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Augmented Reality for Geometry Learning in Primary Education: A Systematic Literature Review

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Abstract: This systematic literature review examines the effectiveness of Augmented Reality (AR) technology in improving geometry learning outcomes at the primary education level in Indonesia. Following the PRISMA 2020 guidelines, a comprehensive search was conducted across Google Scholar, Sinta, and Garuda databases for articles published between 2020 and 2025. Of 100 initially identified articles, 35 met the inclusion criteria and were subjected to descriptive qualitative analysis and meta-synthesis. The findings reveal that AR-based learning media significantly improve students' geometry learning outcomes, with N-Gain scores ranging from 0.40 to 0.87 (moderate to high categories). AR enhances learning by visualizing abstract geometric concepts as interactive 3D models, increasing student motivation (from 39.67% to 92.67%), and facilitating spatial understanding. Key challenges include infrastructure limitations, teacher readiness, technological accessibility, and curriculum integration. The review identifies the ADDIE model as the most prevalent development framework and highlights the potential of integrating ethnomathematics with AR for culturally relevant learning. This study provides theoretical and practical foundations for AR integration in geometry teaching and recommends systematic teacher training, infrastructure improvement, and adaptive learning models for future implementation. Future research should employ longitudinal designs and expand participant contexts to strengthen empirical evidence.

Keywords: Augmented Reality, Geometry Learning Outcomes, Primary Education, Systematic Literature Review

A. Introduction

Mathematics learning, particularly geometry, in primary schools still faces various serious challenges. The numeracy literacy crisis in Indonesia is reflected in the 2022 PISA score of just 366, indicating that Indonesian students' mathematical ability remains low compared to international standards (Iryanto, 2025). This necessitates technology-based pedagogical interventions to improve the quality of the primary school mathematics curriculum, which is often perceived as difficult by students due to its abstract nature and the need for strong visualisation skills.

The teaching of solid geometry in primary schools faces challenges due to its abstract nature and the difficulty students have in visualising it (Amin et al., 2025). Teachers often struggle to present the material in an engaging and concrete manner using three-dimensional solid models, and the limited use of concrete learning materials in the classroom leads to students lacking enthusiasm and experiencing difficulties in understanding spatial geometry concepts(Rohman, 2025). Pupils often face difficulties due to the abstract nature of geometric concepts and the need for spatial visualization skills required to strengthen their conceptual understanding (Nadzeri et al., 2024). This situation presents a problem that needs to be addressed immediately, as an understanding of geometric concepts is a fundamental competence in mathematics education that will influence learning at subsequent levels.

With the advancement of technology, Augmented Reality (AR) is considered a promising approach to support the geometry learning process (Fitriani et al., 2025). AR is an interactive technology capable of enhancing the learning experience through real-time visualization of three-dimensional objects, thereby helping students understand abstract geometric concepts in a more concrete way (Verlita Lomiheke et al., 2025). The use of AR in learning can improve students' understanding of mathematical concepts, particularly in abstract subjects such as geometry and solid figures (Sari et al., 2025). Recent studies indicate that AR technology has attracted significant attention and become a key topic for many professionals and researchers due to its ability to offer various benefits that can enrich diverse areas of life, including education (Zekeik et al., 2025).

A recent meta-analysis reveals that AR has a significant positive impact on student learning outcomes, with an overall effect size indicating a substantial improvement in academic performance (Adi et al., 2025). The analysis indicates that AR is highly effective in subjects requiring spatial reasoning and visualization. Furthermore, AR has been shown to enhance student motivation and engagement, helping them to better understand and retain difficult concepts.

Based on this background, this study aims to systematically analyze the effectiveness of using AR technology on geometry learning outcomes at the primary education level in Indonesia. This study employs a Systematic Literature Review (SLR) approach following PRISMA guidelines to identify, evaluate, and synthesize findings from various previous studies. Specifically, this review addresses the following research questions: 1) What are the characteristics of AR research in geometry learning at the primary education level in Indonesia? 2) How effective is AR technology in improving students' geometry learning outcomes? 3) What factors influence the effectiveness of AR implementation in geometry learning? 4) What are the challenges and solutions for implementing AR in geometry learning? The results of this study are expected to provide a theoretical and practical foundation for the development of adaptive and sustainable AR-based geometry learning innovations in the era of modern educational technology.

B. Methods

This study employs the Systematic Literature Review (SLR) method following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 guidelines to systematically identify, select, and evaluate the literature. The review protocol was not registered with PROSPERO due to time constraints; however, it was conducted in accordance with the PRISMA 2020 checklist items. This approach was chosen because it provides a comprehensive overview of the effectiveness of AR in geometry learning based on the synthesis of various existing studies.

