JOURNAL OF INNOVATION AND RESEARCH IN PRIMARY EDUCATION | ISSN 2829-775X
Vol. 5, No. 1, 2026, 542-552
https://doi.org/10.56916/jirpe.v5i1.2829

Trends and Effectiveness of Augmented Reality in Elementary Mathematics Education: A Systematic Review, 2019–2025

Marlina Ardianti*
Pascasarjana Pendidikan Dasar,Universitas Negeri Semarang, Semarang, Indonesia

Trimurtini
Pascasarjana Pendidikan Dasar,Universitas Negeri Semarang, Semarang, Indonesia

Nuni Widiarti
Pascasarjana Pendidikan Dasar,Universitas Negeri Semarang, Semarang, Indonesia

Arif Widiyatmoko
Pascasarjana Pendidikan Dasar,Universitas Negeri Semarang, Semarang, Indonesia

***Corresponding Author:** marlinaardianti@students.unnes.ac.id

Keywords
Augmented Reality
Mathematics Learning
Elementary Education
Systematic Review

Article History
Received 2025-11-08
Accepted 2026-01-16

Abstract
This study analyzes the trends and effectiveness of Augmented Reality (AR) in elementary mathematics education from 2019 to 2025. A Systematic Literature Review (SLR) was conducted on 30 indexed articles selected using the PRISMA 2020 protocol. The findings reveal that 55% of the studies were conducted in Indonesia, indicating a strong geographical concentration. Quantitatively, the reviewed studies reported significant learning improvements, as evidenced by p-values below 0.05, effectiveness rates of up to 91%, user satisfaction reaching 95.6%, media feasibility scores ranging from 81% to 99%, and one study reporting a high N-Gain value of 0.90. In addition, AR was found to enhance conceptual understanding, geometric ability, spatial reasoning, and learning motivation, while also reducing students' cognitive load. Despite its positive impact, several challenges remain, including variations in teacher readiness, infrastructure limitations, and the lack of long-term evaluation studies. Overall, AR functions not only as a visualization tool but also as a catalyst for more interactive, immersive, and student-centered mathematics learning. Future research is recommended to employ longitudinal designs, broaden participant contexts, and develop more adaptive AR-based learning models to strengthen empirical evidence in primary mathematics education.

INTRODUCTION

Over the past decade, the development of digital technology has brought significant changes to learning paradigms in elementary schools, particularly in mathematics education. The integration of technology into the learning process has been shown to increase efficiency, effectiveness, and student engagement (Mufida et al., 2021). One innovation that has gained increasing attention is Augmented Reality (AR), an interactive medium capable of linking abstract mathematical concepts with concrete and visual learning experiences (Saputro et al., 2021). AR technology can also be utilized in various other instructional contexts, such as scientific exploration, understanding geometric concepts, and simulating science experiments (Puspitasari et al., 2022). These developments highlight the need for an in-depth examination of how AR can be effectively implemented in elementary mathematics instruction, which demands visualization, interactivity, and active student participation.

Previous studies have shown that AR has great potential to enhance students' understanding of geometric concepts and spatial abilities (Jelatu, 2018; Kusumah, 2020; Kholid, 2022). However, the effectiveness of AR implementation is not yet fully understood, particularly in elementary school contexts where learners possess different developmental characteristics compared to other educational levels. Studies by Garzón (2021) and Hincapie (2023) further emphasize that although VR/AR technologies have been widely adopted across various educational fields, research that specifically examines their application in elementary mathematics learning remains limited. This indicates a gap in mapping the effectiveness, implementation contexts, and methodological variations of AR use at the elementary level.

A bibliometric study by EU-JER (2025) reports a significant increase in publications on AR in mathematics education between 2015 and 2024. However, disparities remain in both geographical distribution and educational levels investigated. Most studies focus on secondary and tertiary education, while research at the elementary level is still sparse and scattered (Astarina, 2025). Other findings also report inconsistencies in AR effectiveness, influenced by student characteristics, teacher readiness, and infrastructural support (Astarina, 2025; Huda, 2025). These imbalances and inconsistencies indicate that a solid understanding of research patterns, effectiveness, and the developmental trajectory of AR in elementary education is still lacking.

Given these gaps, a systematic literature review is needed to synthesize recent studies, identify developmental patterns, examine AR effectiveness more rigorously, and map factors influencing its successful implementation in elementary mathematics learning. To address this need, the present study employs a Systematic Literature Review (SLR) approach to analyze research related to the development and implementation of AR-based learning media in elementary mathematics education during the 2019–2025 period. The SLR method aims to identify, examine, evaluate, and interpret relevant scholarly articles (Nurfaidah et al., 2023), as well as to map publication trends, implementation models, media effectiveness, and research gaps that remain unexplored (Rachim et al., 2024).

