

Augmented Reality and Learning Motivation: Effects on Elementary Students' Mathematics Learning Outcomes in Three-Dimensional Geometry

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Article Info

Article history:

Submission Jul 24, 2026
First Revised Aug 23, 2026
Accepted Sep 20, 2026
Published Oct 20, 2026

Keywords:

Augmented Reality
Learning Motivation
Mathematics Learning Outcomes
Three-Dimensional Geometry

ABSTRACT

This study examined the effects of Augmented Reality (AR) and learning motivation on elementary students' mathematics learning outcomes in three-dimensional geometry. A quasi-experimental method with a 2×2 factorial design was employed involving 41 fifth-grade students of SDN Klender 12 Pagi, East Jakarta, who were assigned to an experimental group learning with AR and a control group receiving conventional image-based instruction. Data were collected through a validated and reliable mathematics achievement test and learning motivation questionnaire and were analyzed using a two-way analysis of variance at a significance level of 0.05. The results showed that AR significantly improved students' mathematics learning outcomes ($p = 0.010$), with a mean score of 84.35 compared with 75.10 in the control group. Learning motivation also had a significant effect ($p < 0.001$), and a significant interaction between AR and learning motivation was found ($p = 0.037$), with the highest mean score (89.20) obtained by highly motivated students who learned with AR. These findings indicate that AR is an effective medium for improving elementary students' understanding and achievement in three-dimensional geometry, particularly when it is combined with strategies that sustain students' learning motivation.

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How to cite:

Lilis, Amaliyah, N., & Purwanto, S. E. (2026). Augmented Reality and Learning Motivation: Effects on Elementary Students' Mathematics Learning Outcomes in Three-Dimensional Geometry. *Pedagonal: Jurnal Ilmiah Pendidikan*, 10(2), 65–74. <https://doi.org/10.55215/pedagonal.v10i2.69>

Introduction

Twenty-first-century education requires the integration of digital technologies to improve the quality of teaching and learning as well as student learning outcomes, and the impact of emerging technologies such as Augmented Reality (AR) has been examined extensively in meta-analytic studies (Chang et al., 2022; Zhang et al., 2022). In Indonesia, the Merdeka Curriculum encourages more engaging and student-centered learning experiences, such as project-based learning (Nugroho et al., 2025). However, the results of the Programme for International Student Assessment (PISA) 2022 indicated that Indonesian students' mathematics performance remained below the OECD average (OECD, 2023). This condition highlights the need for innovative instructional approaches that help students develop a deeper and more meaningful understanding of mathematical concepts.

One of the mathematical topics that remains challenging for elementary school students is three-dimensional geometry. This topic requires strong spatial visualization skills, while classroom instruction is often limited to verbal explanations and two-dimensional representations, which may lead students to memorize formulas without fully understanding the underlying concepts (Izzati et al., 2026; Tefa et al., 2025). Technology-enhanced environments have therefore been explored to support primary students' geometry learning (Ng et al., 2020). In addition to the instructional medium, learning motivation is an internal factor that shapes students' persistence, engagement, and achievement (Kurniasih et al., 2025; Nugroho et al., 2025; Ryan & Deci, 2020).

AR has emerged as a promising technological solution to address these challenges. AR enables students to view and interact with three-dimensional virtual objects through digital devices, making abstract concepts more concrete, engaging, and accessible (Rohendi et al., 2025; Tefa et al., 2025). Previous studies have reported that AR can improve primary school students' spatial visualization, spatial reasoning, and geometric understanding (Izzati et al., 2026; Nadzeri et al., 2024; Supli & Yan, 2024; Tarnng et al., 2024; Wang et al., 2025). AR has also been integrated into mathematics teaching and its effectiveness examined (Koparan et al., 2023), including AR-assisted media for three-dimensional shapes (Pramuditya et al., 2022) and for geometry thinking ability (Pujiastuti & Haryadi, 2024). Other studies and reviews have linked AR with higher learning motivation (Amores-Valencia et al., 2022; Panji et al., 2025; Ruijia et al., 2025).

