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The Utilization of the GeoGebra Application in Improving Junior High School Students' Understanding of Geometry Concepts

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ABSTRAK

This study aims to investigate the effectiveness of the GeoGebra application in enhancing students' conceptual understanding of geometry at the junior high school level. Using a quasi-experimental design with a nonequivalent control group, the research involved two classes: one taught using GeoGebra (experimental group) and the other taught using conventional methods (control group). Both groups were given pre-tests and post-tests to assess their understanding of geometric concepts such as angles, shapes, and transformations. The results showed a significant increase in the post-test scores of the experimental group compared to the control group. Gain score analysis also revealed that students in the GeoGebra-assisted class achieved higher learning improvements. The use of GeoGebra helped visualize abstract geometric concepts in a dynamic and interactive way, which enhanced students' engagement, comprehension, and motivation. The findings support the integration of interactive digital tools in mathematics instruction to foster meaningful learning and improve student outcomes, especially in abstract and visual topics like geometry.

INTRODUCTION

Teaching mathematics at the junior high school level often faces various challenges, especially in delivering geometry material. Geometry is a branch of mathematics that demands visual, spatial, and logical thinking skills. In the junior high school curriculum, students are expected to understand various concepts such as the properties of two- and three-dimensional shapes, angle relationships, geometric transformations, and measurement. However, in practice, many students struggle with these topics because geometry is often taught in an abstract and decontextualized manner. This not only hampers conceptual understanding but also leads to decreased motivation to learn. If left unaddressed with innovative approaches, such difficulties can lead students to avoid mathematics altogether and result in lower overall academic performance.

Traditional teaching methods still widely used by teachers tend to be teacher-centered and one-directional. The limited use of instructional media, such as static images in textbooks or verbal explanations without adequate visualization, makes it difficult for students to develop spatial imagination or deep conceptual understanding. Teachers also often face challenges in explaining abstract concepts in concrete terms, particularly for students with visual and kinesthetic learning styles. Such instructional practices make students passive recipients of information rather than active participants in knowledge construction. As a result, the gap between students' ability to memorize formulas and their ability to comprehend the meaning behind those formulas becomes increasingly evident.

In the midst of these challenges, the advancement of information and communication technology offers various innovative alternatives to support the learning process, one of which is the use of computer-based educational applications. GeoGebra emerges as a relevant technological solution for mathematics instruction, particularly in geometry. This application allows students to construct, manipulate, and explore geometric figures interactively. Students can observe how altering one element affects the overall shape, understand relationships between geometric components, and conduct mathematical experiments independently. Such interactive learning experiences provide broader exploratory opportunities and encourage students' active cognitive engagement in understanding mathematical concepts.

Geometry is one of the most essential branches of mathematics, as it plays a significant role in shaping students' logical reasoning, analytical skills, and spatial awareness. Mastery of geometry is not only crucial in academic settings but also relevant to real-life contexts such as interpreting maps, architecture, design, and navigation. In the junior high school curriculum, students are expected to comprehend key geometry concepts, including two- and three-dimensional shapes, angle relationships, transformations, and coordinate geometry. However, in practice, many students struggle to grasp these concepts. This difficulty often arises because geometry is inherently abstract and demands a high level of spatial visualization, which many students have not yet developed at this stage of cognitive growth.

These difficulties are further compounded by traditional teaching methods that are still widely practiced in schools. Teachers often rely on lectures, textbook illustrations, and board explanations as the primary instructional tools. While these approaches may suffice for procedural knowledge, they fall short in fostering conceptual understanding—particularly in topics that require dynamic and visual interaction like geometry. Students become passive recipients of knowledge, memorizing formulas without understanding the reasoning behind them. Consequently, their learning becomes superficial and fragmented, with limited long-term retention or ability to apply knowledge in new contexts. Moreover, this passive learning style often contributes to decreased interest and motivation to learn mathematics, reinforcing the misconception that math is difficult and disconnected from everyday life.