The literature analyzed includes peer-reviewed journal articles and conference proceedings focused on the effectiveness, design, and instructional models of AR-based learning. This approach ensures not only the validity of the findings but also provides a comprehensive understanding of the direction, patterns, and recent developments in educational technology research at the elementary level (Rohmaini et al., 2024). This review aims to identify research trends, assess the effectiveness of AR on mathematics learning outcomes, spatial abilities, and student motivation, and reveal methodological and conceptual gaps within the existing literature. Theoretically, this study reinforces the foundations of constructivism and the Cognitive Theory of Multimedia Learning. Practically, it offers recommendations for educators, media developers, and policymakers in designing mathematics learning that is innovative, contextual, and student-centered.

Thus, this article not only provides a descriptive review but also offers a conceptual contribution to the advancement of immersive digital learning paradigms in elementary education.

METHODS

This study employed a Systematic Literature Review (SLR) approach to identify, evaluate, and synthesize research findings related to the development of interactive learning media based on Augmented Reality (AR) in elementary mathematics education. This approach was chosen to obtain a comprehensive, structured, and evidence-based overview of research trends, implementation effectiveness, and existing scientific gaps. The SLR procedure followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Nurfaidah et al., 2023) and the framework by Budgen et al. (2007) to ensure transparency and coherence throughout all stages, from formulating the research questions to synthesizing the data.

The main research question focused on: "How has interactive Augmented Reality learning media been developed and implemented in elementary mathematics education during the period 2019–2025?" This question was constructed using the PICOS framework, with the population consisting of elementary school students; the intervention referring to the use of AR-based learning media; no comparison group; outcomes including improvements in learning achievement, spatial ability, and conceptual understanding; and study types encompassing empirical or conceptual research published in peer-reviewed journals.

The literature search was conducted through international and national databases such as Scopus, ScienceDirect, SpringerLink, Wiley Online Library, DOAJ, ERIC, Google Scholar, Sinta, and

Garuda. The keywords used included "Augmented Reality," "AR learning media," "interactive learning media," "mathematics education," and "elementary school," combined with Boolean operators (AND, OR, NOT). To ensure reproducibility, explicit search strings were applied across all databases. For Google Scholar, the string used was: ("augmented reality" OR "AR") AND ("elementary school" OR "primary school") AND ("mathematics" OR "geometry") AND (2019 OR 2020 OR 2021 OR 2022 OR 2023 OR 2024 OR 2025). For Scopus, the search was conducted using: TITLE-ABS-KEY ("augmented reality" AND mathematics AND ("elementary" OR "primary")) AND PUBYEAR > 2018 AND PUBYEAR < 2026. On ScienceDirect, the string applied was: ("augmented reality" AND "mathematics education" AND "elementary") AND (2019–2025). ERIC used the string: ("augmented reality" AND "elementary mathematics") OR ("AR media" AND "primary school"). Meanwhile, Sinta and Garuda utilized the Indonesian-adjusted string: "augmented reality" AND "pembelajaran matematika" AND "sekolah dasar". The inclusion criteria consisted of full-text, peer-reviewed articles published between 2019 and 2025, written in English or Indonesian, and discussing the use of AR in elementary mathematics education. Articles were excluded if they focused on different education levels, were not peer-reviewed, were unrelated to mathematics, or had unclear methodologies.

The article selection process followed the PRISMA flow, including identification, screening, eligibility assessment, and final inclusion. All selected articles were recorded in a data extraction sheet to ensure traceability and prevent duplication.

Table 1. Inclusion and Exclusion Criteria for Article Selection

Criteria	Inclusion	Exclusion
Year of publication	2019–2025	Before 2019
Language	English/Indonesian	Other languages
Educational level	Elementary school	Junior high school, senior high school, or higher education
Type of article	Peer-reviewed journals, academic proceedings	Popular articles, theses, dissertations
Topic focus	Use of AR in mathematics learning	AR in other fields
Data availability	Full-text available	Abstract-only, incomplete data

The article selection process followed the PRISMA 2020 flow, as illustrated in Figure 1.

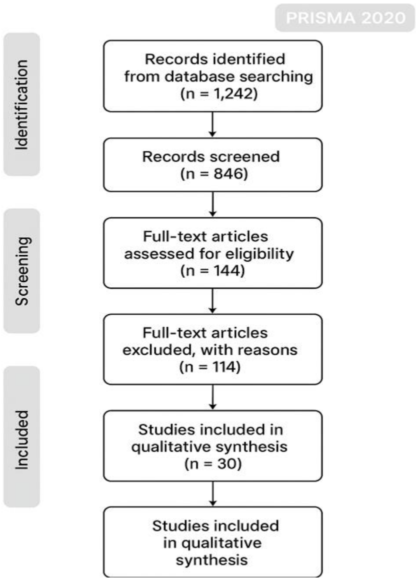

Figure 1. Prisma Flow Diagram

The article selection process followed the PRISMA 2020 flowchart. In this diagram, "n" represents the number of articles at each stage of identification, screening, eligibility, and inclusion.