Search Strategy

The literature search was conducted on January 15, 2025, using three academic databases: (1) Google Scholar, (2) SINTA (Science and Technology Index), which is an Indonesian scientific journal indexing portal managed by the Ministry of Education, Culture, Research, and Technology, and (3) GARUDA (Garba Rujukan Digital), which is an Indonesian scientific reference portal.

The search strings used were combinations of the following keywords: Google Scholar: (“Augmented Reality” OR “AR”) AND (“mathematics” OR “geometry” OR “solid figures” OR “bangun ruang”) AND (“primary school” OR “elementary school” OR “sekolah dasar” OR “SD”) AND (“learning outcomes” OR “hasil belajar”) AND “Indonesia” SINTA: “Augmented Reality” AND “geometri” AND “sekolah dasar” GARUDA: “Augmented Reality” AND “matematika” AND “pembelajaran”. The publication time range was set from 2020 to 2025 to ensure the relevance and currency of the research findings.

Inclusion and Exclusion Criteria

The inclusion criteria established were: (1) research discussing the use of AR in mathematics or geometry learning, (2) research subjects were primary school or Islamic primary school (madrasah ibtidaiyah) students in Indonesia, (3) research measuring learning outcomes or understanding of geometry concepts, (4) articles published in reputable journals or proceedings and available in full text, and (5) articles written in Indonesian or English. The exclusion criteria included: (1) review articles or editorials without empirical data, (2) research that did not report learning outcomes quantitatively, (3) duplicate articles, and (4) articles that could not be accessed in full.

Study Selection Process

The selection process was conducted by two researchers independently using a two-stage approach. The first stage involved screening titles and abstracts, while the second stage involved eligibility assessment based on full text. Disagreements between researchers were resolved through consensus discussion, and if necessary, a third researcher was involved as an arbiter.

The initial search identified a total of 100 articles: Google Scholar (n=68), SINTA (n=22), and GARUDA (n=10). After removing duplicates (n=15), 85 articles remained for title and abstract screening. Of these, 50 articles were excluded for not meeting the inclusion criteria. The remaining 35 articles were assessed for eligibility based on full text, and all of them met the criteria for further analysis.