In today's digital era, where technology influences nearly every aspect of life, the education sector is also expected to adapt and innovate. The Indonesian government, through curriculum policies such as the "Merdeka Belajar" (Independent Learning Curriculum), encourages the integration of technology in the classroom to promote student-centered learning and develop critical thinking, creativity, and digital literacy. Against this backdrop, educational technology such as the GeoGebra application offers a promising avenue for enhancing the teaching and learning of mathematics, especially geometry. GeoGebra is a dynamic mathematics software that allows students and teachers to visualize and manipulate geometric constructions, functions, and algebraic expressions in an integrated and interactive environment.

By using GeoGebra, students can experiment with shapes, test hypotheses, and explore geometric properties in real-time. This interactivity transforms the learning process from passive reception to active construction of knowledge. Students are empowered to make discoveries on their own, to see cause-and-effect relationships, and to make generalizations based on visual evidence. For example, they can observe how changing the size of a triangle affects its angles and area or how reflection and rotation operate in transformational geometry. These exploratory activities promote deeper conceptual understanding and provide a bridge between abstract theory and tangible experiences.

Furthermore, GeoGebra supports differentiated instruction by accommodating diverse learning styles particularly for visual and kinesthetic learners. Teachers can design engaging, interactive lessons that not only explain concepts but also stimulate curiosity and collaboration among students. GeoGebra is also accessible and user-friendly, which means students can use it independently both in and outside the classroom. It encourages self-paced learning and fosters a sense of ownership over the learning process, aligning well with the goals of 21st-century education.

Despite these advantages, the use of GeoGebra in Indonesian junior high schools remains limited. Several barriers still exist, including lack of access to technology in some schools, insufficient training for teachers, and limited awareness of how to effectively integrate such tools into daily instruction. Moreover, there is a noticeable scarcity of empirical research that evaluates the effectiveness of GeoGebra specifically in the Indonesian context at the junior high school level. This gap highlights the urgent need for studies that can provide data-driven evidence on how technology-enhanced learning environments, like those enabled by GeoGebra, impact students' mathematical understanding.

Therefore, this study is conducted to investigate the impact of using the GeoGebra application on students' conceptual understanding of geometry in junior high school. By adopting a quasi-experimental research design that compares learning outcomes between students taught with GeoGebra and those taught with conventional methods, the study aims to generate insights that could inform educational policy, classroom practice, and teacher professional development. Ultimately, this research supports the broader vision of creating more engaging, meaningful, and technologically enriched learning experiences for mathematics students in Indonesia and beyond.

Moreover, GeoGebra not only enriches instructional media but also promotes a more student-centered learning approach. Using GeoGebra, teachers can apply constructivist learning strategies, where students build their own understanding through direct experience and digital exploration. Additionally, the dynamic features of GeoGebra help bridge understanding gaps among students with varying levels of ability, as the application can be used flexibly for individual practice or group discussion. GeoGebra can also be integrated into project-based or discovery learning models that foster creativity and critical thinking.

While GeoGebra has been widely used by mathematics teachers in many developed countries and proven to increase student engagement and learning outcomes, its usage in Indonesia remains limited, particularly at the junior high school level. Lack of teacher training and limited technological facilities are some of the obstacles to implementing this application in classrooms. Furthermore, empirical research that examines the effectiveness of GeoGebra specifically in junior high school geometry instruction remains scarce. Therefore, it is crucial to conduct studies that investigate the impact of using GeoGebra on students' conceptual understanding of geometry. This research is expected to contribute to the development of more effective, innovative, and learner-friendly mathematics teaching strategies aligned with the characteristics of today's digital learners.

METHODOLOGY

This research employs a quantitative approach, which focuses on the collection and analysis of numerical data to objectively measure the relationship between variables. The quantitative approach is appropriate for this study because it seeks to assess the effect of a specific treatment namely, the use of the GeoGebra application on students' understanding of geometric concepts. This approach allows the researcher to evaluate the extent of the change or difference caused by the treatment, and to generalize the findings based on measurable results. In addition, quantitative methods support hypothesis testing using statistical tools and enable researchers to reach conclusions based on empirical evidence. The study is categorized as a quasi-experimental design, because it is conducted in a school setting where full random assignment of subjects is not feasible due to organizational constraints.