Data analysis was conducted using a descriptive–comparative approach through two methods: qualitative synthesis to categorize the studies based on themes such as the effectiveness of AR media, methodological approaches, and supporting or inhibiting factors in implementation; and quantitative synthesis or meta-analysis when homogeneous numerical data were available to measure the relationship between the use of AR and improvements in students' learning outcomes.

Research validity was maintained through adherence to PRISMA standards and the guidelines of Kitchenham & Charters, transparent documentation of selection decisions, and the use of Mendeley software for reference management. Through systematic, verified, and replicable procedures, this method is expected to produce an empirical and credible literature synthesis that makes a significant contribution to the development of theory and practice related to Augmented Reality–based mathematics learning at the elementary school level

RESULTS AND DISCUSSION

Results

The results of the analysis of 30 articles can be observed in Table 2. The findings of the article analysis are as follows:

Table 2. Results of Article Analysis

No	Researchers & Year	Research Objective	Method	Main Findings / Significant Results
1	Abi Suwito et al. (2023)	To implement AR in the teaching–learning process	Qualitative	AR enhances teachers' learning experiences during instructional activities.
2	Akbar et al. (2025)	To analyze the effect of AR on elementary students' critical thinking skills	Quasi-experiment	AR improves critical thinking skills ($p = 0.015$), particularly in inference and analytical aspects.
3	Alisa et al. (2024)	To analyze the effect of AR on mathematical understanding of fifth-grade students	Quasi-experiment	There is an increase in students' critical thinking abilities before and after learning with AR.
4	Andini Amalia Swardi et al. (2024)	To analyze the effect of AR on students' learning outcomes	Normality test, Homogeneity test, Hypothesis testing	The t-test value 0.003 < 0.05 indicates that AR digital media significantly influences students' learning outcomes in geometry.
5	Arianti et al. (2023)	To develop AR-based learning media for three-dimensional shapes	R&D (ADDIE)	Media expert validation 87%, material validation 84%, and student response 99%; highly feasible for use.
6	Azmi & Cetin (2022)	To assess the effectiveness of AR in teaching liquid measurement	Quasi-experiment	AR improves achievement and reduces math anxiety ($p < 0.01$).
7	Chelly Nur Malihah et al. (2022)	To evaluate the influence of AR in elementary mathematics learning	Literature Study	Integrating AR models in elementary mathematics learning shows strong potential to enhance teaching effectiveness and student learning outcomes.
8	Cindy et al. (2024)	To design an AR application for learning three-dimensional shapes	MDLC	The EXPLORUANG application functions optimally and meets the needs of young learners.
9	Dian Mursyidah & Erwin Rahayu Saputra (2022)	To test the effectiveness of AR in introducing geometric solid concepts to elementary students	Qualitative Descriptive	AR effectively supports students' understanding of three-dimensional geometric concepts.
10	Fajariyah & Hanik (2024)	To develop BERUANG (AR) media for three-dimensional shapes	R&D (Sugiyono)	The media is valid (≥82%) and effective in improving conceptual understanding of geometric space.
11	Fasha et al. (2025)	To implement AR in the learning of three-dimensional geometry	Qualitative descriptive	93% of students reported that learning became more engaging and easier to understand.