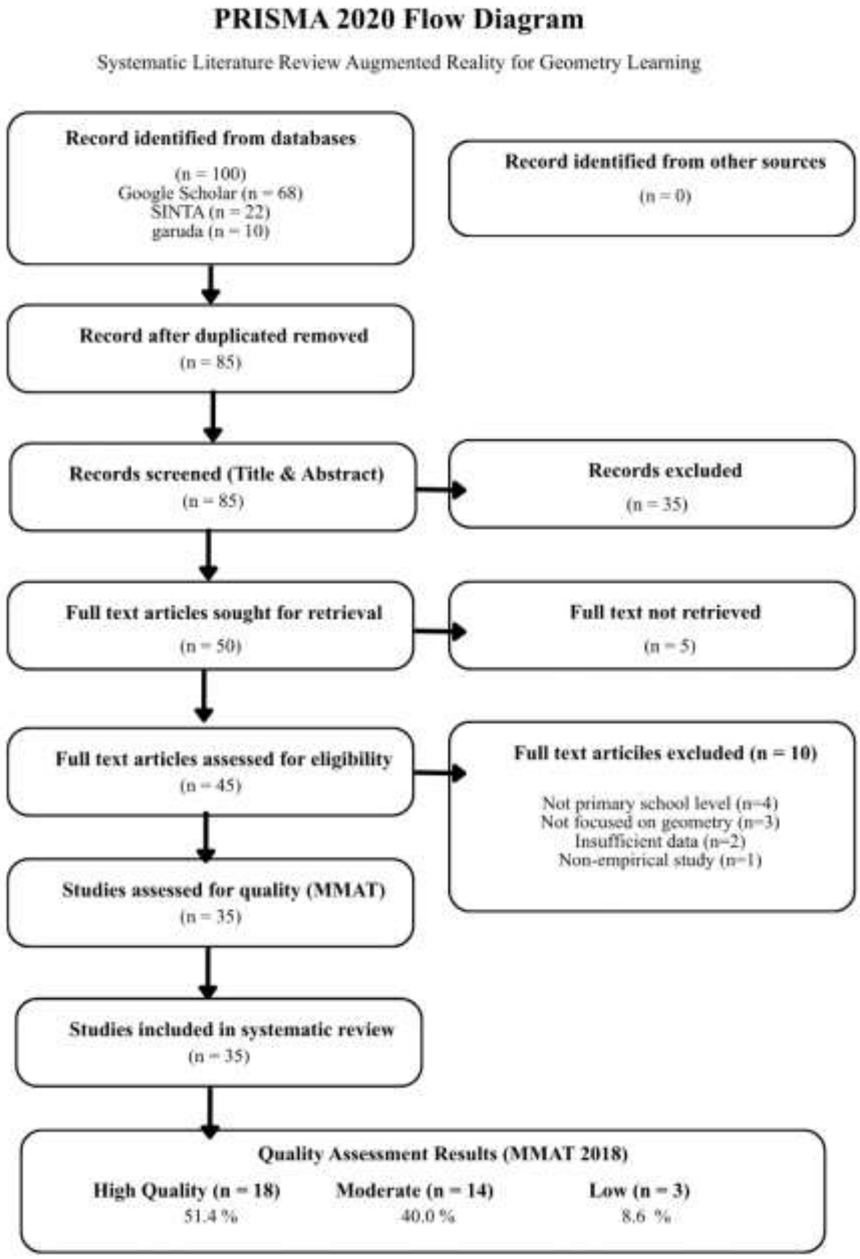

Figure 1. The PRISMA Flow Diagram

Study Quality Assessment

Methodological quality assessment was conducted using the Mixed Methods Appraisal Tool (MMAT) version 2018 to accommodate the diversity of research designs included. Each article was evaluated based on five criteria according to its research type (quantitative descriptive, quantitative non-randomized, quantitative randomized, qualitative, or mixed methods). Quality scores were categorized as: high (meeting all criteria), moderate (meeting 3-4 criteria), and low (meeting ≤2 criteria). Of the 35 articles analyzed, 18 articles (51.4%) had high quality, 14 articles (40%) had moderate quality, and 3 articles (8.6%) had low quality. Articles with low quality were still included in the analysis but were given less weight in the synthesis of findings.

Data Extraction

Data extraction was performed by the first researcher using a standardized extraction form, then verified by the second researcher. The extracted data included: (1) bibliographic information (author, year, journal), (2) research design, (3) subject characteristics (education level, sample size), (4) type of AR media used, (5) geometry material taught, (6) measurement instruments, (7) pre-test and post-test results, and (8) N-Gain scores.

Discrepancies in data extraction were resolved through discussion and re-verification against the original articles. Inter-rater reliability was calculated using Cohen's Kappa and showed a value of $\kappa = 0.85$, indicating an excellent level of agreement.

Data Synthesis and Analysis

Data were analyzed using qualitative descriptive analysis techniques to describe study characteristics and meta-synthesis to identify consistent patterns of findings across various studies. Given the high heterogeneity in research designs and outcome measures, quantitative meta-analysis was not performed. Instead, narrative synthesis was conducted to integrate findings from various studies.

Risk of Bias and Limitations

Potential publication bias was considered by including research from various sources including nationally accredited journals and conference proceedings. However, the limitation of searching only three databases may have caused some relevant studies to be missed. Additionally, the dominance of Research and Development (R&D) studies in the sample may limit the generalizability of findings regarding the causal effectiveness of AR.

C. Results and Discussion

Based on the analysis of 35 articles meeting the inclusion criteria, the following research characteristics were identified. The distribution of publication years shows a trend of increasing numbers of AR studies in geometry learning year on year, with a peak in publications in 2025. This indicates a growing interest among researchers in Indonesia in the integration of AR technology into mathematics learning. A systematic review of 117 articles published from 2010 to 2022 shows that the total number of studies has grown rapidly over the last six years, with the greatest focus on VR/AR-supported mathematics learning (Jiang et al., 2025).