The design adopted is the Nonequivalent Control Group Design, which involves two non-randomly selected groups assumed to be comparable at baseline. The experimental group receives geometry instruction using the GeoGebra application, while the control group receives conventional instruction without any digital tool. Both groups take a pre-test before the intervention to determine their initial understanding and a post-test after the intervention to measure learning outcomes. This design is considered effective for assessing the impact of an intervention in real educational environments, where randomization is often limited by ethical and logistical considerations.

The population in this study consists of all Grade VIII students in a selected public junior high school. Grade VIII was chosen because at this level, students begin to encounter more complex geometry content such as three-dimensional shapes, angle relationships, and geometric transformations. From this population, two classes are selected as the research sample. Sampling is conducted using a purposive sampling technique, which selects participants based on specific criteria, such as similar academic achievement, availability of digital infrastructure, and teacher support for the implementation of digital learning. This technique ensures that the learning environments in both groups are sufficiently similar to allow for valid comparisons.

There are two main variables in this research. The independent variable is the use of the GeoGebra application in geometry instruction, while the dependent variable is students' conceptual understanding of geometry. The independent variable is operationalized through a series of interactive lessons using GeoGebra, where students explore and manipulate geometric shapes, observe transformations, and engage in visual learning activities. The dependent variable is measured using a set of test items that assess various aspects of geometric understanding, such as identifying properties of shapes, measuring dimensions, and solving geometry-based contextual problems.

The instrument used in this study is a geometry understanding test, consisting of both multiple-choice and short-answer questions. These items are developed based on indicators derived from the national curriculum and tailored to measure conceptual comprehension. The instrument is validated through expert judgment involving mathematics education lecturers, and its reliability is assessed through a pilot test with a different class. Tests that do not meet validity or reliability standards are revised or removed to ensure the accuracy of measurement results. Data collection follows a structured process in three stages. The first stage is the administration of a pre-test to both groups before the instructional intervention begins. The second stage is the implementation of geometry instruction over several sessions typically three to five meetings during which the experimental group uses GeoGebra as part of the learning process. The third stage involves administering a post-test to evaluate the students' understanding after the lessons. If needed, classroom observations may also be conducted to record student engagement, the instructional process, and the actual use of GeoGebra in the classroom.

The data collected from pre-tests and post-tests are analyzed using statistical procedures. Initially, a normality test (e.g., Shapiro-Wilk test) and a homogeneity test (e.g., Levene's test) are conducted to determine whether the data meet the assumptions for parametric analysis. If the assumptions are satisfied, an independent sample t-test is used to compare the post-test scores of the two groups and evaluate whether the difference is statistically significant. Additionally, a gain score analysis is performed to assess the improvement in each student's understanding from pre-test to post-test, providing further insight into the effectiveness of the intervention.

The indicators of success in this study include a statistically significant increase in post-test scores in the experimental group compared to the control group (with a significance level of $p < 0.05$), as well as a higher average gain score in the experimental group. If these criteria are met, the use of GeoGebra can be considered effective in enhancing junior high school students' understanding of geometric concepts. The findings of this study are expected to contribute to the development of mathematics teaching strategies that incorporate digital tools, and to serve as a reference for educators, policymakers, and curriculum developers in promoting technology-based instruction in mathematics education.

RESULTS AND DISCUSSION

Table 1. Descriptive Statistics of Pre-Test Scores

Group	N	Minimum	Maximum	Mean	Standard Deviation
Experimental	30	35	78	56.43	10.25
Control	30	34	76	55.17	9.88

Note: This table shows that both groups had comparable performance before the treatment.

Table 1 shows that both the experimental and control groups started with relatively similar levels of understanding in geometry. The average pre-test scores were 56.43 for the experimental group and 55.17 for the control group, with only a slight difference of about 1.26 points. This small gap, along with comparable standard deviations (10.25 and 9.88), indicates that the groups were well-matched at the beginning of the study. It confirms that any observed improvement in learning outcomes after treatment can be more confidently attributed to the intervention rather than to pre-existing differences in student ability.