No	Researchers & Year	Research Objective	Method	Main Findings / Significant Results
12	Fatasya et al. (2023)	To develop AR-based media for introducing three-dimensional shapes	R&D (4D)	Feasibility score of 81% (highly feasible); AR increases students' learning interest.
13	Firmansyah et al. (2020)	To develop AR-based interactive multimedia for mathematics learning	DnD	AR integrated with Google Classroom effectively supports distance learning.
14	Flavin et al. (2025)	To assess the role of AR in area measurement reasoning	Case study	Significant improvement in geometric reasoning (from phase 3 to phase 8).
15	Hartami & Maarif (2025)	To develop ARBA to enhance mathematical literacy	R&D (4D)	N-Gain 0.90 (high category); AR improves mathematical literacy.
16	Indah Purnama Sari et al. (2022)	To implement AR as a learning medium for three-dimensional geometry	Multimedia Development	AR processes data quickly and in real time, provides easy-to-understand displays, and offers interactive 3D visualization.
17	Iswahyuni et al. (2025)	To identify the need for AR media in prism geometry learning	Qualitative descriptive	Students struggle with abstract concepts; AR is needed as a concrete visual medium.
18	Kazmierczak et al. (2025)	To enhance spatial reasoning through the EDU-MAT AR platform	Mixed method	AR increases motivation and spatial reasoning for both elementary students and teachers.
19	Maryanti et al. (2024)	To develop a marker-based AR application for three-dimensional shapes	MDLC	The application functions effectively, supports independent learning, and received positive validation.
20	Muhammad Zaid et al. (2022)	To examine the effectiveness of AR in improving learning quality	Experimental	AR effectively enhances the quality of science learning.
21	Mutmainah & Purwowidodo (2024)	To develop AR to improve motivation in learning mathematics	Modified ADDIE	Validation >90%; effectiveness reaches 91%; learning motivation increases significantly.
22	Ningrum Fadillah Yuniadi et al. (2024)	To understand the effectiveness of AR in enhancing student experience and comprehension	Literature Review	AR is effective as a potential tool ready to enrich the landscape of mathematics education.
23	Qadhli Jafar Adrian et al. (2020)	To utilize AR in designing an electronic book for mathematics learning	Prototyping	The AR book application functions well and can be implemented in classroom mathematics instruction.
24	Rian & Sutarman (2023)	To design an Android-based AR application for elementary geometry	R&D + functionality testing	User satisfaction reached 95.6%; the application is effective for introducing three-dimensional shapes.
25	Tarng et al. (2024)	To evaluate AR in relation to understanding and cognitive load	Quasi-experiment	AR improves achievement for low-performing students and reduces cognitive load.
26	Volioti et al. (2023)	To evaluate the usability of the AR-based "Cooking Math" application	Qualitative (SUS testing & interviews)	AR rated "acceptable" (SUS = 70.01) and enhances elementary student motivation.
27	Wu et al. (2024)	To analyze the effect of AR books on geometric thinking and cognitive load	Mixed method	AR increases geometric thinking levels and reduces cognitive load.
28	Yang et al. (2022)	To design interactive AR-based mathematics media	MDLC	The application runs optimally and supports interactive and creative learning.
29	Yogiek Indra Kurniawan & Agung Fajar Surya Kusuma (2019)	To implement AR in developing learning media	Experimental	AR increases student learning interest, supported by a User Acceptance Test average score of 89.88% ("Very Good").

No	Researchers & Year	Research Objective	Method	Main Findings / Significant Results
30	Zhong Zhengtao & Riyan Hidayat (2025)	To analyze the effect of AR on achievement in graph and geometry topics	Quasi-experiment	AR significantly improves achievement (p = 0.001) and encourages implementation in lower-grade classrooms.

The analysis of the twenty selected articles published between 2019 and 2025 indicates that the use of Augmented Reality (AR) in elementary mathematics education has experienced substantial growth, both in terms of publication volume and thematic variation. A significant surge occurred during the 2023–2025 period, when discussions on AR integration expanded beyond media development to encompass pedagogical effectiveness, cognitive load reduction, and the enhancement of students' mathematical literacy. The dominance of publications originating from Indonesia (55%) reflects a strong local interest in AR-based instructional innovation, although contributions from China, Taiwan, Turkey, Greece, and Central Europe have increasingly enriched cross-contextual perspectives.

Table 3. Distribution by Country/Region of Study

Country/Region	Number	Percentage
Indonesia	11	55%
China	2	10%
Taiwan	1	5%
Turkey	1	5%
Greece	1	5%
Poland/Central Europe	1	5%
Mixed (country not explicitly stated, but contextually linked to Indonesia)	3	15%

From a methodological perspective, 45% of the studies employed Research and Development (R&D) approaches such as ADDIE, 4D, and MDLC, followed by 40% quantitative studies using quasi-experimental designs, and 15% qualitative or mixed-method studies. This pattern indicates that research in this field remains largely focused on product validation and short-term effectiveness testing. Most topics are centered on three-dimensional geometry (cubes, rectangular prisms, prisms, pyramids), while other areas such as algebra and statistics remain underexplored. This suggests that AR is primarily utilized to support students in understanding three-dimensional concepts that are abstract and difficult to explain using conventional instructional methods.

Table 4. Distribution by Research Method

Research Method	Number	Percentage
Quantitative (including quasi-experimental)	8	40%
Research and Development (R&D: ADDIE, 4D, MDLC, Sugiyono)	9	45%
Qualitative / Mixed Methods	3	15%

Discussion

Overall, all reviewed articles report positive outcomes regarding improvements in conceptual understanding, learning motivation, and critical thinking skills among elementary school students. Akbar et al. (2025) identified a significant enhancement in critical thinking skills (p = 0.015), particularly in the areas of inference and analysis, which are essential indicators of 21st-century mathematical literacy. Similar findings were reported by Tarng et al. (2024) and Wu et al. (2024b), who demonstrated that the use of interactive Augmented Reality books reduces cognitive load while simultaneously strengthening students' geometric thinking abilities. These results reinforce the principles of the Cognitive Theory of Multimedia Learning (Mayer et al., 2009), which posits that interactive visual learning optimizes dual coding between verbal and visual channels, thereby enhancing information retention and minimizing extraneous cognitive load.

