly with three-dimensional mathematical objects, making abstract concepts more concrete and easier to understand (Wu et al., 2024; Tarng et al., 2024). In several studies, experimental groups using AR demonstrated significantly higher post-test scores than control groups using conventional teaching media (Zhengtao & Hidayat, 2025; Nadzri et al., 2023). These improvements are associated with AR's ability to provide real-time visual manipulation, which supports deeper cognitive processing. However, not all studies reported uniform improvements across all learning domains. For example, Wang et al. (2025) found that while AR improved certain aspects of spatial movement skills, it did not lead to comprehensive enhancement across all spatial skills. Despite this nuance, overall findings suggest that AR functions as an effective instructional support tool that enhances conceptual understanding and elevates academic performance in mathematics at the primary school level.

A substantial portion of the reviewed research demonstrates the effectiveness of AR in developing spatial reasoning and higher-order thinking skills. By enabling learners to explore, rotate, and manipulate geometric shapes in three-dimensional space, AR supports the formation of spatial visualization and mental rotation abilities (Nadzeri et al., 2024; Hwang et al., 2023). This aligns with cognitive theories suggesting that spatial representation is crucial for understanding geometry and measurement (Pittalis & Christou, 2010). In addition, AR-assisted learning environments encourage analytical and evaluative thinking, especially when students compare different geometric configurations or engage in problem-solving tasks (Akbar et al., 2025). However, the degree of improvement in spatial or critical thinking depends on the learning design and scaffolding provided by teachers. Wang et al. (2025) highlight that the benefits of AR are maximized when learning tasks explicitly require students to engage in reasoning, rather than merely observing digital artifacts. Therefore, AR is most impactful when integrated with inquiry-oriented instructional strategies.

Beyond cognitive outcomes, the reviewed studies highlight that AR also influences affective and emotional factors in mathematics learning. AR environments tend to be perceived as enjoyable and engaging, which increases students' interest, curiosity, and willingness to persist in solving mathematical tasks (Wu et al., 2024; Demitriadou et al., 2020). The interactive elements of AR produce a sense of immersion that can reduce students' anxiety toward mathematics, making learning more approachable (Wangid et al., 2020). Moreover, AR promotes students' sense of autonomy and confidence as they gain control over manipulating mathematical objects, thereby enhancing motivation. However, motivation outcomes can vary depending on the design features of AR tools. For example, Tarng et al. (2024) found that motivation did not increase significantly when AR applications lacked gamification features. These findings underline the importance of designing AR learning experiences that are both pedagogically meaningful and affectively supportive.

Despite the overall positive trends identified in the reviewed studies, several limitations across the body of literature should be critically acknowledged. First, most studies employed quasi-experimental designs with non-randomized grouping, raising concerns about internal validity and the extent to which improvements can be attributed solely to the AR intervention. Moreover, the duration of the intervention in many studies was relatively short, typically spanning only a few lesson sessions, which limits the ability to assess the long-term sustainability of learning gains. The majority of studies also focused on geometry and spatial topics, yielding limited evidence on the effectiveness of AR across broader mathematical domains, such as algebraic reasoning and problem-solving. Additionally, while several articles reported increases in motivation and engagement, few examined deeper learning processes such as metacognition or conceptual transfer. These methodological and thematic gaps indicate that although current evidence supports AR as a promising instructional tool, further research is needed to strengthen its theoretical, empirical, and practical grounding in mathematics education at the primary level.

Although AR demonstrates strong potential in improving learning processes, its successful implementation depends heavily on teacher readiness and pedagogical decision-making. Several studies note that teachers may face challenges related to limited familiarity with AR tools, insufficient technical infrastructure, and a lack of training in integrating AR into lesson planning (Hunhui Na & Willet, 2025; Amir et al., 2020). Effective AR integration requires not only technical skill but also the ability to design learning experiences that leverage AR to support conceptual reasoning rather than mere visual demonstration. Additionally, implementing AR in classroom settings may require additional preparation time and adaptation to classroom management routines. These challenges indicate the need for sustained professional development programs and institutional support to ensure that AR can be meaningfully embedded in mathematics instruction. Strengthening teacher digital pedagogy is therefore essential for maximizing the instructional benefits of AR in primary schools.

Overall, the findings from the reviewed studies indicate that the use of AR in primary school mathematics learning has a comprehensive positive impact across cognitive, affective, and psychomotor domains. AR facilitates conceptual understanding by visualizing mathematical objects in concrete and interactive forms, thereby making abstract concepts in geometry and spatial figures easier for students to comprehend. Beyond improving learning outcomes, AR enhances spatial reasoning and critical thinking by enabling students to explore, manipulate, and reflect on mathematical objects and relationships. Moreover, AR creates an enjoyable and engaging learning environment that increases students' interest and reduces anxiety toward mathematics. These results suggest that AR is not merely a visual tool, but an instructional component capable of shaping how students construct mathematical knowledge.

However, the effectiveness of AR largely depends on teacher readiness and the context of its implementation. AR yields optimal results when integrated into well-designed, constructive, exploratory, and student-centred learning strategies. Challenges remain regarding teachers' technological proficiency, the availability of school infrastructure, and the integration of AR into instructional planning. Therefore, professional development focused on digital pedagogical literacy and effective AR-based instructional design is essential. With adequate teacher support and a conducive learning environment, AR has strong potential not only to improve academic achievement but also to foster students' motivation and confidence as they engage more deeply with mathematical reasoning.

CONCLUSIONS AND RECOMMENDATION

This review concludes that Augmented Reality (AR) is effective in supporting mathematics learning at the primary school level. AR reduces abstraction and helps students better understand geometric and spatial concepts through three-dimensional visualization and interactive exploration. The reviewed studies also show that AR can improve spatial reasoning, critical thinking skills, and student engagement, while also creating a more enjoyable and less anxiety-inducing learning environment. Thus, the effectiveness of AR is evident not only in academic outcomes but also in affective and motivational aspects of learning.

However, its successful implementation in classrooms requires adequate teacher readiness and appropriate instructional design. The majority of the reviewed studies employed short intervention periods and non-randomized designs, which may limit the generalizability of the findings. Schools, therefore, need to provide professional development that equips teachers with the competence to plan, integrate, and manage AR-based activities effectively. Future research is recommended to investigate long-term classroom implementation, expand AR use to a broader range of mathematical topics, and explore its role in developing metacognitive and reasoning skills. Strengthening these aspects will ensure that AR contributes more consistently and sustainably to improving the quality of mathematics learning in primary schools.

Credit authorship contribution statement

The first author wrote this article. Meanwhile, the second and third authors served as supervisors, guiding the article's ideas, content, and structure.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethical Declaration

All participants provided informed consent before their involvement in the study. They were informed about the study's purpose, procedures, and their right to withdraw at any time without consequence.

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