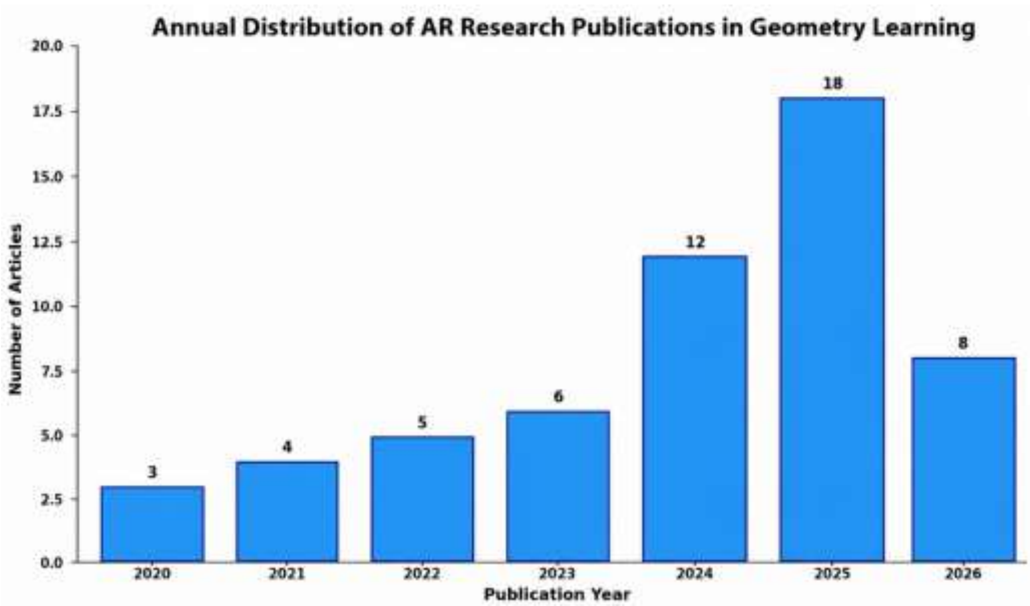

Figure 2. Distribution of Publication Years for AR Research in Geometry Education in Indonesia

The most commonly used research method was Research and Development (R&D) at 37.1%, followed by quasi-experimental studies at 28.6% (Candra Verdiatmoko & Pinandita, 2025). The dominant use of the R&D method indicates that research focuses more on the development of valid, practical, and effective AR learning media, prior to conducting effectiveness tests on a larger scale. AR-based smartphones/tablets are the most widely used technology, whilst very few studies utilise specialised immersive AR devices (Jiang et al., 2025).

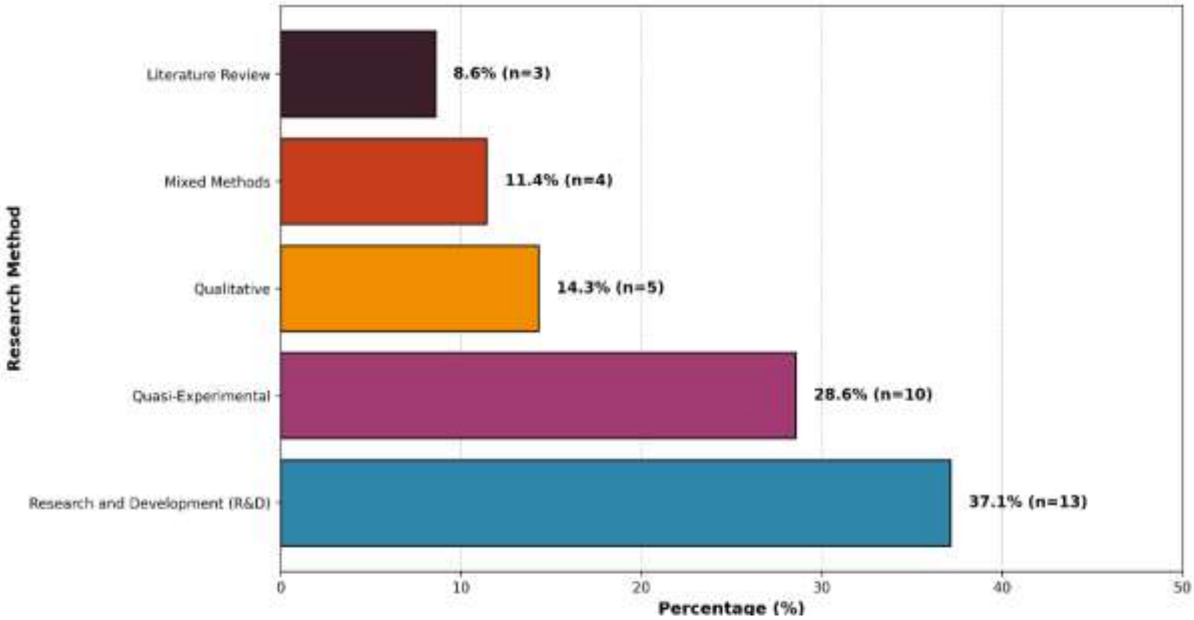

Figure 3. Distribution of AR Research Methods in Geometry Learning

Table 1. Characteristics of AR Research in Geometry Learning in Indonesia

Aspect	Category	Number	Percentage
Level of Education	Primary School/Madrasah Ibtidaiyah	28	80%
	Lower Secondary School/MTs	7	20%
Geometry	3D Shapes	25	71.4%
	2D Shapes	10	28.6%
AR Platform	Android	30	85.7%
	Desktop/Web	5	14.3%
Development Model	ADDIE	22	62.9%
	Other models	13	37.1%

The synthesis results indicate that the use of AR is consistently effective in improving students' geometry learning outcomes. The implementation of the Geometry Space Augmented Reality Box (GR Box) media showed a significant increase in students' average scores from 38.46 to 92.31 (Rohman, 2025). The GR Box media helps to concretise abstract concepts through a combination of physical manipulatives and Augmented Reality-based visualisations, enabling students to better understand the relationships between the elements of three-dimensional shapes.

