

The impact of GeoGebra AR on students' geometric thinking based on Van Hiele theory

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Abstract

Traditional instructional approaches to teaching three-dimensional (3D) geometric shapes are often ineffective in promoting student engagement and deep conceptual understanding of geometric principles. This study investigates the integration of GeoGebra Augmented Reality (AR) as an innovative pedagogical tool for the enhancement of 3D geometry instruction and assesses its effectiveness in developing students' geometric thinking, based on Van Hiele's theoretical framework. A series of interactive learning lessons facilitated students' interactive with 3D models and dynamic simulations, aimed at fostering more robust conceptual understanding. The research employed a one-group pretest-posttest design involving 60 secondary school students who participated in geometry learning using GeoGebra AR. Data were collected through a geometric thinking test and categorized according to Van Hiele's level taxonomy. Statistical analysis using the Wilcoxon signed-rank test revealed a significant improvement in students' geometric thinking levels following the intervention ($p < 0.05$), leading to the rejection of the null hypothesis. These findings provide empirical support for the effectiveness of GeoGebra AR in advancing students' Van Hiele levels and enhancing their comprehension of geometric concepts. These results highlight the potential of GeoGebra AR as a pedagogically valuable tool for supporting students' cognitive development in geometry and increasing their engagement in mathematics learning. Further investigations are recommended to examine the long-term impacts of GeoGebra AR across diverse educational contexts and demographic settings.

Keywords: augmented reality, GeoGebra AR, geometric thinking, mathematics education, Van Hiele theory

Introduction

Geometry is often perceived as one of the most abstract and challenging areas in mathematics. However, it has the potential to be more accessible to students because geometric concepts are embedded in everyday life for instance, in the forms of buildings, traffic signs, and natural patterns such as leaves and honeycombs. This real-world presence of geometry provides opportunities to make learning more meaningful and relatable for students (Fachrudin & Juniati, 2023; Nggaba & Ndakularak, 2025; Sugiyarti & Ruslau, 2019). Nevertheless, Mawarsari et al. (2023) argue that geometry is insufficiently emphasized in the mathematics curriculum and that its relevance to students' daily experiences is often underutilized in current instructional practices. Despite this, students are frequently exposed to geometric objects in their everyday experiences. Nevertheless, students' ability to think mathematically and visualize geometric concepts remains low and far from optimal, as evidenced by several studies. Sugiyarti and Ruslau (2019) found that students' geometric thinking was still at a low level specifically at level 0 (visualization) and level 1 (analysis) when asked to sketch positions and solve distance problems in three-dimensional space. Similarly, Hendriyanto et al. (2021) reported that 71.5% of students were at a low Van Hiele level when dealing with ethnomathematical problems involving geometric pattern recognition and construction. Consequently, teachers must design learning experiences that align with students' cognitive development stages (Fachrudin & Juniati, 2023; Sugiyarti & Ruslau, 2019). Given the inherently abstract nature of mathematics, the use of instructional media and teaching aids is essential to support student comprehension and promote meaningful learning experiences.

Nusaibah et al. (2021) stated that geometric thinking is a key indicator of successful mathematics learning, as it reflects students' abilities in reasoning, visualizing, and solving spatial problems. Geometry holds a unique position in mathematics due to its strong connection with real-life contexts, as seen in common objects like windows, doors, and kites (Nggaba & Ndakularak, 2025). It also plays a vital role in areas such as spatial navigation, architecture, art, and design. Conversely, weak geometric thinking skills may signal gaps in instructional effectiveness. Developing geometric thinking is therefore crucial, not only because it is a core component of the mathematics curriculum, but also because it helps students make sense of the world in a logical and structured way (Baah-Duodu et al., 2020; Desai et al., 2021; Jablonski & Ludwid, 2023). To support these competencies, teachers must design interactive learning environments that foster critical thinking and problem-solving (Sartika et al., 2023). This research has shown that students who engage in interactive learning are better able to think critically and solve problems. One example of implementing interactive learning is using technology in the classroom, such as interactive software, applications, games, and other digital media. The incorporation of such technologies can enrich students' learning experiences, support the development of higher-order thinking skills, and ultimately contribute to improved learning outcomes (Deswita et al., 2025; Hernawari & Jailani, 2019; Firmanti et al., 2024).