Interestingly, all studies included in this review reported positive results, such as improved conceptual understanding, increased motivation, enhanced spatial reasoning, or higher learning outcomes. While this consistency supports the pedagogical potential of AR, it also suggests the possibility of publication bias, where studies with non-significant or negative findings are less likely to be published. The absence of neutral or contradictory results limits the ability to evaluate AR's effectiveness comprehensively, and future research should also explore conditions under which AR may not produce significant learning gains to obtain a more balanced understanding of its impact.

Hartami and Maarif (2025) further reported a substantial improvement in mathematical literacy with a high N-Gain score (0.90), confirming that AR media functions not only as a visual aid but also as a tool for fostering constructive and reflective learning experiences. Additionally, development studies by Arianti et al. (2023) and Fajariyah & Hanik (2024) reported expert validation scores above 80%, indicating that the instructional design quality of AR media has met strong pedagogical criteria and is considered suitable for elementary school implementation.

Nevertheless, the effectiveness of AR is not universal, as outcomes vary across studies depending on intervention design, instructional duration, and learner characteristics. Several studies (Tarng et al., 2024; Volioti et al., 2023) revealed that increases in learning motivation are not always significant when AR media lack elements such as gamification, adaptive challenges, or interactive feedback that facilitate a flow experience for students. These findings align with Self-Determination Theory (Deci & Ryan, 2000), which asserts that intrinsic motivation develops when the needs for autonomy, competence, and relatedness are met. Therefore, the presence of AR technology alone does not guarantee improved learning outcomes; its effectiveness strongly depends on how teachers design meaningful and contextualized learning experiences. Within the framework of the Kurikulum Merdeka, this becomes particularly relevant, as the curriculum emphasizes fostering student independence, creativity, and collaboration through active and reflective learning experiences. Consequently, the integration of AR with student-centered learning approaches can serve as a key strategy for realizing mathematics instruction that is responsive to the demands of the digital era and aligned with 21st-century competency requirements.

Importantly, the fact that a majority of AR media are designed or co-designed by teachers enhances their relevance and usability in real classroom contexts (Kaźmierczak et al., 2025). Teachers bring insights into students' prior knowledge, learning difficulties, and classroom dynamics, ensuring that AR interventions are pedagogically sound and practically implementable. This **teacher-led innovation** approach helps bridge the gap between theoretical designs and actual classroom application, improving both learning outcomes and student engagement.

Thematically, the research findings can be categorized into four interrelated focal areas: (1) the integration of AR as a pedagogical innovation, (2) the impact of AR on learning outcomes and mathematical cognition, (3) the role of AR in affective and motivational dimensions, and (4) the limitations and future directions of AR-based research. First, the integration of AR functions as a pedagogical innovation that strengthens constructivist learning paradigms, in which knowledge is built through direct experience and active interaction with digital learning environments. Studies such as Arianti et al. (2023), Firmansyah et al. (2020), and Cindy et al. (2024) demonstrate that AR is not merely a tool for visualizing abstract concepts, but has evolved into an integral component of experience-based instructional design. This approach enables students to directly explore three-dimensional virtual objects, thereby deepening conceptual understanding and enhancing knowledge transfer. This principle aligns with Dual Coding Theory and the Cognitive Theory of Multimedia Learning (Mayer et al., 2009), which emphasize that integrating visual and verbal channels strengthens information processing and supports the formation of more robust mental representations.

Second, from a cognitive perspective, ten studies such as those by Akbar et al. (2025), Hartami and Maarif (2025), and Wu et al. (2024) affirm that AR has a significant effect on improving learning outcomes, spatial reasoning, and mathematical literacy. AR-based media have been shown to reduce extraneous cognitive load by providing concrete visual representations relevant to the learning context, thereby enhancing information-processing efficiency (Sweller, 1998). Within the framework of Generative Learning Theory (Fiorella & Mayer, 2015), students' active interaction with 3D elements facilitates the formation of stable and meaningful mental representations. Furthermore, AR-based learning encourages reflective processes and conceptual elaboration, consistent with the Kurikulum Merdeka orientation toward meaningful, student-centered learning.

Third, the affective dimension emerges as an important aspect that further highlights the added value of AR implementation. Studies by Azmi, Turki, and Cetin (2022), Volioti et al. (2023), and Mutmainah and Purwowidodo (2024) show that AR use can reduce mathematics anxiety while increasing positive emotions, curiosity, and student engagement. However, these effects are contextual and highly dependent on the quality of media interaction design. Based on Self-Determination Theory (Deci & Ryan, 2000), increases in intrinsic motivation arise when AR fulfills students' three basic psychological needs: autonomy, competence, and relatedness. Therefore, AR designs that support independent exploration, provide adaptive feedback, and foster a sense of personal accomplishment have the potential to cultivate more sustainable learning motivation.