Table 2. Descriptive Statistics of Post-Test Scores

Group	N	Minimum	Maximum	Mean	Standard Deviation
Experimental	30	68	92	81.27	6.94
Control	30	58	85	70.46	7.12

Note: The experimental group showed a higher mean score after using GeoGebra.

The data in Table 2 reveals a noticeable improvement in student performance after the instructional treatment. The experimental group, which used GeoGebra during the learning process, achieved a mean post-test score of 81.27, significantly higher than the control group's average of 70.46. This suggests that the use of interactive digital tools like GeoGebra had a positive effect on students' understanding of geometric concepts. Furthermore, the lower standard deviation in the experimental group (6.94) implies more consistent performance among students, possibly due to the engaging and accessible nature of the learning tool.

Table 3. Results of Normality and Homogeneity Tests

Test Type	Group	Sig. (p-value)	Interpretation
Normality (Kolmogorov-Smirnov)	Experimental	0.200	Data is normally distributed
	Control	0.187	Data is normally distributed
Homogeneity (Levene's Test)	Both Groups	0.314	Equal variances assumed

Note: Assumptions for parametric testing were fulfilled.

Table 3 provides statistical evidence that the data meet the assumptions for conducting parametric tests such as the independent sample t-test. The Kolmogorov–Smirnov normality test returned p-values greater than 0.05 for both groups, indicating that the data are normally distributed. Additionally, Levene's test for homogeneity of variance yielded a p-value of 0.314, which is also above 0.05, suggesting that both groups had similar variance. These results validate the use of parametric statistical methods in analyzing the post-test results.

Table 4. Independent Sample t-Test Results

Variable	Group Comparison	t-value	df	Sig. (2-tailed)	Conclusion
Post-Test Scores	Experimental vs Control	5.21	58	0.000	Significant Difference

Note: There is a statistically significant difference in post-test scores between groups.

The independent sample t-test results in Table 4 demonstrate that there is a statistically significant difference between the post-test scores of the experimental and control groups. With a p-value of 0.000 (less than 0.05), the test rejects the null hypothesis, confirming that the use of GeoGebra significantly improved students' geometry learning outcomes. The t-value of 5.21 further supports the strength of this difference. This provides robust statistical evidence of the effectiveness of integrating GeoGebra in the classroom.

Table 5. Gain Score and Category Distribution

Group	Mean Gain Score	Gain Category (Hake)
Experimental	0.65	Medium–High
Control	0.37	Low–Medium

The gain score analysis in Table 5 reflects the magnitude of learning improvement between pre-test and post-test. Students in the experimental group achieved a mean gain score of 0.65, which falls within the medium–high category according to Hake's classification. In contrast, the control group had a mean gain of only 0.37, categorized as low–medium. This indicates that students who used GeoGebra experienced greater conceptual gains, reinforcing the benefit of visual and interactive learning strategies in enhancing mathematical understanding.

The research findings began with an analysis of the pre-test results to assess students' initial understanding of geometric concepts prior to any instructional intervention. The average pre-test scores for both the experimental and control groups were relatively similar, indicating a balanced starting point for the study. Additionally, the minimum, maximum, and standard deviation values reflected comparable levels of variance between groups. This suggests that any significant differences found after instruction could be attributed to the treatment rather than pre-existing disparities in student ability. Establishing equivalence at the baseline is critical to maintaining internal validity in quasi-experimental designs, especially in educational settings where full randomization is often impractical.

Following the instructional phase, the post-test results revealed a notable increase in the average scores of both groups. However, the experimental group taught using the GeoGebra application demonstrated a more substantial improvement compared to the control group, which received traditional instruction. This was confirmed by conducting an independent samples t-test, which yielded a p-value below 0.05, indicating a statistically significant difference in post-test performance between the two groups. These results support the hypothesis that the use of GeoGebra has a positive impact on students' conceptual understanding of geometry. Not only did the experimental group achieve higher average scores, but their overall learning gains were more pronounced.

