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UTILIZATION OF GEOGEBRA IN ENHANCING HIGH SCHOOL STUDENTS' MATHEMATICAL REASONING ABILITY

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ABSTRACT

Students' low mathematical reasoning skills, particularly regarding abstract concepts such Students' mathematical reasoning ability in the topic of tangent lines to a circle remains relatively low, particularly in integrating geometric and algebraic concepts. This indicates limitations in students' conceptual understanding, which may be influenced by the use of conventional teaching methods with minimal visualization. This study aims to examine the effectiveness of GeoGebra in improving high school students' mathematical reasoning ability. This study employed a quasi-experimental method with a pretest–posttest control group design involving 44 eleventh-grade students' at SMAN 5 Banda Aceh. The data were analyzed using the Method of Successive Interval (MSI) and an independent sample t-test. The results showed that the experimental group achieved a higher average post-test score (13.13) compared to the control group (11.04). The calculated t-value (5.13) exceeded the critical t-value (2.018), indicating a significant difference between the two groups. Therefore, the use of GeoGebra was proven to be effective in improving students' mathematical reasoning ability compared to conventional methods. These findings confirm that the integration of technology in geometry learning can create a more interactive learning environment and support the development of students' logical thinking skills.

INTRODUCTION

Mathematical reasoning ability is a crucial competence in mathematics education, playing a vital role in constructing logical arguments, formulating conjectures, and drawing conclusions systematically (Hendriana et al., 2017). However, this ability remains relatively low, particularly regarding abstract geometric concepts (Fitria, 2022). Based on preliminary observations conducted at SMAN 5 Banda Aceh, students' experience substantial difficulties in understanding the concept of equations of tangent lines to a circle, specifically in linking geometric and algebraic representations. Students' tend to memorize procedures without grasping the interconnections between concepts, preventing their mathematical reasoning ability from developing optimally. This condition is presumed to be influenced by the prevalence of conventional instructional methods that offer minimal visualization, which hinders students' from comprehensively understanding the interrelations among mathematical concepts (Sari et al., 2014; Purcell & Varberg, 2003).

The integration of technology via dynamic software such as GeoGebra serves as a strategic solution to bridge this gap. GeoGebra is capable of simultaneously combining algebraic and geometric representations, which has been proven to reinforce abstract conceptual understanding and learning motivation (Nur Hamidah et al., 2020). Through a constructivist approach, students' do not merely receive information passively but actively explore and verify their own conjectures (Juandi et al., 2021). Although research on GeoGebra has been extensive, studies specifically highlighting its effectiveness in enhancing mathematical reasoning within the topic of circle tangent lines remain limited (Mukuka et al., 2023). Yet, dynamic visualization is critical in this topic to assist students' in interconnecting the concepts of circles, gradients, and the distance from a point to a line.

This study aims to analyze the effectiveness of utilizing GeoGebra to improve high school students' mathematical reasoning ability in the topic of equations of tangent lines to a circle using a quasi-experimental approach. The urgency of this study lies not only in increasing academic achievement but also in developing 21st-century skills (the 4Cs) and digital literacy, which constitute integral components of the *Pelajar Pancasila* (Pancasila Student) profile (Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi, 2024). The findings of this research are expected to provide practical contributions for educators in implementing more innovative and interactive instructional strategies in the digital era.

RESEARCH METHOD

This study is a quantitative research employing a quasi-experimental approach with a pretest–posttest control group design. This design involved an experimental class that received treatment in the form of GeoGebra-assisted learning and a control class taught using conventional methods.

The instructional procedures and stages in the experimental class followed a guided inquiry syntax integrated with GeoGebra, comprising five phases: 1) Orientation; 2) Formulating problems and hypotheses; 3) Data collection through GeoGebra exploration; 4) Interpretation and reasoning; and 5) Reflection. For instance, during the exploration phase, students were instructed to utilize the slider feature and the tangent tool in

GeoGebra to observe how changes in the position of the tangent point directly affected the line equation. This activity was designed to enable students' to independently discover the perpendicular relationship between the radius and the tangent line through dynamic visualization before formulating it analytically.