The development of 3D Geo AR Cards has also yielded very positive results. Evaluation results indicate a significant improvement in students' conceptual understanding, with an N-Gain score of 78%, which falls within the "effective" category (Marshanawiah et al., 2025). Through the use of 3D Geo AR Cards, students can visualise and interact with three-dimensional geometric objects, making it easier for them to grasp these concepts. Validation showed a score of 95% from subject matter experts and 97.5% from media experts, both falling within the "highly suitable" category.

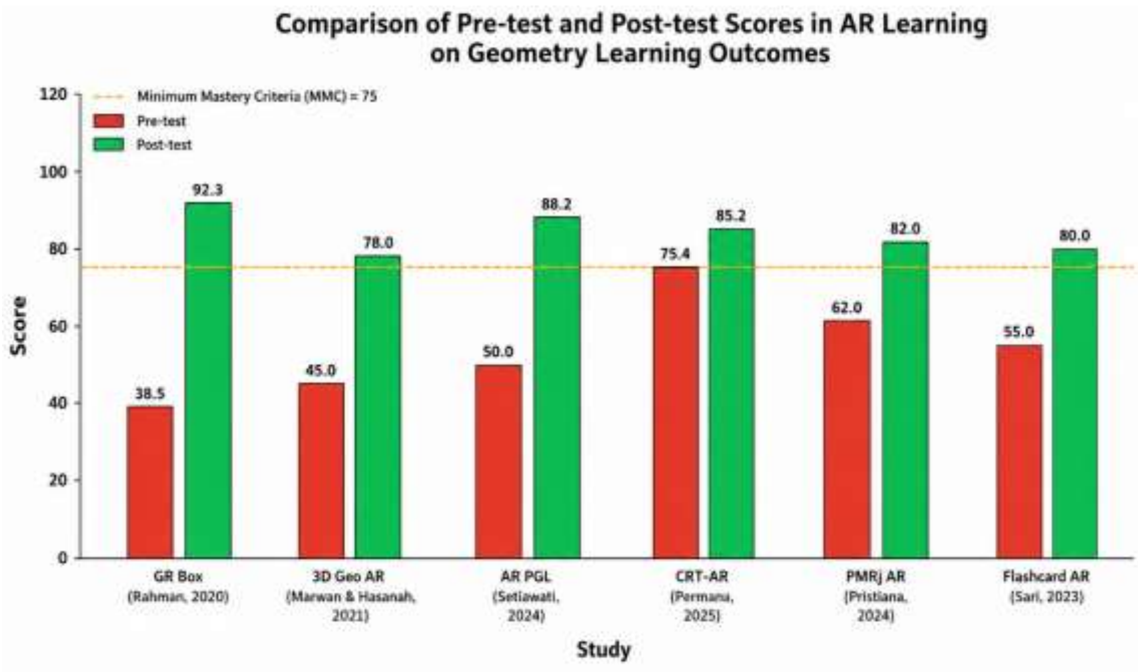

Figure 4. Comparison of Pre-test and Post-test Scores for AR-based Learning on Geometry Learning Outcomes

Research on the use of AR applications for teaching geometry in secondary schools has shown a significant improvement in pupils' conceptual understanding, with average scores rising from 46.31 (pre-test) to 92.91 (post-test) (Aulia Putri & Taris, 2025). These findings suggest that AR technology can enhance engagement and understanding in mathematics. Another study of Year 5 primary school pupils in Taiwan showed that the AR group significantly outperformed the control group in learning achievement (adjusted mean: 90.14 vs 74.13, p2= 0.26) and motivation (Chao, 2025).

Table 2. Summary of the Effectiveness of AR Media on Geometry Learning Outcomes

Research	Pre-test	Post-test	N-Gain	Category
GR Box (Rohman, 2026)	38.46	92.31	0.87	Height
3D-Geo AR Cards (Marshanawiah, 2025)	45.00	78.00	0.78	High
AR PBL (Setiawati, 2024)	50.00	88.16	0.76	High
CRT-AR (Permana, 2025)	75.36	85.18	0.40	Medium
PMRI-AR (Ristiana, 2024)	62.00	82.00	0.54	Moderate
Slice and Shape (Holilah, 2026)	44.60	64.21	0.42	Moderate
MathFlex (Silalahi, 2025)	62.00	90.00	0.73	High

AR contributes significantly to improving students' spatial visualisation, mental rotation, and geometric representation skills through interactive three-dimensional visualisation and immersive learning experiences (Najamuddin et al., 2025). The geometric thinking skills of students using AR media showed improvement across various Van Hiele levels, ranging from visualisation to informal deduction (Ramadhani, 2025). The implementation of AR-based learning media effectively improved students' geometric thinking skills from level 0 to level 3 ($p<0.05$), with the greatest improvement observed at the informal deduction level.