In the context of mathematics which is often perceived by students as difficult and unengaging the integration of mobile technology offers new opportunities to create more interactive and meaningful learning experiences, both within and beyond the classroom

environment (Guler et al., 2022; Nofriyanti et al., 2024; Sunzuma, 2023; Tang et al., 2023). Furthermore, augmented reality (AR) applications are the best interactive technology for enhancing students' creativity, motivation, visual-spatial skills, and mathematics learning outcomes (Hidajat, 2023; Lainufar et al., 2021; Mandala et al., 2025). Empirical studies have shown that AR can be successfully employed in teaching geometric concepts, enabling educators to shift from traditional approaches to more constructive and experiential learning methods.

The use of GeoGebra in geometry instruction has gained attention for its capacity to make geometric concepts more visual and interactive (Khoeriyah et al., 2024; Narh-Kert & Sabtiwu, 2022; Valori et al., 2024). However, most previous studies have focused on the classical version of GeoGebra rather than its AR-enhanced format. GeoGebra AR allows students to explore three-dimensional geometric objects placed virtually within their physical environment, allowing for immersive interaction such as walking around and observing shapes from multiple angles. This highlights the importance of using GeoGebra AR for geometry learning. Research by Widada et al., (2021) indicate that students taught with conventional teaching methods are unable to understand geometry concepts as well as students taught with the help of GeoGebra AR. Through AR-based learning, students can engage multiple sensory modalities auditory, kinesthetic, and visual thereby optimizing their cognitive engagement in the learning process.

In this study, the use of GeoGebra AR is expected to provide a realistic representation of geometric shapes and their components. It will also help teachers improve the quality of school learning by teaching more effectively, enabling students to acquire sufficient abilities and skills related to geometry concepts and technology thinking, which are essential in 21st-century job demands. Additionally, students should possess strong geometric thinking skills corresponding to their level of thinking.

The theoretical foundation of this study is the Van Hiele model of geometric thinking, which outlines five hierarchical levels: visualization (recognizing shapes), analysis (identifying properties), informal deduction (recognizing relationships), formal deduction (constructing proofs), and rigor (logical reasoning) (Bada, 2024; Mawarsari et al., 2023; Naufal et al., 2021). Effective instruction, particularly with the integration of technological tools such as GeoGebra AR, can support students in progressing through these levels by offering interactive and exploratory learning experiences. However, existing research indicates that many students remain at the lower levels of the Van Hiele hierarchy, highlighting the urgent need for innovative pedagogical interventions. Therefore, this study aims to investigate whether the use of GeoGebra AR can significantly improve students' geometric thinking levels. The research question guiding this study is: Does the use of GeoGebra AR significantly enhance students' geometric thinking levels based on the Van Hiele model? Addressing this question will provide empirical evidence regarding the effectiveness of GeoGebra AR in supporting conceptual understanding and cognitive development in geometry learning.

Methods

This study employed a quantitative approach using a one-group pretest-posttest design to investigate the effectiveness of GeoGebra Augmented Reality (AR) in enhancing students' geometric thinking. The participants consisted of eighth- and ninth-grade students from BP Al-Munawwaroh Middle School, comprising 27 students from Grade 8 and 33 students from Grade 9, for a total of 60 participants in the experimental group. Students were taught three-dimensional geometry concepts specifically cubes, rectangular prisms, and cylinders using GeoGebra AR as the primary instructional tool.

The main variable in this study was students' geometric thinking ability, operationalized through Van Hiele's levels of geometric reasoning. These levels include: (1) visualization recognizing shapes based on their appearance; (2) analysis identifying properties such as edges, vertices, and faces; (3) informal deduction understanding relationships among geometric properties; (4) formal deduction constructing logical arguments or simple proofs; and (5) rigor understanding geometry within an axiomatic system (Bada, 2024; Mawarsari et al., 2023; Naufal et al., 2021).

The test consists of several items that aim to measure students' abilities at each Van Hiele level, from visualization to informal deduction. The same set of test items was administered in both the pre-test and post-test to ensure comparability of results. To ensure the validity and reliability of the instrument, the test underwent expert validation involving mathematics education lecturers and was piloted with a group of students outside the research sample. Revisions were made based on feedback to refine item clarity, alignment with Van Hiele levels, and appropriateness for the students' cognitive development stage. Students' responses are analyzed and classified into the appropriate Van Hiele levels. The pretest and posttest data were statistically analyzed using a Wilcoxon signed-rank test at a 5% significance level to see if students' geometric thinking levels improved significantly after learning with GeoGebra AR. This analytical approach enabled the researchers to assess the extent to which GeoGebra AR facilitated students' progression in geometric thinking, as delineated by Van Hiele's theoretical model.