Compared to other media, such as simulations, 2D animations, or digital manipulatives, AR provides unique advantages in 3D visualization and interactivity, allowing multimodal and immersive learning experiences. However, conventional digital tools remain relevant because they are more accessible, cost-effective, and easier to integrate in classrooms without 3D capabilities (Cindy et al., 2024). Moreover, recent studies have begun incorporating Artificial Intelligence (AI) into AR to provide adaptive learning systems, automated feedback, and personalized content delivery, enhancing learning personalization and instructional effectiveness (Akbar et al., 2025; Hartami & Maarif, 2025). This integration highlights the future potential of AR combined with AI and other emerging educational technologies.

Fourth, although empirical findings indicate promising effectiveness, several methodological and contextual limitations remain. Most studies employ small sample sizes, short intervention durations (two to four meetings), and do not assess long-term impacts. In addition, the majority of AR developments are carried out by researchers or university students rather than teachers, resulting in pedagogical contexts that are often not fully represented (Kaźmierczak et al., 2025). Other limitations include dependency on a single Android platform, the scarcity of cross-cultural studies, and the lack of attention to digital inclusivity for students with special needs.

From a theoretical perspective, most studies still rely on constructivism and cognitive multimedia theory without advancing new conceptual models that integrate spatial representation, cognitive load, and the transfer of mathematical knowledge. Cross-domain research that incorporates cognitive, affective, and sociocultural dimensions is urgently needed to provide a comprehensive explanation of AR-based learning mechanisms.

These findings indicate that research on AR in elementary mathematics education is shifting from the phase of technological innovation toward pedagogical and conceptual maturation. Longitudinal mixed-method studies involving teachers as co-designers are necessary to better understand students' learning dynamics in authentic contexts. Additionally, the development of standardized evaluation frameworks that integrate pedagogical effectiveness, user experience, and cognitive load should become a key research agenda moving forward.

Conceptually, this synthesis reinforces the position of AR as a bridge between constructivist theory and multimodal learning theory. The 3D visualizations afforded by AR enable students to connect abstract concepts with concrete experiences, while its interactivity supports meaning-making through active and reflective engagement. Thus, AR is not merely an instructional aid but a medium for transforming the paradigm of mathematics learning in elementary schools—from passive instruction to active, multimodal, and student-centered learning.

CONCLUSION

Augmented Reality (AR) has the potential to serve as a pedagogical catalyst in elementary mathematics education, making learning more interactive, immersive, and experience-based, while enhancing student engagement, conceptual understanding, spatial reasoning, and motivation. Despite its promise, current research has limitations: interventions are generally short-term, sample sizes are small, studies mostly focus on geometry, and research is predominantly conducted in Indonesia.

Future studies should explore a wider range of mathematical topics, implement longitudinal interventions, examine cross-cultural contexts, develop integrative conceptual models, and investigate the potential of combining AR with AI for adaptive and personalized learning. With these directions, AR can be optimally leveraged as a transformational tool, shifting mathematics learning from abstract to concrete, passive to active, and conventional to immersive digital experiences aligned with the demands of 21st-century education.

REFERENCES

Adrian, Q. J., Ambarwari, A., & Lubis, M. (2020). Perancangan buku elektronik pada pelajaran matematika bangun ruang sekolah dasar berbasis augmented reality. *Jurnal SIMETRIS, 11*(1), 171–176. https://doi.org/10.24176/simet.v11i1.3842

Akbar, A., Herman, T., Suryadi, D., Mursalim, Alman, Putra, E. D., & Blegur, J. (2025). Integrating augmented reality in mathematics learning to improve critical thinking skills of elementary school students. *Emerging Science Journal, 9*(2), 764–779. https://doi.org/10.28991/ESJ-2025-09-02-014

Alisa, A., Suwangsih, E., & Solihah, P. (2024). Pengaruh model problem based learning berbantuan augmented reality (AR) terhadap peningkatan kemampuan pemahaman matematika siswa kelas V sekolah dasar. *Jurnal Ilmiah Wahana Pendidikan, 10*(2), 89–102. https://doi.org/10.5281/zenodo.10472526

Arianti, B. D. D., Djamaluddin, M., & Sabila, H. (2023). Pengembangan media pembelajaran bangun ruang berbasis augmented reality. *Infotek: Jurnal Informatika dan Teknologi, 6*(2), 478–490. https://doi.org/10.29408/jit.v6i2.18812

Arianti, N., Rahmawati, S., & Dewi, A. (2023). Pengembangan media pembelajaran bangun ruang berbasis augmented reality dengan model ADDIE. *Jurnal Pendidikan Dasar Indonesia, 8*(1), 45–57. https://doi.org/10.29408/jpdi.v8i1.18812

Astarina, D. (2025). Kesiapan guru dan infrastruktur sekolah dalam implementasi teknologi AR pada pembelajaran matematika SD. *Jurnal Inovasi Pendidikan Dasar, 9*(2), 115–129. https://www.researchgate.net/publication/392464235

Azmi Turki, A., & Cetin, H. (2022). Efektivitas aplikasi berbasis realitas tertambah pada tema pengukuran zat cair dalam mata kuliah matematika: Sebuah studi eksperimental. *Journal of Psychoeducational Research, 9*(1), 12–25.*