Studies on primary school pupils demonstrated significant improvements in both spatial skills ($t = 19.795$, $p < 0.05$) and science achievement ($t = 24.801$, $p < 0.05$), with the most substantial progress observed among pupils who initially exhibited lower spatial abilities (Nincarean et al., 2025). Statistical analysis revealed a strong positive correlation ($r = 0.713$, $p = 0.000$) between spatial visualisation and science performance, highlighting the interaction between cognitive and academic growth within the STEM context.

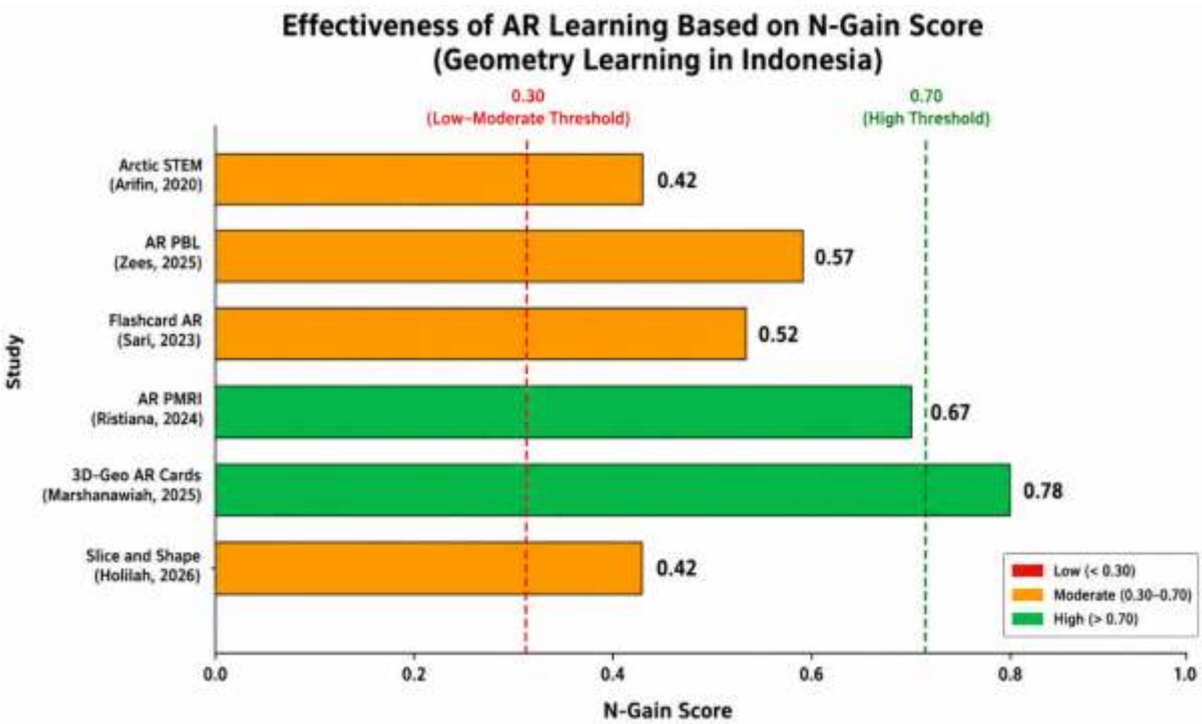

Figure 5. Effectiveness of AR Learning Based on N-Gain Score

Research on secondary school students using GeoGebra AR demonstrated a significant increase in students' geometric thinking levels following the intervention ($p < 0.05$), leading to the rejection of the null hypothesis (Ruslau et al., 2025). These findings provide empirical support for the effectiveness of GeoGebra AR in advancing students' Van Hiele levels and enhancing their understanding of geometric concepts.

The development of Augmented Reality-based Ethnomathematics (EMAR) media to strengthen pupils' spatial reasoning in primary schools has yielded positive results. An independent t-test revealed a significant difference between the post-test scores of students using the media and those who did not, with a significance value of 0.033, indicating that this media is effective in improving students' spatial reasoning (Fathuloh et al., 2025). The integration of AR into learning is capable of providing a more concrete learning experience and facilitating the understanding of abstract geometric concepts.

In addition to improving cognitive learning outcomes, AR has also been shown to increase students' motivation and interest in learning. Research findings show a significant increase in student motivation from 39.67% (the "Poor" category) to 92.67% (the "Very Good" category) following the implementation of AR in basic mathematics learning (Verlita Lomiheke et al., 2025). This finding demonstrates that AR is effective in creating a more interactive, engaging, and motivating mathematics learning experience.

