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The Effect of Augmented Reality-Based Learning Media on Higher Order Thinking Skills (HOTS) of Junior High School Students

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ABSTRACT

The low level of Higher Order Thinking Skills (HOTS) among junior high school students in Indonesia, particularly in three-dimensional geometry, requires innovative instructional solutions. This study aims to investigate the effect of Augmented Reality (AR)-based learning media on the HOTS improvement of eighth-grade students in the topic of solid geometry at SMP Negeri 27 Surakarta. A quasi-experimental approach with a pretest-posttest control group design was employed. The sample consisted of 63 students (experimental group: n=31, control group: n=32) selected through purposive sampling. Data collection instruments were HOTS tests based on the revised Bloom's taxonomy (C4–C6), validated by experts. Data were analyzed using the Shapiro-Wilk normality test, Levene's homogeneity test, independent sample t-test, and N-Gain analysis. Results showed that the mean posttest score of the experimental group (75.11) was significantly higher than the control group (51.49). The independent sample t-test yielded a significance value of <0.001 (t = −11.348), leading to rejection of H_0. N-Gain analysis indicated an improvement of 60.31% (fairly effective category) in the experimental group versus 23.33% (ineffective category) in the control group. It is concluded that AR-based learning media significantly improves students' HOTS in solid geometry.

Keywords: *Augmented Reality, Higher Order Thinking Skills, Junior High School Mathematics, Learning Media, Solid Geometry*

INTRODUCTION

Twenty-first-century education demands higher-order thinking skills as the primary competency that students must possess. Higher Order Thinking Skills (HOTS), encompassing the abilities to analyze (C4), evaluate (C5), and create (C6) based on the revised Bloom's taxonomy by Anderson & Krathwohl (2001), are required by the Indonesian national curriculum, in line with Law Number 20 of 2003 on the National Education System, which emphasizes developing students' creative and independent potential. However, the demands of the 21st century are not limited to critical-mathematical thinking skills, but also include readiness to adapt to the massive development of digital multimedia in various educational institutions worldwide (Setyaningsih, 2023).

Today's digital multimedia has transformed from mere text and sound to a combination of graphics, animation, and interactive video that has a tremendous impact on the way students construct knowledge (Setyaningsih, 2023). Global dynamics and the demands of the industry 4.0 era of work also emphasize the importance of human resources who are digitally competent, creative, innovative, and able to solve technical problems (Vitariyanti et al., 2024). Teachers are required to be more creative and avoid monotonous learning in order to overcome learning boredom and align the teaching process with students' diverse learning styles (Arifin et al., 2025). Therefore, the integration of technology-based pedagogical innovation is an absolute urgency to prepare graduates with relevant competencies to face future competition (Raziana & Wibawanto, 2025).

In reality, however, the HOTS achievement of Indonesian students remains critically low. PISA 2018 data placed Indonesia's mathematics score at 379, far below the OECD average of 487, with 71% of students failing to reach the minimum problem-solving competency (Yuniar et al., 2025). TIMSS 2011–2015 results further confirmed that Indonesian students are only capable of recognizing basic facts without the ability to relate or apply complex concepts. A study by Septiansyah et al. (2025) involving 98 students from high-achieving schools found that the percentage of students able to analyze was only at a moderate criterion, while their abilities to evaluate and create were very low. This performance gap stems from traditional or conventional learning approaches that lack variety and tend to be boring, making students less active during the learning process (Fitriani & Ridhani, 2025).

Similar problems were found in early childhood and informal education, where traditional approaches are deemed ineffective in accommodating children's holistic developmental needs (Nongko et al., 2025), and there is still a lack of appropriate control and guidance in the practice of using educational technology from an early age (Pinilih, 2023). In fact, higher-order reasoning-based assessments such as Computational Thinking (CT) and metacognition are still in their early stages of development (infancy), and metacognitive strategies are rarely taught explicitly (Buwono et al., 2025). On the other hand, science and biology learning at the secondary school level also faces similar challenges related to low higher-order thinking skills due to poorly structured digital learning management strategies (Sasongko et al., 2025).