Budgen, D., Kitchenham, B., Charters, S., Turner, M., Brereton, P., & Linkman, S. (2007). Preliminary results of a study of the completeness and clarity of structured abstracts. *11th International Conference on Evaluation and Assessment in Software Engineering (EASE).* https://doi.org/10.14236/ewic/EASE2007.7

Cindy, R., Prasetya, D., & Kurniawan, E. (2024). Perancangan aplikasi media pembelajaran matematika bangun ruang berbasis augmented reality (AR) untuk siswa sekolah dasar. *Jurnal Teknologi Pendidikan, 12*(3), 140–155. https://doi.org/10.51351/jtm.13.2.2024782

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*(4), 227–268. https://doi.org/10.1207/S15327965PLI1104_01

EU-JER. (2025). Trends and bibliometric analysis of augmented reality in mathematics education (2015–2024). *Eurasia Journal of Educational Research, 110*, 15–28.

Fadilah, R., & Sutarman. (2023). Geometry learning media application for elementary school students using Android-based augmented reality technology. *Indonesian Journal of Computer Science, 12.* https://doi.org/10.33022/ijcs.v12i5.3433

Fajariyah, L., & Hanik, S. (2024). Pengembangan media BERUANG berbasis augmented reality untuk kelas V sekolah dasar. *Jurnal Inovasi Pendidikan Dasar, 8*(2), 90–102. https://doi.org/10.31004/basicedu.v8i2.7346

Fasha, R., Lestari, I., & Maulana, Y. (2025). Implementasi media augmented reality dalam pembelajaran bangun ruang di Sekolah Dasar Taallumul Huda Bumiayu. *Jurnal Ilmiah Pendidikan Dasar, 10*(1), 45–59. https://doi.org/10.25134/empowerment.v8i02.11886

Fatasya, D., Nuraini, S., & Arifin, F. (2023). Pengembangan media pembelajaran pengenalan bangun ruang berbasis augmented reality untuk anak sekolah dasar. *Jurnal EduTech, 7*(2), 112–121. https://doi.org/10.29100/jipi.v8i3.3834

Fiorella, L., & Mayer, R. E. (2015). *Learning as a generative activity*. Cambridge University Press.

Firmansyah, Y., Nugroho, A., & Rahman, T. (2020). Pengembangan multimedia pembelajaran interaktif untuk matematika kelas 5 sekolah dasar dengan integrasi AR. *Jurnal Teknologi Pendidikan, 8*(2), 33–42. https://doi.org/10.17509/edsence.v2i2.29783

Flavin, E., Chung, M., Hwang, S., & Flavin, M. T. (2025). Augmented reality for area measurement reasoning of elementary students. *Educational Technology Research and Development, 73*(4), 1–20. https://doi.org/10.1007/s11423-025-10502-0

Hartami, H., & Maarif, S. (2025). Pengembangan media augmented reality bangun ruang (ARBA) untuk meningkatkan literasi matematis siswa kelas V sekolah dasar. *ITQAN, 16*(1), 149–162. https://doi.org/10.47766/itqan.v16i1.6201

Huda, M. A. I. (2025). Pengembangan media pembelajaran berbasis augmented reality untuk pengenalan topologi jaringan. *JPTIIK, 9*(5), 2548–2964.*

Indah Maryanti, R., Kusumah, F. S. F., & Fajri, H. (2024). Aplikasi media pembelajaran bangun ruang menggunakan marker-based augmented reality. *JATI, 8*(3), 3003–3009. https://doi.org/10.36040/jati.v8i3.9605

Iswahyuni, Mariana, N., Hendratno, & Istiqfaroh, N. (2025). Analisis kebutuhan awal pengembangan media pembelajaran prisma berbasis augmented reality. *ELSE, 9*(1), 147–153. https://doi.org/10.30651/else.v9i1.24738

Kaźmierczak, R., Grunwald, G., Skowroński, R., Kaźmierczak, L., & Kowalczyk, C. (2025). Augmented reality tools for mathematics and geoscience education. *Scientific Reports, 15*(1), 1–16. https://doi.org/10.1038/s41598-025-02090-z

Kurniawan, Y. I., & Kusuma, A. F. S. (2021). Aplikasi augmented reality untuk pembelajaran salat bagi siswa sekolah dasar. *Jurnal Teknologi Informasi dan Ilmu Komputer, 8*(1), 7–14. https://doi.org/10.25126/jtiik.0812182

Mayer, R. E., Stull, A., DeLeeuw, K., Almeroth, K., Bimber, B., Chun, D., … Zhang, H. (2009). Clicker di ruang kelas perguruan tinggi: Mendorong pembelajaran dengan metode bertanya. *Contemporary Educational Psychology, 34*(1), 51–57. https://doi.org/10.1016/j.cedpsych.2008.04.002