Despite these promising findings, most previous studies have focused on the direct effects of AR on learning outcomes, conceptual understanding, or spatial ability. Although moderators of AR effectiveness have been examined in meta-analytic research (Xu et al., 2022), limited attention has been given to learning motivation as a factor that may influence the effectiveness of AR-based instruction, particularly in elementary mathematics learning (Amores-Valencia et al., 2022). For example, a recent factorial study in fourth-grade science (IPAS) found significant main effects of AR media and learning motivation but no interaction between them (Misliza et al., 2025), which suggests that the evidence on this interaction is still inconclusive. Empirical studies examining the interaction between AR media and learning motivation in three-dimensional geometry learning therefore remain scarce.

Therefore, this study offers a novel contribution by simultaneously investigating the effects of AR media and learning motivation on students' mathematics learning outcomes, as well as examining the interaction between these variables. Specifically, the study aims to: (1) determine the effect of AR media on fifth-grade students' mathematics

learning outcomes in three-dimensional geometry; (2) examine the effect of learning motivation on mathematics learning outcomes; and (3) analyze the interaction between AR media and learning motivation on students' mathematics learning outcomes at SDN Klender 12 Pagi, East Jakarta. The findings are expected to contribute to the theoretical development of technology-enhanced learning and to provide practical implications for teachers in designing more interactive, innovative, and effective mathematics instruction.

Method

This study employed a quasi-experimental method with a 2×2 factorial design (Sugiyono, 2023) to examine the effects of AR media and learning motivation on students' mathematics learning outcomes in three-dimensional geometry. The factorial design involved two independent variables, namely learning media (AR media versus conventional image-based media) and learning motivation (high versus low), and one dependent variable, namely mathematics learning outcomes. This design allowed the main effect of each variable and their interaction to be tested simultaneously, as in recent factorial studies of AR in elementary education (Misliza et al., 2025). The design was quasi-experimental because the groups were intact classes.

The research was conducted at SDN Klender 12 Pagi, East Jakarta, during the second semester of the 2024/2025 academic year. The population consisted of all fifth-grade students of the school, totaling 41 students. The sample was selected using the cluster random sampling technique, with Class VA (21 students) assigned as the experimental group and Class VB (20 students) as the control group. The experimental group received instruction using AR media, whereas the control group received instruction using conventional image-based media. Based on their scores on the learning motivation questionnaire, students in both classes were categorized as having high or low learning motivation, resulting in four groups: A1B1 (AR, high motivation), A1B2 (AR, low motivation), A2B1 (conventional media, high motivation), and A2B2 (conventional media, low motivation).

Data were collected through a mathematics achievement test and a learning motivation questionnaire. The achievement test consisted of multiple-choice questions on three-dimensional geometry and had met validity and reliability requirements. The learning motivation questionnaire was adapted from the Mathematics Motivation Questionnaire (MMQ; Fiorella et al., 2021) and consisted of nine items measured on a five-point Likert scale. The indicators of the questionnaire represented intrinsic, identified, and controlled motivation, which are conceptually grounded in self-determination theory (Ryan & Deci, 2020). Classroom observations were also conducted during the learning process to support the research findings.

Prior to hypothesis testing, the data were subjected to prerequisite analyses, namely the Shapiro–Wilk normality test and Levene's test of homogeneity of variance at a significance level of 0.05. Subsequently, the data were analyzed using a two-way analysis of variance (two-way ANOVA) to determine the effects of AR media, learning motivation, and their interaction on students' mathematics learning outcomes (Misliza et al., 2025; Sugiyono, 2023).

Results and Discussion

The findings indicated that students who learned using AR media achieved higher mathematics learning outcomes than those who learned through conventional media.

Students with high learning motivation also demonstrated better achievement than students with low motivation, as shown in Table 1. This pattern is in line with recent syntheses reporting positive effects of AR on mathematics and geometry learning (Izzati et al., 2026; Tefa et al., 2025).