Similar problems were also found at SMP Negeri 27 Surakarta. End-of-semester summative assessment (PSAS) data for the second semester of 2024/2025 showed average scores across all Grade VIII classes ranging from 68–69, slightly below the passing grade (KKM) of 70. A total of 32.26% of students had not met the KKM and experienced difficulties with visualization tasks such as calculating volume, surface area, and identifying components of geometric solids. Observations and interviews with mathematics teachers indicated that instruction was still dominated by the lecture method with conventional media that insufficiently facilitated the development of HOTS.

The topic of solid geometry has an abstract nature that requires spatial visualization skills. Conventional instruction without adequate visual representation makes it difficult for students to build connections between symbolic concepts and more concrete realities (Ridhani et al., 2025). The use of learning variations that integrate the latest media has proven to be the main key to building an inclusive, adaptive, and active classroom atmosphere (Arifin et al., 2025). Innovation efforts can be carried out through the implementation of problem-solving-oriented learning models. For example, the implementation of Problem-Based Learning (PBL) with a differentiated approach and the Zone of Proximal Development (ZPD) theory has been proven effective in increasing student activeness through active participation in discussions and independent task completion (Pawitra et al., 2025). Furthermore, the adoption of cloud computing technologies such as Google Forms, Quizizz, and Wordwall in assessments has also been proven to significantly increase the efficiency, effectiveness, and quality of student learning outcomes (Purnama et al., 2024). At the elementary education level, the development of multimodal digital interactive media based on Flipbook using Dick & Carey's instructional design has also been proven "very valid" and able to massively boost elementary school students' problem-solving creativity (Yasni et al., 2025). This optimization effort is also in line with the crucial role of teachers in facilitating emotional intelligence (EQ) and character education such as honesty, responsibility, and cooperation in order to create a safe and supportive classroom environment for students' holistic development (Septyventia et al., 2024).

Accordingly, innovative learning media are needed to provide rich, interactive, and visual learning experiences. The post-pandemic shift in learning systems from face-to-face to screen-to-screen requires the use of educational technology to facilitate and improve learning outcomes (Peramtasari, 2023). One future trend promising a natural, immersive experience is the concept of the Metaverse, a 3D digital space that combines the real and virtual worlds (Alhakimi, 2023). Although the Metaverse offers new opportunities for education, its study from a pedagogical perspective is still rarely discussed (Alhakimi, 2023). As a pragmatic step before adopting a full-fledged virtual ecosystem like the Metaverse, Augmented Reality (AR) technology presents a highly relevant intermediary solution.

Augmented Reality (AR) is a technology that merges virtual objects into the real environment in real-time, enabling students to see and interact with three-dimensional objects directly through a smartphone (Rejekiningsih et al., 2023). Unlike Virtual Reality (VR), which fully replaces the real world, AR retains the real world as a backdrop and adds digital elements onto it. In the context of geometry learning, AR allows students to explore geometric solids in a manipulative and interactive way, thereby facilitating the knowledge-construction process consistent with Piaget's formal operational stage of cognitive theory and Mayer's multimedia learning principles.

Prior research has demonstrated positive impacts of AR on learning outcomes. Pujiastuti and Haryadi (2023) found that AR-based hybrid learning combined with innovative instructional models significantly improved students' higher-order thinking skills. A meta-analysis by Lu et al. (2025) confirmed the positive effect of AR on HOTS with a large effect size. A systematic review by Li et al. (2025) also showed that AR-based learning had a significant impact on learning outcomes and student engagement.

Based on the identified problems and literature review, this study aims to examine the effect of AR-based learning media on HOTS improvement among Grade VIII students at SMP Negeri 27 Surakarta in the topic of flat-sided solid geometry. The novelty of this study lies in the direct application of an AR application in classroom learning activities as part of the regular mathematics curriculum, as well as a comprehensive analysis of HOTS learning outcomes covering all three high-order cognitive aspects.

METHODS

Research Design

This study employed a quantitative approach with a quasi-experimental method using a pretest-posttest control group design. The experimental group received instruction using AR-based media, while the control group received conventional instruction. A pretest was administered before the treatment and a posttest after the treatment to measure HOTS improvement in both groups.