Results and Discussion

The GeoGebra application was used to teach the concepts of surface area and volume of cubes, rectangular prisms, and cylinders in an interactive and engaging way. Students were also given an immersive learning experience using Augmented Reality (AR) features in GeoGebra, which made the learning process more enjoyable and meaningful. To assess students' comprehension of geometric concepts, literacy and geometry skills were measured before and after the learning session. Geometry thinking skills were analyzed using the Van Hiele theoretical framework, which provides a systematic and hierarchical model for categorizing students' levels of cognitive development in geometry. Figure 1 shows students' activities by using GeoGebra AR during learning process.

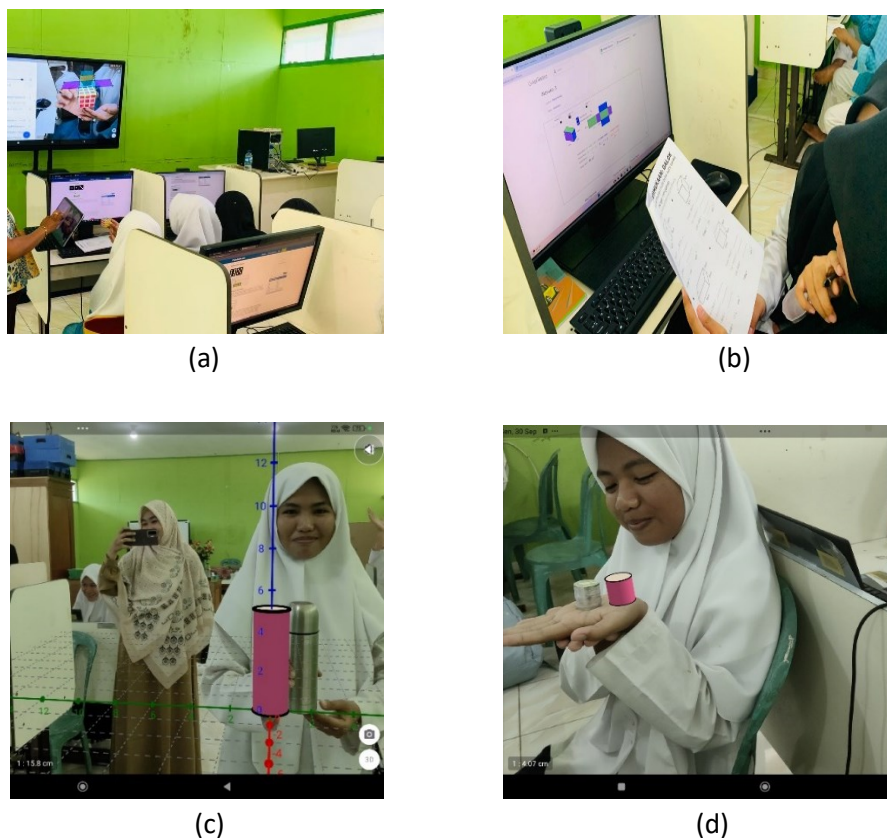


Figure 1. Student Activities using GeoGebra AR

The Descriptive Results

The pretest results revealed that most students were positioned at Level 0, indicating that their geometric abilities were limited to visually recognizing geometric shapes without a thorough thinking of the shapes' properties or relationships. However, a small number of students demonstrated proficiency at Level 4, demonstrating their thinking ability to understand deductive relationships between geometric concepts as well as organize and analyze evidence logically. This variation reveals significant differences in students' levels of geometric thinking, which is an important foundation for designing learning that can meet the needs of students of varying abilities.

Learning activities using GeoGebra AR resulted in a significant increase in grade 8 students' Geometry Thinking. According to post-activity measurements, students' Geometry Thinking were at least at Level 2 in Van Hiele's theory, indicating that they could recognize the fundamental properties of geometric shapes and comprehend simple relationships between shapes. Most students achieved Level 4, demonstrating their thinking to understand deductive relationships, construct logical arguments, and analyze geometric evidence. Overall, all participants demonstrated high-level geometric thinking post-intervention (Level 2 to Level 4), evidencing their capacity for abstract reasoning, relational understanding, and logical argumentation in geometry. These findings suggest that the use of GeoGebra AR significantly enhances students' conceptual development and cognitive engagement in the domain of three-dimensional geometry.