Table 1. Mean Scores of Mathematics Learning Outcomes Based on Learning Media and Learning Motivation

Learning Media	High Motivation	Low Motivation	Mean
Augmented Reality (A1)	89.20	79.50	84.35
Conventional Media (A2)	80.10	70.10	75.10

Table 1 and Figure 1 show that the group of students who learned using AR and had high motivation (A1B1) achieved the highest average score (89.20), whereas the group that learned with conventional media and had low motivation (A2B2) obtained the lowest average score (70.10). In both motivation levels, students taught with AR outperformed those taught with conventional media. These findings suggest that interactive learning media and students' motivation both play a role in mathematics learning outcomes.

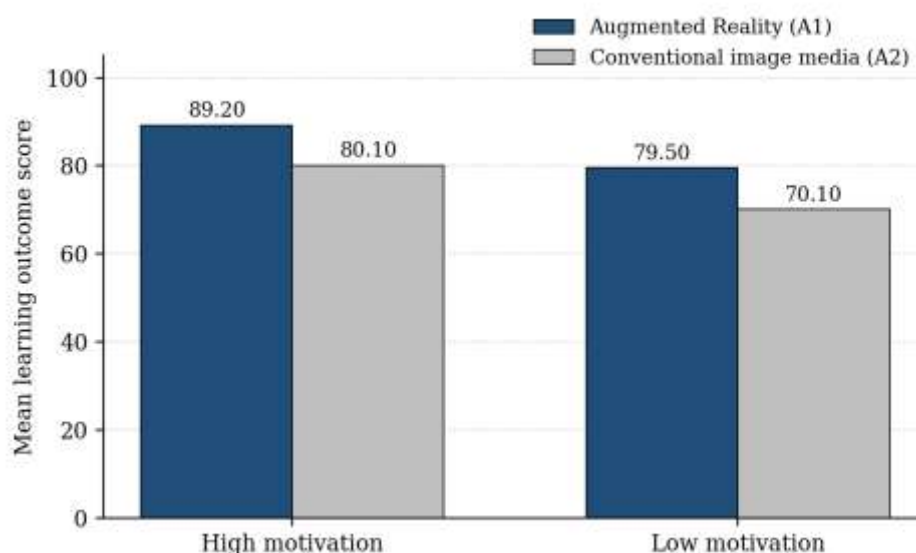


Figure 1. Mean Mathematics Learning Outcome Scores by Learning Media and Learning Motivation Level

Based on the research data from the two classes, there are differences in the average scores for each motivation indicator. A detailed comparison of the average scores for the motivation indicators across the four groups is shown in Figure 2.

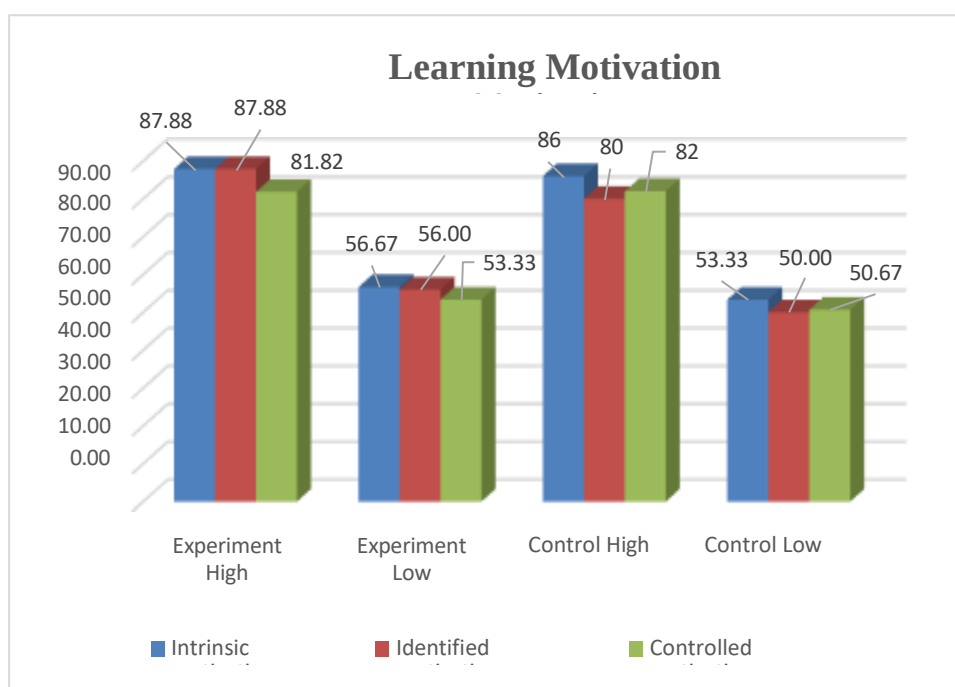


Figure 2. Data on High and Low Motivation for Each Indicator in Augmented Reality and Image Media