Table 1. Quasi-Experimental Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X_1 (AR Media)	O_2
Control	O_3	X_2 (Conventional)	O_4
Group	**Pretest**	**Treatment**	**Posttest**

Note: O = HOTS Test; X = Instructional Treatment

Population and Sample

The study was conducted at SMP Negeri 27 Surakarta during the 2025/2026 academic year. The research population consisted of all Grade VIII students across 6 classes. The sample was selected using purposive sampling based on the equivalence of prior academic ability, resulting in two classes: the experimental class (31 students) and the control class (32 students). The equivalence of initial ability between the two classes was confirmed through the previous semester's PSAS data and the pretest results, which showed no significant difference (a mean difference of only 0.07%).

Instruments and Data Collection Techniques

The primary research instrument was a reasoned multiple-choice HOTS test consisting of 21 items, measuring the ability to analyze (C4), evaluate (C5), and create (C6) on the topic of flat-sided solid geometry (cubes and rectangular prisms). The instrument was validated by two experts (a lecturer and a mathematics teacher) and piloted on a class outside the sample. Validity testing results showed that all items were valid, with adequate instrument reliability. Supporting data were collected through observations and interviews to describe the learning conditions.

Research Procedures

The study was carried out over approximately 4 weeks following these procedures: (a) instrument preparation and coordination with the school; (b) pretest administration in both classes; (c) treatment delivery over 5 sessions (@35 minutes each), the experimental class used an Android-based AR application to explore cubes and rectangular prisms visually and interactively, while the control class followed instruction using the lecture method and conventional media; (d) posttest administration; and (e) data analysis.

RESULTS AND DISCUSSION

Results

1. Pre-test and Post-test Descriptive Data

Prior to the treatment, both groups were at equivalent initial ability levels. The experimental class had a pretest mean of 35.79, while the control class had 35.86, with a difference of only 0.07%. After the treatment, the experimental class showed a drastic increase, reaching a post-test mean of 75.11, whereas the control class only reached 51.49.

Table 2. Descriptive Statistics of Pre-test and Post-test Data

Statistic	Pre-test Control	Pre-test Experimental	Post-test Control	Post-test Experimental
N	32	31	32	31
Highest Score	47.62	47.62	66.67	90.48
Lowest Score	23.81	23.81	38.10	57.14
Mean	35.86	35.79	51.49	75.11
Median	35.72	38.10	52.38	76.19
Std. Deviation	6.62	6.01	7.50	8.84

Source: Research data analysis (2026)

Table 2 shows a highly significant increase in the experimental class. The mean score rose from 35.79 (pre-test) to 75.11 (post-test), an increase of 39.32 points. In the control class, the increase was only 15.63 points (from 35.86 to 51.49). The post-test mean difference of 23.62 points between the two groups indicates the positive impact of AR media on students' HOTS.

2. Pre-requisite Analysis Tests

Before hypothesis testing, normality and homogeneity tests were conducted as prerequisites for parametric analysis.

Table 3. Shapiro-Wilk Normality Test Results

Data	Significance Value (Sig.)	Conclusion
Control Pretest	0.065	Normal
Control Posttest	0.101	Normal
Experimental Pretest	0.062	Normal
Experimental Posttest	0.086	Normal

Source: SPSS analysis results (2026)

The Shapiro-Wilk test results in Table 3 show that all significance values are >0.05, indicating that the pre-test and post-test data in both groups are normally distributed. Subsequently, the Levene's homogeneity test yielded a significance value of 0.395 (>0.05), meaning the variance of data between the experimental and control classes was homogeneous. With both assumptions satisfied, the parametric analysis using the independent sample t-test could proceed.