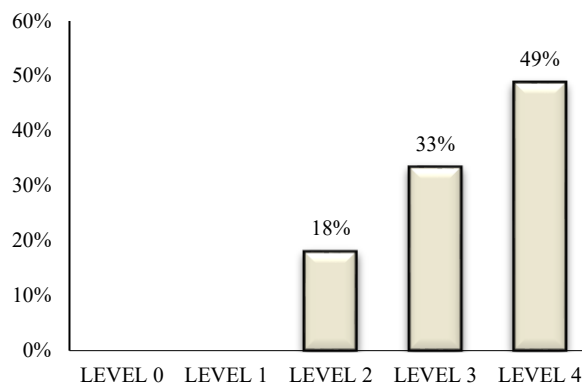


Figure 2. The geometric thinking of eighth-grade students according to Van Hiele's levels during learning activities

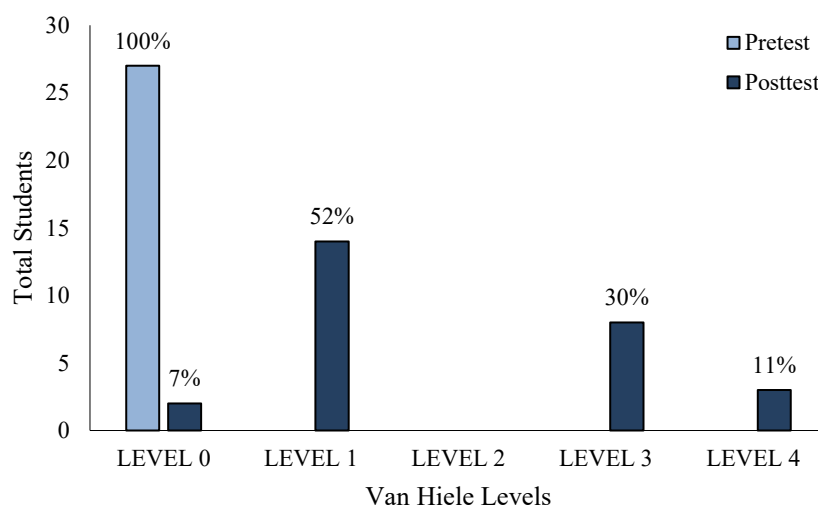


Figure 3. The geometric thinking of eighth-grade students based on Van Hiele's levels

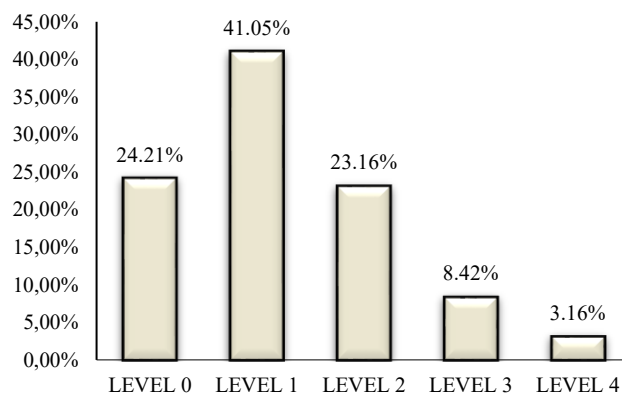


Figure 4. The geometric thinking of ninth-grade students according to Van Hiele's levels during learning activities

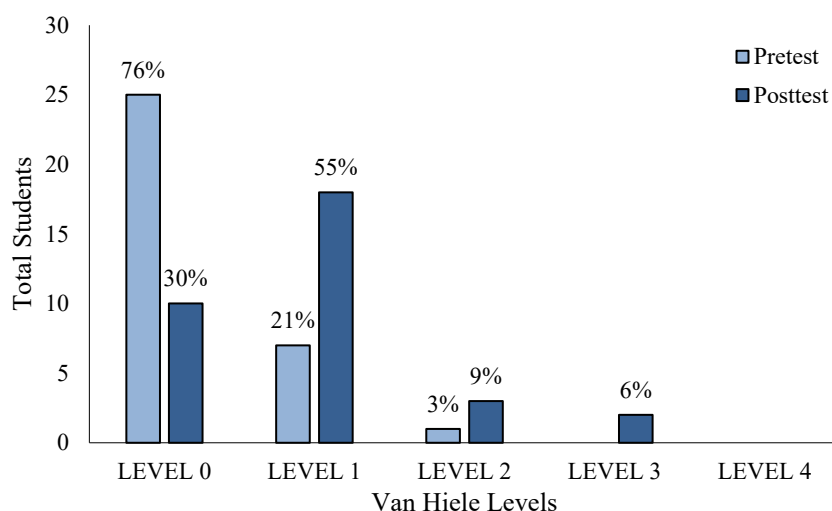


Figure 5. The geometric thinking of ninth-grade students based on Van Hiele's levels