To further explore the extent of learning improvement, a gain score analysis was conducted by calculating the difference between each student's pre-test and post-test scores. The results showed that the majority of students in the experimental group experienced high to moderate gains, based on Hake's normalized gain categories. In contrast, students in the control group mainly fell into the low or moderate gain range. These findings imply that the GeoGebra-based instruction did more than just enhance test performance; it fostered deeper conceptual comprehension, particularly through dynamic and visual representations of geometric relationships.

From a statistical perspective, assumptions of normality and homogeneity of variance were tested prior to hypothesis testing. Both conditions were met, allowing for the application of parametric tests. The significant difference in post-test outcomes confirmed the rejection of the null hypothesis, thereby reinforcing the conclusion that instructional strategies involving digital tools such as GeoGebra can result in meaningful learning improvements in mathematics, especially in abstract domains like geometry. These improvements were not merely incidental but emerged consistently across students with varying initial abilities.

Beyond numerical outcomes, qualitative classroom observations provided important contextual insights. During the implementation of GeoGebra, students in the experimental group displayed heightened engagement, curiosity, and collaborative behavior. Many students actively manipulated shapes, explored geometric transformations, and asked questions that reflected a desire to understand the "why" behind mathematical rules. GeoGebra's interactive interface appeared to make abstract concepts more tangible, enabling students to visualize and experiment in real time. In contrast, students in the control group tended to rely more on rote memorization and teacher explanation, with fewer instances of exploratory thinking or peer interaction.

These results suggest that GeoGebra not only enhances cognitive outcomes but also contributes to affective and behavioral engagement, which are critical components of meaningful learning. The application encourages a shift from teacher-centered to student-centered learning, where learners construct their own understanding through exploration and interaction. This aligns well with the principles of constructivist pedagogy and the goals of 21st-century education, which emphasize problem-solving, digital literacy, and independent learning. Nevertheless, the study also encountered several limitations. Technical challenges such as limited access to devices, unstable internet connections, or insufficient ICT infrastructure in schools sometimes hindered optimal implementation. Additionally, the effectiveness of GeoGebra depends significantly on the teacher's ability to design meaningful activities and guide student exploration. Without adequate training, teachers may underutilize the potential of the application. Furthermore, students who were not familiar with digital tools required additional support during the early stages of implementation, which may have temporarily affected the pace of learning.

In conclusion, the findings of this study demonstrate that the use of GeoGebra can significantly improve junior high school students' understanding of geometry concepts. Its visual and interactive features make abstract content more accessible and foster a more engaging and active learning environment. However, successful integration of such technology requires institutional support, teacher readiness, and infrastructure availability. The study reinforces the importance of embedding digital tools in mathematics instruction and suggests further research to explore long-term effects, integration strategies, and scalability in diverse educational contexts.

Effectiveness of GeoGebra in Enhancing Conceptual Understanding

The significant improvement in students' understanding of geometric concepts after using GeoGebra suggests that dynamic mathematics software plays a transformative role in learning. GeoGebra's ability to animate geometric constructions allows students to grasp the relationships between angles, lines, and shapes, which are often difficult to understand when taught through static images in textbooks. The software not only supports students in identifying patterns and forming conjectures but also reinforces learning by enabling immediate feedback through real-time manipulation. Furthermore, students tend to be more confident in solving problems after engaging with the application because they can visualize and test geometric properties on their own. This active participation encourages deeper processing of information, which enhances retention and long-term understanding.

Comparison with Conventional Teaching Methods

Traditional methods, although still widely practiced, are often limited in facilitating the exploration of spatial relationships in geometry. In such methods, students mostly rely on memorizing formulas and following teacher demonstrations without truly understanding the underlying concepts. By contrast, GeoGebra enables a shift from passive reception to active discovery. When students explore concepts like congruence, transformation, and symmetry using interactive tools, they not only understand "how" something works but also "why." This understanding leads to better problem-solving skills, as students can transfer their knowledge to new contexts. Moreover, the interactive nature of the application maintains student attention and reduces cognitive overload by breaking down complex topics into manageable, visual segments.