The findings revealed that the experimental group using AR with high learning motivation (A1B1) achieved the highest scores across most indicators of mathematics learning motivation. For both intrinsic motivation and identified motivation, the A1B1 group outperformed the other groups (87.88 for both indicators), followed by A2B1 (86.00 and 80.00), A1B2 (56.67 and 56.00), and A2B2 (53.33 and 50.00). These results indicate that AR media enhanced students' interest, engagement, and awareness of the importance of learning mathematics (Amores-Valencia et al., 2022; Ruijia et al., 2025). The interactive three-dimensional visualization provided by AR created a more concrete and meaningful learning experience, encouraging students to participate actively in the learning process (Panji et al., 2025; Rohendi et al., 2025).

In contrast, for the controlled motivation indicator, the control group with high motivation (A2B1) obtained the highest score (82.00), although the A1B1 group also demonstrated relatively high achievement (81.82). This finding suggests that highly motivated students tend to maintain strong external learning drives, such as academic demands, teacher expectations, and rewards provided during instruction. Nevertheless, AR media appeared to be more effective in fostering intrinsic and identified motivation, which are closely related to students' internal awareness and personal learning goals (Ryan & Deci, 2020).

Overall, the results suggest that the use of AR contributes positively to students' mathematics learning motivation, particularly among students with high learning motivation. These findings are consistent with previous studies indicating that AR-based learning creates an interactive, engaging, and meaningful learning environment that enhances student participation and supports better learning outcomes (Amores-Valencia et al., 2022; Misliza et al., 2025; Tefa et al., 2025). Therefore, AR can be considered an effective instructional alternative for improving both learning motivation and mathematics achievement, particularly in teaching three-dimensional geometry at the elementary school level.

Before hypothesis testing, the homogeneity of variance of the mathematics learning outcome data was examined, with the results presented in Table 2.

Table 2. Results of the Homogeneity Test for Mathematics Learning Outcomes

Levene's Test (Learning Outcomes)	Levene Statistic	df1	df2	Sig.
Based on Mean	4.083	1	39	0.051
Based on Median	2.689	1	39	0.109
Based on Median and with adjusted df	2.689	1	36.711	0.110
Based on trimmed mean	4.055	1	39	0.051

The homogeneity test for the mathematics learning outcomes variable yielded a significance value of 0.051, which is slightly greater than 0.05 (sig. 0.051 > 0.05), indicating that the data variance in this study is homogeneous. Hypothesis testing in this study used the two-way ANOVA method, with the results presented in Table 3.

Table 3. Results of the Two-Way ANOVA Hypothesis Test (Dependent Variable: Learning Outcomes)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	10415.815	3	3471.938	42.034	0.000
Intercept	178722.119	1	178722.119	2163.751	0.000
Learning Media	222.119	1	222.119	21.689	0.010
Learning Motivation	9618.399	1	9618.399	116.448	0.000
Learning Media × Learning Motivation	388.166	1	388.166	4.699	0.037
Error	3056.136	37	82.598		
Total	195250.000	41			
Corrected Total	13471.951	40			

The findings of this study demonstrated that the use of AR media significantly improved students' mathematics learning outcomes in three-dimensional geometry ($p = 0.010$; Table 3). Students who learned through AR achieved better academic performance than those who received conventional instruction. The interactive visualization provided by AR enabled students to observe and manipulate three-dimensional objects directly, making abstract geometric concepts more concrete and easier to understand. This finding supports constructivist learning theory and Mayer's cognitive theory of multimedia learning, which emphasize that meaningful learning occurs when learners actively engage with visual and interactive representations of knowledge (Çeken & Taşkın, 2022; Mayer, 2021). It is also in line with earlier studies reporting that AR improves mathematics-related outcomes such as computational thinking, conceptual understanding, and spatial abilities (Angraini et al., 2024; Izzati et al., 2026; Tefa et al., 2025).