The implementation of the Zyra app, equipped with AR features for visualizing flat-sided three-dimensional shapes, has had a significant positive impact on students' interest and learning outcomes (Salsabilla et al., 2025). Before using the app, students struggled to visualise three-dimensional geometric concepts; however, after using the AR feature, their understanding improved drastically. The "learning by playing" strategy successfully created a fun and interactive learning environment.

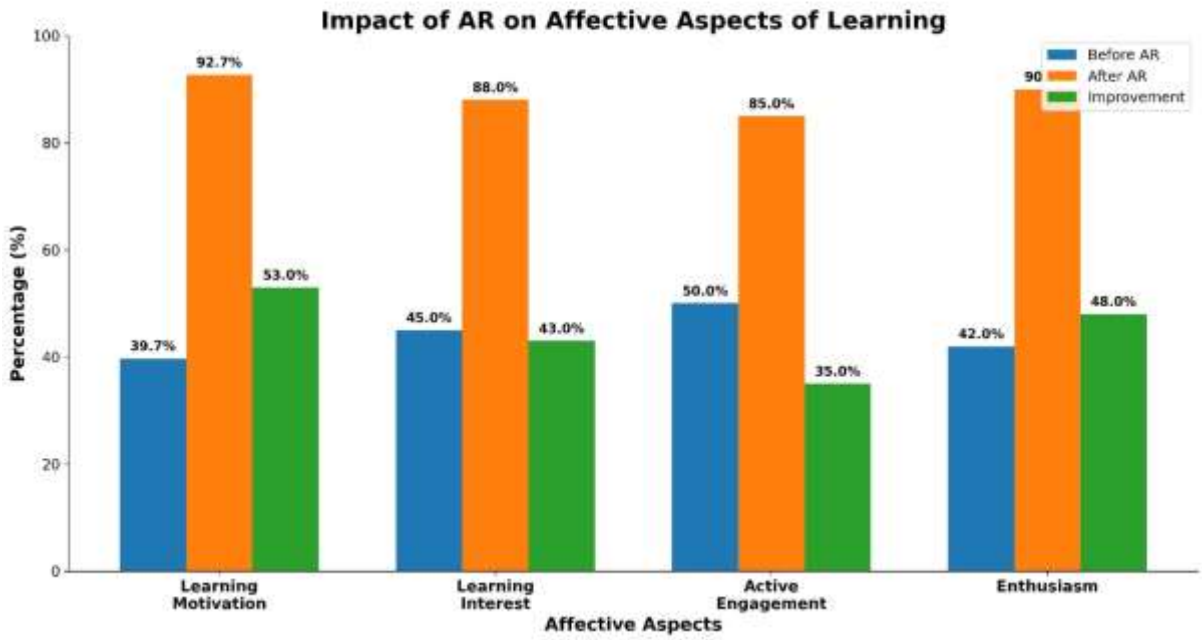

Figure 6. The Impact of AR on the Affective Aspects of Learning

Table 3. The Impact of AR on the Affective Aspects of Learning

Aspect	Before AR	After AR	Improvement
Motivation to Learn	39.67%	92.67%	53.00%
Interest in learning	45.00%	88.00%	43.00
Active Engagement	50.00%	85.00%	35.00%
Enthusiasm	42.00%	90.00%	48.00

Although the results were positive, there are several challenges in the implementation of AR in primary schools. These challenges include resource requirements, teacher training, and integration into the existing curriculum (Fitriani et al., 2025). Recommended solutions include intensive training for teachers, improvements to the school's technological infrastructure, and further research into the implementation of AR-based learning.

The success of AR implementation is influenced by constructivist-based pedagogical design, teachers' technological competence, and infrastructure readiness (Najamuddin et al., 2025). The limitations of interactive learning media in explaining abstract concepts such as mathematical solids remain a challenge for primary school pupils, where conventional methods relying on books and static teaching aids often fail to optimise understanding (Candra Verdiatmoko & Pinandita, 2025). Studies indicate that whilst AR is gaining traction in technical education, wider adoption remains hampered by technical challenges and the need for better curriculum integration (Suhail et al., 2024).

A systematic review highlights several challenges faced by learners, including distractions, reduced efficiency and effectiveness, diminished inquiry and imagination, operational issues, and discomfort (Jiang et al., 2025). Teachers face difficulties in classroom management, designing activities, acquiring technical competencies, and adapting to new roles to facilitate student-centred learning. Schools struggle with high costs, inadequate infrastructure, a lack of personal virtual spaces, and privacy issues.