Mufida, B. A., Putra, F. N., & Yusron, R. D. R. (2021). Pembuatan game edukasi pengenalan hewan berbasis augmented reality. *JACIS, 1*(2), 120–130. https://doi.org/10.47134/jacis.v1i2.20

Mursyidah, D., & Saputra, E. R. (2022). Aplikasi augmented reality untuk pengenalan bangun ruang bagi siswa sekolah dasar. *Tunas Nusantara, 4*(1), 427–433.*

Mutmainah, M., & Purwowidodo, A. (2024). Pengembangan media pembelajaran interaktif berbasis augmented reality untuk meningkatkan motivasi belajar matematika siswa kelas V. *MODELING, 11*(2), 83–90. https://doi.org/10.69896/modeling.v11i2.2285

Nurfaidah, N., Pujiastuti, E., Cahyono, A. N., & Sugiman, S. (2023). Systematic literature review: Penggunaan augmented reality (AR) pada pembelajaran matematika. *PRISMA, 12*(2), 380–389. https://doi.org/10.35194/jp.v12i2.3291

Puspitasari, A., Rudianto, B., & Prasetya, M. A. (2022). Game edukasi pengenalan tumbuhan berbasis augmented reality. *JIKA, 6*(1), 10–17. https://doi.org/10.31000/jika.v6i1.5155

Rachim, M. R., Salim, A., & Qomario, Q. (2024). Pemanfaatan augmented reality terhadap keaktifan belajar siswa. *JRIP, 4*(1), 594–605. https://doi.org/10.51574/jrip.v4i1.1407

Rohmaini, M., Fathurrohman, M., & Syamsuri, S. (2024). Pengaruh augmented reality pada kemampuan berpikir kreatif siswa. *JIIP, 7*(10), 12378–12383. https://doi.org/10.54371/jiip.v7i10.6109

Saputro, I. P., Adrian, A. M., & Joseph, L. D. (2021). Game "Finding Easter Egg" berbasis augmented reality. *CogITo Smart Journal, 7*(1), 15–25. https://doi.org/10.31154/cogito.v7i1.289

Sari, I. P., Batubara, I. H., & Basri, M. (2023). Pengenalan bangun ruang menggunakan augmented reality. *Hello World Jurnal Ilmu Komputer, 1*(4), 209–215. https://doi.org/10.56211/helloworld.v1i4.142

Solihah, A. P. S. S., & Ramadan, C. S. R. (2025). Mengeksplorasi pengaruh augmented reality dalam pembelajaran matematika. *Buletin Ilmiah Pendidikan, 4*(1), 1–9. https://doi.org/10.56916/bip.v4i1.1744

Suwito, A., Astuti, N. I., Sunardi, S., & A'yun, Q. (2023). Implementasi augmented reality dalam pengajaran matematika di SDN Rambigundam 1. *Jurnal Altifani, 3*(2), 223–227. https://doi.org/10.59395/altifani.v3i2.370

Sweller, J. (1998). Cognitive load during problem solving. *Cognitive Science, 12*(2), 257–285.

Tarng, W., Huang, J. K., & Ou, K. L. (2024). Improving elementary students' geometric understanding through augmented reality. *Systems, 12*(11). https://doi.org/10.3390/systems12110493

Volioti, C., Orovas, C., Sapounidis, T., Trachanas, G., & Keramopoulos, E. (2023). Augmented reality in primary education: An active learning approach in mathematics. *Computers, 12*(10). https://doi.org/10.3390/computers12100207

Wu, J., Jiang, H., Long, L., & Zhang, X. (2024). Effects of AR mathematical picture books on geometric thinking, cognitive load, and flow experience. *Education and Information Technologies, 29*(18), 24627–24652. https://doi.org/10.1007/s10639-024-12768-y

Yang, L., Susanti, W., Hajjah, A., Marlim, Y. N., & Tendra, G. (2022). Perancangan media pembelajaran matematika menggunakan augmented reality. *Edukasi: Jurnal Pendidikan, 20*(1), 122–136. https://doi.org/10.31571/edukasi.v20i1.3830

Yuniadi, N. F., Cintia, R., & Ikrom, F. D. (2024). Penerapan media pembelajaran augmented reality untuk siswa sekolah dasar. *MESIR, 1*(2), 437–444. https://doi.org/10.57235/mesir.v1i2.3020

Zaid, M., Razak, F., & Alam, A. A. F. (2022). Keefektifan media pembelajaran augmented reality berbasis STEAM dalam pembelajaran IPA. *Jurnal PELITA, 2*(2), 59–68. https://doi.org/10.54065/pelita.2.2.2022.316

Zhengtao, Z., & Hidayat, R. (2025). The effects of augmented reality toward achievement on graphs and geometry among third-grade students. *Mathematics Teaching-Research Journal, 17*(1), 82–98. https://files.eric.ed.gov/fulltext/EJ1470636.pdf