The population and sample of this study consisted of all eleventh-grade students' at SMAN 5 Banda Aceh. Through a random sampling technique, class XI-2 (comprising 22 students') was selected as the experimental group, and class XI-3 (comprising 22 students') was selected as the control group. The research instrument was an essay test measuring four indicators of mathematical reasoning: formulating conjectures, performing mathematical manipulation, constructing proofs, and drawing conclusions. The instrument was validated by experts and declared reliable with a Cronbach's Alpha coefficient of > 0.70. The data analysis technique first converted the raw ordinal test scores into interval-scaled data using the Method of Successive Interval (MSI). This step was crucial to satisfy the assumptions of parametric statistics so that hypothesis testing via the t-test could be validly conducted. Subsequently, prerequisite tests, namely normality and homogeneity tests, were performed. Once these assumptions were met, the final analysis utilized an independent sample t-test at a significance level of 0.05 to examine the difference in mean mathematical reasoning ability between the two groups. The research design is presented in Table 1.

Table 1. *Pretest–Posttest Control Group Research Design*

Group	Pre test	Treatment	Post test
Experimental	0_1	X	0_2
Control	0_1	−	0_2

Notes:
0_1 = Pre test prior to treatment
0_2 = Post test following treatment

RESULTS AND DISCUSSION

This research was conducted at SMAN 5 Banda Aceh involving 44 students from two eleventh-grade classes as the sample, namely XI MIPA 4 as the experimental group and XI MIPA 5 as the control group. Learning in the experimental group was carried out by utilizing the GeoGebra application, whereas the control group utilized conventional methods. The research instrument, consisting of a mathematical reasoning essay test, was administered in two stages: a pre-test prior to the treatment and a post-test following the treatment. The mean score results of these abilities are presented in Table 2.

Table 2. Mean Pre test and Post test Scores of Mathematical Reasoning Ability

Group	Number of Students'	Pre test Mean	Post test Mean	Improvement
Experimental	22	8,72	13,13	4,41
Control	22	8,31	11,04	2,73

Based on Table 2, the mean pre-test scores of both classes were relatively balanced, with 8.72 in the experimental group and 8.31 in the control group. This finding ilustrated that the initial ability of students in both groups was relatively equivalent. However, after the treatments were administered, the mean post-test score of the experimental group increased significantly to 13.13, while the control group only reached 11.04. The difference in improvement of 1.68 points indicates that the utilization of GeoGebra contributed more effectively to enhancing students' mathematical reasoning ability compared to conventional instruction.

To ensure that the data met the prerequisites for parametric analysis, normality and homogeneity tests were conducted, as presented in Table 3.

Table 3. Result of Data Normality Testing for Post test Scores

Group	N	Sig.	Criteria	Conclusion
Experimental	22	0,176	$Sig. > 0,05$	Normally
Control	22	0,200	$Sig. > 0,05$	Normally

The results in Table 3 reveal that the significance value for the experimental group was 0.176 and for the control group was 0.200, both of which are greater than 0.05. Consequently, the post-test data from both groups can be declared normally distributed. This condition is crucial as it constitutes a foundational requirement for employing parametric tests for mean difference analysis between groups, which is presented in Table 4.

Table 4. Results of Data Homogeneity Testing for Post test Scores

Levene Statistic	df1	df2	Sig.	Conclusion
0,215	1	42	0,645	Homogeneous

As observed in Table 4, the homogeneity test data show a significance value of 0.645, which is greater than o.05. This implies that the variance of both groups is homogeneous or equal, thereby satisfying the assumption of homogeneity. This condition strengthens the validity of using the t-test to examine the hypothesis regarding the differences in mathematical reasoning ability between the experimental and control classes.

Once the prerequisite tests were satisfied, hypothesis testing was carried out using an independent sample t-test, as presented in Table 5.

Table 5. Post test *T-test Result*

Variable	Calculated t-value	Critical t-table (α = 0.05)	Conclusion
Post test (Experimental vs. Control)	5.13	2.018	Significant

Based on Table 5, the analysis yielded a calculated t-value of 5.13, which substantially exceeds the critical t-table value of 2.018 at a significance level of 0.05. This finding indicates a statistically significant difference between the learning outcomes of students' in the experimental class and those in the control class. Thus, the implementation of GeoGebra is proven to exert a pronounced effect on enhancing students' mathematical reasoning ability.

To clarify the comparison of improvements between pre-test and post-test scores, a summary is displayed in Table 6.