Learning motivation was also found to have a significant influence on mathematics learning outcomes ($p < 0.001$). Students with high learning motivation consistently achieved higher scores than those with low motivation. Highly motivated students tend to demonstrate greater persistence, engagement, and willingness to overcome learning

difficulties, which can lead to improved academic achievement. This result is consistent with Social Cognitive Theory, which highlights the role of motivation and self-efficacy in shaping learning behaviors (Schunk & DiBenedetto, 2020), and with self-determination theory, which distinguishes the types of motivation that sustain engagement (Ryan & Deci, 2020). A significant main effect of motivation has also been reported in elementary AR research (Misliza et al., 2025), and motivation has been associated with learning outcomes and engagement in other studies (Kurniasih et al., 2025; Nugroho et al., 2025).

Furthermore, the study revealed a significant interaction between AR media and learning motivation ($p = 0.037$). This indicates that the effect of learning media on mathematics learning outcomes was not entirely independent of students' motivation level; students who were both highly motivated and exposed to AR-based learning obtained the highest outcomes among all groups (Table 1). Motivated students may explore the interactive features of AR more actively and therefore benefit more from them, which is in line with evidence that the effectiveness of AR depends on moderating factors (Amores-Valencia et al., 2022; Xu et al., 2022). This finding differs from that of Misliza et al. (2025), who reported no interaction between AR media and motivation in fourth-grade science learning. Differences in subject matter, grade level, motivation measurement, and sample characteristics may explain this discrepancy; three-dimensional geometry in particular depends heavily on spatial visualization, which AR directly supports (Izzati et al., 2026).

These findings suggest that integrating interactive technology with strategies that foster student motivation can create a more engaging and effective learning environment. Teachers may therefore combine AR with activities that build students' interest and awareness of the value of learning mathematics, while schools need to consider infrastructure and teacher readiness, which remain barriers to the adoption of AR (Izzati et al., 2026; Tefa et al., 2025). The results should nevertheless be interpreted with caution because the study involved a small sample ($N = 41$) from a single school and used intact classes.

Conclusion

This study demonstrated that Augmented Reality (AR) media significantly improved fifth-grade students' mathematics learning outcomes in three-dimensional geometry, that learning motivation had a significant positive effect on students' achievement, with highly motivated students obtaining better learning outcomes than those with lower motivation, and that a significant interaction existed between AR media and learning motivation, with the combination of AR and high motivation yielding the highest mean score. These findings highlight the novelty of the study by showing that AR and learning motivation should be considered together when designing technology-enhanced mathematics instruction in elementary education. In practice, AR can serve as an innovative and effective learning medium that supports conceptual understanding and student engagement, provided that teachers also foster students' motivation. Future research is recommended to apply AR to other mathematical topics, involve larger and more diverse samples, and integrate AR with other technology-enhanced learning approaches to further optimize students' learning outcomes.

Acknowledgment

The authors would like to express their sincere gratitude to the principal, teachers, and students of SDN Klender 12 Pagi, East Jakarta, for their support, cooperation, and

participation throughout the research process. Special appreciation is extended to the school administration for granting permission and facilitating the implementation of this study. The authors also thank all individuals who contributed to the preparation of the research instruments, data collection, and data analysis, as well as the academic supervisors and colleagues whose insights helped improve the quality of this article.

Author Contributions

Conceptualization: NA, LL; Methodology: NA, LL, SEP; Formal analysis: LL, SEP; Investigation: NA, LL, SEP; Writing – original draft: NA, LL, SEP; Writing – review & editing: NA, LL, SEP; Supervision: NA, LL.

Funding

This research received no external funding.

Declaration of Competing Interest

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

Use of Artificial Intelligence

The authors used QuillBot to assist with language refinement, grammar correction, and improvements in sentence clarity and readability. All AI-assisted suggestions were carefully reviewed and verified by the authors, who take full responsibility for the accuracy, originality, and final content of the manuscript.

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