3. Hypothesis Testing

Table 4. Independent Sample t-test Results

Group	N	Mean	Std. Deviation	t-value	Sig. (2-tailed)	Decision
Experimental	31	74.97	8.886	−11.348	<0.001	H_0 Rejected
Control	32	51.53	7.466	−11.348	<0.001	H_0 Rejected

Source: SPSS analysis results (2026)

Based on the independent sample t-test results in Table 4, a t-value of −11.348 was obtained with a significance of <0.001. Because the significance value is <0.05, H_0 is rejected and H_1 is accepted. It can be concluded that there is a statistically significant difference between the HOTS learning outcomes of the experimental and control classes. The mean difference of 23.44 points demonstrates the clear superiority of the group that used AR media.

4. N-Gain Analysis

Table 5. N-Gain Analysis Results

Group	N	Mean N-Gain (%)	Min	Max	Category
Experimental	31	60.31	25	86	Fairly Effective
Control	32	23.33	−19	54	Ineffective

Source: SPSS analysis results (2026)

Table 5 shows that the experimental class had a mean N-Gain of 60.31%, falling in the fairly effective category, while the control class only reached 23.33%, classified as ineffective. The minimum N-Gain value in the control class was even negative (−19), indicating that some students experienced a decline in learning outcomes. In contrast, all students in the experimental class showed improvement (minimum N-Gain of 25%). The mean N-Gain difference of 36.98% further reinforces the finding that AR media is more effective in improving HOTS than conventional instruction.

Discussion

The findings of this study consistently demonstrate that AR-based learning media exerts a positive and significant influence on students' HOTS improvement in the topic of solid geometry. These findings can be explained from several theoretical perspectives.

From the perspective of Piaget's cognitive theory, Grade VIII junior high school students are at the formal operational stage, which requires concrete representations to understand abstract three-dimensional geometry concepts. AR media can present geometric solid objects in three-dimensional form that can be virtually manipulated, thereby providing a more concrete and meaningful learning experience. This aligns with the characteristics of current digital multimedia developments, which integrate text, graphics, animation, and audio/video to enable users to navigate, interact, create, and communicate actively (Setyaningsih, 2023). Furthermore, in informal education and within the family environment, the introduction and control of digital technology from an early age have formed the foundation of digital habits, character, and adaptive behavior for the current generation of students (Pinilih, 2023). Through the presentation of manipulative objects in AR, students are helped to transcend the limitations of abstract visualization, similar to the success of the BERAKSI (Playing, Creating, Discussing, and Cheerful) learning model, which optimizes engagement and a fun learning atmosphere for better cognitive and social outcomes (Nongko et al., 2025). This condition encourages students to actively construct their knowledge through exploration, which is the core of Piaget's cognitive constructivism.

From the perspective of Mayer's Cognitive Theory of Multimedia Learning, the AR media developed in this study implements the principles of coherence, signaling, spatial contiguity, multimedia, and segmentation. The visualization of three-dimensional objects combined with labels and content explanations helps students connect visual information with verbal concepts simultaneously through two information-processing channels (visual and verbal), thereby optimizing cognitive processing and minimizing irrelevant cognitive load. The advantages of this interactive multimedia conditioning resemble the effectiveness of utilizing cloud computing technologies (such as Google Forms, Quizizz, and Wordwall), which can significantly improve the efficiency and quality of learning outcomes through instant feedback (Purnama et al., 2024). This strong integration of visual representations also addresses the needs of today's digital-era job market, where the ability to utilize digital services, understand applications, and solve technical problems are key assets for graduates' career development (Vitariyanti et al., 2024).

From a practical instructional perspective, the use of AR media transforms the learning paradigm from teacher-centered to student-centered. The theoretical and practical implications of these findings strengthen the synthesis of technology-based pedagogical innovations, such as the integration of AI and play-based strategies in creating inclusive and meaningful post-pandemic classrooms (Arifin et al., 2025). The success of AR in training higher-order cognitive skills is equivalent to the effectiveness of Game-Based Learning (GBL) pedagogical innovations—such as serious games and VR simulations—and the use of concrete media (such as globes and flashlights) in the Numbered Heads Together method, which has been proven to massively increase student motivation, conceptual understanding, logical skills, and academic performance (Fitriani & Ridhani, 2025; Raziana & Wibawanto, 2025). This structured AR-based teaching design provides important theoretical contributions, similar to the integration of digital platforms (such as Nearpod) developed with the Dick and Carey instructional design model to support higher-order cognitive processes through coherent digital learning management (Sasongko et al., 2025). Furthermore, adaptive visualization in AR also reflects the successful combination of the PBL model, differentiated instruction, and the ZPD in creating a motivating interactive learning environment based on students' initial abilities (Pawitra et al., 2025). This interactive interaction not only stimulates cognitive aspects but is also supported by the crucial role of teachers as facilitators and role models in integrating character values and strengthening students' emotional intelligence in the classroom (Septyventia et al., 2024).