Table 4. Challenges and Solutions for Implementing AR in Geometry Learning

Challenges	Recommended Solutions
Limitations of technological infrastructure	Improvement of ICT facilities and internet connectivity in schools
Teacher competence readiness	Intensive and ongoing training for teachers
Costs of developing AR media	Collaboration with developers and the use of free platforms
Integration with the curriculum	Development of systematic implementation guidelines
Device accessibility	Provision of shared devices and offline applications

The results of this systematic review provide important implications for the development of geometry learning in Indonesia. AR has great potential as a medium for geometry learning to develop conceptual and spatial abilities simultaneously (Salim & Lailiyah, 2025). The combination of ethnomathematics and AR creates learning that is interactive, contextual, and culturally relevant (MS et al., 2025). This is in line with the spirit of the 'Merdeka' curriculum, which emphasises meaningful, contextual learning.

Studies on AR-based learning media integrated with ethnomathematics indicate that AR offers significant advantages in presenting three-dimensional geometric objects in an interactive, visual, and concrete manner, which enhances students' understanding of abstract spatial relationships and improves mental manipulation of objects (Gustina et al., 2025). These findings support Van Hiele's theory, emphasizing the importance of gradual stages in the understanding of geometry. The combination of AR and ethnomathematics not only deepens spatial reasoning but also promotes meaningful and culturally relevant learning experiences.

The integration of AR technology into learning bridges the gap between abstract theory and real-world understanding in Indonesian classrooms (Kholish, 2025). AR helps visualize invisible phenomena, facilitates interactive exploration, and fosters student-centred learning experiences. Meaningful mathematics learning needs to combine culturally responsive approaches and immersive technology, whilst fostering students' mental resilience to face academic challenges (Indra Permana, 2025).

The development of AR and the ADDIE model has yielded highly positive results across various learning contexts (Syakinnah et al., 2025). Research findings indicate that the developed media achieved a validity rate of 82% from subject matter experts and 90% from media experts, both categorized as highly valid. Furthermore, the practicality test conducted on students yielded a score of 86%, which was categorized as highly practical. These findings indicate that the developed media is suitable and supports students in understanding and visualizing the concept of polyhedral.

D. Conclusion

This systematic literature review examined the effectiveness of Augmented Reality (AR) technology in improving geometry learning outcomes at the primary education level in Indonesia. Following the PRISMA guidelines, 35 peer-reviewed articles published between 2020 and 2025 were systematically identified, screened, and analysed. The review addressed four research questions regarding research characteristics, effectiveness on learning outcomes, influencing factors, and implementation challenges. The findings demonstrate that AR technology consistently improves geometry learning outcomes, with N-Gain scores ranging from 0.40 to 0.87 (moderate to high categories). AR enhances learning by visualising abstract geometric concepts as interactive three-dimensional models, facilitating spatial understanding and conceptual development. The review reveals that effective AR implementation requires integration of multiple dimensions: pedagogical design grounded in constructivist principles, systematic development following the ADDIE model, and attention to both cognitive and affective outcomes. Beyond cognitive gains, AR significantly improves learning motivation (increasing from 39.67% to 92.67%), interest, and active engagement, creating more meaningful and enjoyable learning experiences for primary school pupils. The review identifies several theoretical contributions. First, findings support constructivist theory by demonstrating that AR enables active knowledge construction through interactive visualisation and manipulation of virtual objects. Second, extension of Van Hiele's theory shows that AR can accelerate progression through geometric thinking levels. Third, integration of ethnomathematics with AR supports culturally relevant learning, connecting abstract concepts to students' cultural contexts. Fourth, the systematic application of the ADDIE model validates structured approaches to educational technology development. Practically, the findings suggest that AR implementation should move beyond technology adoption to integrated pedagogical strategies. Schools require infrastructure improvement, teacher professional development, and curriculum alignment. Policymakers should consider developing systematic implementation frameworks and investing in AR infrastructure. Future research should employ longitudinal designs to examine sustained learning gains, investigate differential effectiveness based on student characteristics, and explore scalable implementation models. Research is also needed on cost-effectiveness and sustainability of AR implementation in diverse educational contexts. The study acknowledges limitations, including dependence on available literature quality, potential publication bias, limited international comparison, and heterogeneity of study designs. Despite these limitations, this review provides a comprehensive synthesis of evidence on AR effectiveness in Indonesian primary education, offering theoretical contributions and practical guidance for researchers, practitioners, and policymakers. The review confirms that AR technology, when pedagogically well-designed, can significantly enhance geometry learning outcomes and student engagement, contributing to improved mathematics education quality in Indonesia. This is particularly important given Indonesia's PISA mathematics performance and the need for innovative approaches to address persistent educational challenges.

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