Based on Van Hiele's theory, the results of GeoGebra AR learning activities among ninth-grade students show significant variations in their thinking of geometry. Although a small number of students remain at Level 0, where their thinking of geometry is limited to visual recognition and they are unable to identify the properties or relationships of shapes, most students have advanced to Level 1. Students at this level can identify and informally describe the fundamental properties of geometric shapes. Interestingly, several students have progressed to Level 4, demonstrating the thinking to understand deductive relationships between concepts, construct logical arguments, and analyze geometric evidence.

The study's findings revealed that participation in the learning process improved students' geometric thinking. After the learning process, the distribution of abilities among eighth-grade students became more balanced across the various levels of Van Hiele's theory, with some students reaching Levels 3 and 4. Although the improvement was statistically significant, most ninth-grade students remained at Van Hiele Level 1, indicating limited progress. This may be due to differences in prior learning; while both eighth- and ninth-grade students had studied geometry, the ninth graders had more established but rigid conceptions that made adapting to new methods more difficult. In contrast, eighth graders, who encountered the material more recently, responded more flexibly to the GeoGebra AR-based activities. These findings suggest that prior learning experiences influence students' responsiveness to innovative instructional tools, though both groups showed positive engagement overall (AlGerafi et al, 2023; Wood & Shirazi, 2020). Consistent practice and targeted familiarization are essential to further enhance students' geometric thinking, enabling them to develop a deeper comprehension of geometric concepts and reasoning.

The Comparing Results

The purpose of this step is to compare the results of the geometry thinking test for eighth- and ninth-grade students before and after the test, to determine whether the observed improvement in thinking is a genuine effect of the applied learning method or merely a coincidence. This test provides reliable evidence of the effectiveness of the learning methods. The Wilcoxon Signed

Rank Test was used to determine whether the observed changes in each student were statistically significant and whether there was a meaningful increase at each Van Hiele level. Descriptive analysis indicates that students' geometry thinking improves at each Van Hiele level; however, most ninth-grade students have not yet reached the higher levels of geometric thinking. The detailed results of this analysis are presented in [Table 1](#).

Table 1. Wilcoxon signed rank test results

Statistics	N	n	W_{stat}	W	z	p
	Total	Effective	$[\min(W^+, W^-)]$	Critical		
Class 8	27	25	0	101	-4.484	0.000
Class 9	33	20	0	60	-4.379	0.000

The results of the study show that GeoGebra AR had a statistically significant impact on students' geometric thinking, as evidenced by the improvement in their Van Hiele levels. The statistical analysis conducted using the Wilcoxon Signed Rank Test, as summarized in Table 1, reveals a significant improvement in both eighth and ninth-grade students' geometric thinking levels after the intervention. The null hypothesis was rejected, with a p-value of 0.00, which is less than the significance level of 0.05, indicating that the difference between the pre-test and post-test scores was statistically significant. These findings indicate that GeoGebra AR effectively enhanced students' geometric reasoning abilities, consistent with earlier studies highlighting the positive contributions of augmented reality (AR) technologies in geometry education.

Interestingly, the intervention appeared to have a greater impact on eighth-grade students compared to ninth-grade students. One possible explanation for this difference is that eighth-grade students were in the early stages of learning geometric concepts and had not yet developed fixed or procedural ways of thinking. This lack of established schemas made them more open to exploratory learning and constructing understanding through interactive tools like GeoGebra AR.

In contrast, ninth-grade students may have already formed more rigid schemas from prior instruction, often relying on memorization and procedural strategies rather than conceptual reasoning. This rigid thinking may have made them less receptive to the exploratory and interactive nature of AR, requiring more time or different pedagogical approaches to shift their thinking. These outcomes suggest that technology-based interventions like GeoGebra AR might be more effective when introduced early in students' conceptual development, before misconceptions and rigid thinking patterns become ingrained.