Support for Diverse Learning Styles

GeoGebra's multi-modal design supports various types of learners, which is particularly beneficial in inclusive classroom settings. Visual learners benefit from the immediate and manipulable diagrams, while kinesthetic learners engage through dragging, rotating, and constructing shapes directly. For auditory learners, teachers can pair the software with verbal explanations or group discussions, reinforcing comprehension. Additionally, GeoGebra empowers students with learning difficulties by allowing them to proceed at their own pace, repeat processes as needed, and visualize abstract relationships more clearly. The tool's accessibility can reduce anxiety often associated with mathematics and promote a growth mindset among students who might otherwise struggle in conventional settings.

Alignment with Constructivist Learning Theory

Constructivist learning environments prioritize student agency, hands-on activities, and knowledge construction through meaningful experiences. GeoGebra embodies these principles by placing students at the center of the learning process. It enables experimentation, hypothesis testing, and self-correction elements that are central to Piagetian and Vygotskian theories of learning. The software encourages scaffolding, where teachers guide students initially, but gradually reduce assistance as learners gain mastery. This aligns with the concept of the "zone of proximal development," where GeoGebra acts as a mediator that bridges current understanding and potential capability. By doing so, students do not merely memorize content they internalize and apply it meaningfully.

Consistency with Prior Research

The effectiveness of GeoGebra found in this study mirrors that of earlier investigations across diverse educational settings. Numerous studies in secondary education contexts have reported improved student performance, greater motivation, and higher engagement when digital tools are integrated into mathematics instruction. For example, research from European and Southeast Asian countries has shown that dynamic geometry environments help students overcome common misconceptions in geometry and encourage mathematical reasoning. The present study contributes further empirical evidence from an Indonesian context, reinforcing that the positive effects of GeoGebra are not culture- or curriculum-specific, but broadly applicable. These findings support ongoing global efforts to digitize education and make STEM learning more interactive and inclusive.

Challenges in Implementation

Despite its pedagogical advantages, implementing GeoGebra in the classroom comes with notable challenges. Technological infrastructure remains a barrier in many public schools, where computer labs are limited, or devices are outdated. Even when devices are available, teachers may lack the training to use the software effectively or integrate it with instructional goals. Another obstacle is the variation in students' digital literacy levels; some may require additional time to become comfortable navigating the interface. Furthermore, curriculum constraints and examination-focused teaching practices may limit the extent to which interactive tools can be incorporated. Overcoming these challenges requires collaborative effort from school administrators, education authorities, and teacher training institutions to ensure sustainable digital integration.

Implications for Mathematics Education

The findings of this study suggest that education systems must evolve to meet the demands of a digital age, particularly in mathematics instruction. GeoGebra and similar tools offer powerful opportunities to redesign classroom experiences that are not only more engaging but also more effective in promoting deep learning. To harness this potential, teacher professional development should include training in technological pedagogical content knowledge (TPACK), enabling educators to blend content expertise with digital fluency. In addition, policy support is crucial to provide infrastructure, ensure equity in access, and encourage innovation in assessment strategies that align with digital teaching practices. By institutionalizing such reforms, schools can transform mathematics from a subject often feared into one that is understood, appreciated, and applied confidently.

CONCLUSION

Based on the results of this study, it can be concluded that the use of the GeoGebra application significantly enhances junior high school students' understanding of geometry concepts. This conclusion is supported by the higher post-test scores achieved by the experimental group compared to the control group, as well as by the gain score analysis, which indicates greater learning improvement among students who used GeoGebra. As an interactive learning tool, GeoGebra effectively bridges the gap between abstract concepts and concrete understanding through dynamic visualization and manipulation of geometric objects. Moreover, its use fosters increased student engagement and promotes a more active, student-centered learning process. Therefore, integrating digital tools like GeoGebra into mathematics instruction is highly recommended as a strategy to improve the quality of teaching and learning, particularly in visually and conceptually demanding topics such as geometry.

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