Methodologically, the empirical findings in this study (N-Gain 60.31%) provide concrete answers to the challenges of current metacognitive and computational thinking assessments, which still lack validation through rigorous experimental methods and long-term interventions

(Buwono et al., 2025). The enhancement of spatial thinking skills through AR demonstrates that the design of digital interactive media systematically developed based on multimedia theory is valid and highly effective in supporting creative-critical thinking processes, making it highly relevant for adoption in 21st-century learning (Yasni et al., 2025). This also emphasizes the practical role of post-pandemic educational technology in optimally transforming the teaching landscape from face-to-face to screen-to-screen to improve student learning outcomes (Peramtasari, 2023). On a macro scale, the effectiveness of real-time visualization in AR validates the potential of future immersive technologies such as the Metaverse, which is predicted to provide a 3D digital space that blends with the real world to disrupt the way humans teach and learn in schools across the world (Alhakimi, 2023). Students are encouraged to actively explore geometric solids, analyze their components, evaluate the relationships between concepts, and even create visual hypotheses—processes that directly train all three HOTS aspects (C4, C5, C6). The high enthusiasm of students toward AR technology, combined with their background as digital natives accustomed to visual-interactive activities, also contributed to the effectiveness of the instruction.

These research findings are consistent with the results of Pujiastuti and Haryadi (2023), who demonstrated that AR-based hybrid learning significantly improved the HOTS of junior high school students. The meta-analysis by Lu et al. (2025) across various AR studies also confirmed the large positive effect of AR use on higher-order thinking skills. The systematic review by Li et al. (2025) further showed that AR in secondary education had a positive impact on higher-order cognitive learning outcomes.

Constraints identified in this study include students' limited smartphone devices, differences in device specifications, and internet network stability. This is an important note for larger-scale implementation, particularly in schools with limited technological infrastructure. Providing backup devices and organizing group learning arrangements can serve as practical solutions to overcome these barriers.

CONCLUSION

Based on the analysis and discussion, it can be concluded that the use of Augmented Reality (AR)-based learning media has a significant positive impact on improving students' Higher Order Thinking Skills (HOTS) in the geometry of flat surfaces. The interactive and manipulative three-dimensional visualizations in this technology have been proven to bridge abstract mathematical concepts into concrete representations, thus facilitating students' independent knowledge construction. Consequently, learning with AR media is far more effective in boosting students' higher-order thinking skills—especially in the areas of analysis, evaluation, and creation—compared to conventional approaches. This finding also addresses the initial problem in schools where mathematics learning activities are still dominated by lecture methods and the use of static media, which have not been able to optimally stimulate the development of students' critical reasoning skills. Theoretically and practically, the results of this study emphasize the importance of integrating immersive technology into digital learning management to create a 21st-century classroom ecosystem that is inclusive, adaptive, active, and problem-solving-oriented.

As a practical recommendation, mathematics teachers are advised to begin adopting and integrating AR-based media into their classroom learning plans, particularly for abstract topics that require advanced spatial visualization skills. To ensure optimal implementation of this technology, schools are expected to provide concrete support by providing adequate digital infrastructure, improving internet network stability, and facilitating teacher training to enrich their pedagogical offerings. Meanwhile, future researchers are advised to develop more comprehensive AR applications by integrating them with other innovative learning models—such as differentiated learning or game-based learning—and expanding the scope of trials across different mathematics topics and educational levels to strengthen the validity and generalizability of this educational technology's effectiveness.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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