These findings align with existing research on the benefits of AR in geometric education. Tasci and Soyulu (2023) found that using AR applications in teaching geometric objects to sixth-grade students led to significant improvements in their geometric thinking and spatial abilities. This is consistent with the current study's results, which also show a positive effect of AR on students' geometric thinking. Similarly, Pujiastuti and Haryadi (2024) demonstrated that AR learning in geometry for eighth-grade students resulted in higher academic achievement compared to a control group. The study revealed that students in the experimental group, who

were exposed to AR-based learning, showed more active participation and enthusiasm during lessons, reinforcing the positive impact of AR on student engagement and motivation.

In addition, Nadzeri et al. (2024) investigated the impact of AR on primary school students' spatial visualization skills in geometry. The results of this study also showed that AR applications enhanced students' abilities to visualize geometric concepts, a skill that is foundational to more advanced geometric thinking. This reinforces the notion that AR can be a powerful tool not only for enhancing geometry learning at higher grade levels but also for fostering essential spatial reasoning skills in younger students. Furthermore, Asnawi et al. (2023) highlighted the effectiveness of GeoGebra-assisted digital learning media for geometry transformations, which also supports the integration of GeoGebra AR in promoting Van Hiele's levels of geometric thinking.

Expanding the scope, AlGerafi et al. (2023) conducted a comprehensive review of the educational applications of AR and VR, highlighting their significant impact on student motivation, learning outcomes, and engagement. The study emphasized how AR and VR foster immersive and interactive learning environments that promote active learning, collaboration, and critical thinking. These findings reinforce the pedagogical value of AR not only for enhancing cognitive skills but also for improving students' attitudes and enthusiasm toward learning. It also provided practical recommendations for effective AR/VR integration, emphasizing pedagogically sound design, educator training, and equitable access.

Finally, the findings of this study, supported by relevant literature, highlight the effectiveness of GeoGebra AR in enhancing students' geometric thinking. When aligned with students' cognitive development, AR not only facilitates visualization of geometric concepts but also promotes engagement, motivation, and deeper conceptual understanding of the underlying principles. These results suggest that GeoGebra AR is a promising educational tool for fostering critical thinking and problem-solving skills in geometry learning.

Conclusion

The test results show that the null hypothesis was rejected, indicating a statistically significant improvement in students' geometric thinking levels after the intervention. The use of GeoGebra AR has been proven effective in helping students progress through the Van Hiele levels by providing an interactive and exploratory learning experience. The integration of augmented reality in geometry instruction enhances students' engagement and conceptual thinking, enabling them to visualize and manipulate geometric objects dynamically.

Based on the findings, students have generally improved in their ability to recognize and describe geometric shapes (Level 0 - Visualization) and analyze their properties (Level 1 - Analysis). However, only 41% of eighth-grade students and 15% of ninth-grade students were able to reach higher levels (Levels 2, 3, and 4), which involve logical reasoning, deductive thinking, and formal proofs. This suggests that while students are now better at identifying shapes and thinking their characteristics, many still struggle with making logical connections between properties (Level 3 - Informal Deduction) and constructing formal geometric proofs (Level 4 - Deduction).

Despite the promising results, this study has several limitations. First, the duration of the intervention was relatively short, which may have limited the depth of understanding students could achieve using GeoGebra AR. Second, the study sample was limited to students from two specific grade levels, which may not fully represent the broader student population. Additionally, the study was reliant on a single geometric thinking test to measure improvement, which may not have captured all aspects of students' conceptual understanding. Other external factors, such as students' prior experiences and motivation, were also not fully controlled in this study. Finally, while GeoGebra AR proved to be an effective tool, not all students may have felt equally comfortable or engaged with this technology, which could have influenced the overall impact of the intervention. Despite these limitations, statistical analysis confirms a significant overall improvement in students' Van Hiele levels after learning with GeoGebra AR. These findings suggest that while GeoGebra AR effectively supports students' geometric development, additional instructional strategies such as explicit reasoning exercises, structured problem-solving activities, and guided proof construction may be necessary to help more students reach the advanced levels of geometric thinking.

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Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this research. This study was conducted independently, and no external influences affected the design, data collection, analysis, or interpretation of the results. All findings and conclusions presented are based solely on objective analysis and academic integrity.

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