Table 6. Summary of Score Improvements in Mathematical Reasoning Ability

Group	*Pre-test* Mean	*Post-test* Mean	Improvement
Experimental	8,72	13,13	4,41
Control	8,31	11,04	2,73

Table 6 demonstrates that the mean improvement in mathematical reasoning ability within the experimental group reached 4.41 points, which is higher than that of the control group at only 2.73 points. This finding underscores the effectiveness of using GeoGebra to support the development of students' logical, analytical, and systematic thinking skills. Through the dynamic visualization offered by GeoGebra, learners can more easily comprehend the linkages between mathematical concepts compared to learning with conventional methods.

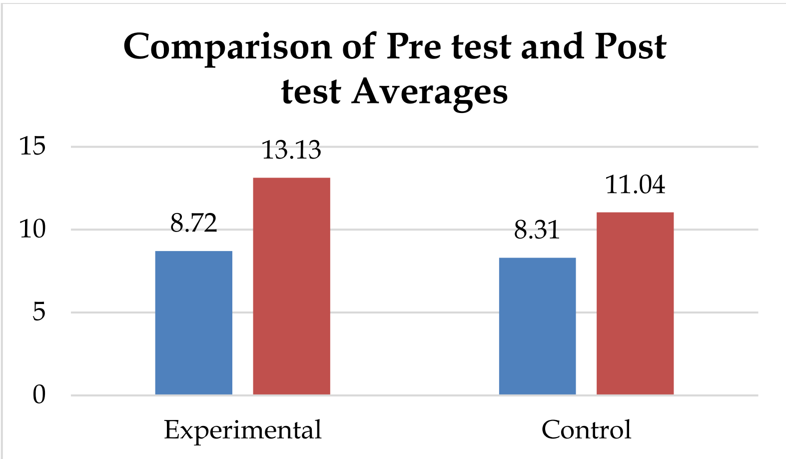

Figure 1. Chart of mathematical reasoning improvement

Based on Figure 1, it can be observed that the diagrams of the mean pre-test scores for both the experimental and control classes are relatively similar, at 8.72 and 8.31, respectively. This condition indicates that the baseline ability of both classes was at an equivalent level. Following the execution of the instructional processes, the mean post-test score of the experimental class increased sharply to 13.13, whereas the control class only reached 11.04.

The mean improvement in the experimental class (4.41) was far higher than that of the control class (2.73). The graphical visualization further solidifies the previous finding that the application of GeoGebra in instruction offers higher effectiveness in enhancing students' mathematical reasoning ability. In other words, the use of technology-based media not only yields a significant impact on learning outcomes but also improves the overall quality of the instructional process, specifically regarding the topic of equations of tangent lines to a circle.

The success of utilizing GeoGebra in enhancing the mathematical reasoning ability of eleventh-grade students at SMAN 5 Banda Aceh is closely linked to the instructional design, which does not merely treat the software as an isolated tool but integrates it directly into an active learning framework. In this study, the implementation of GeoGebra was systematically combined with a guided inquiry model. When students were faced with the phases of problem formulation and hypothesis generation, GeoGebra functioned effectively as a dynamic virtual laboratory that facilitated mental experimentation. This cognitive phenomenon aligns with the core principles of constructivist learning theory, which state that learners actively build new knowledge frameworks based on internalizing empirical and visual experiences rather than receiving information passively.

In the specific context of circle tangent line equations, students' mathematical reasoning is challenged when they must establish conceptual links between the gradient, the center point, and the radius. Conventionally, students tend to memorize abstract algebraic structures without understanding their geometric origins. Through the strategic optimization of the slider feature in GeoGebra, students in the experimental group were able to manipulate variables in real time and observe how geometric orientations shift dynamically. This active exploration stimulated the first indicator of mathematical reasoning, which is formulating conjectures. Students independently deduced that the distance from the center of the circle to the tangent line remains constant, establishing a logical baseline before executing formal mathematical manipulations during analytical proof construction.

One of the primary obstacles to developing geometric reasoning skills among high school students is weak spatial visualization. Analytic geometry demands external representational competence, which is the cognitive ability to transform abstract algebraic notation into accurate graphic representations, and vice versa. Traditional learning environments, like the one experienced by the control group, rely on static drawings on whiteboards that often fail to illustrate precise spatial relations. This limitation is particularly prominent when depicting the perpendicular relationship between a circle's radius and its tangent line at the exact point of tangency.

GeoGebra effectively addresses this visualization barrier through its simultaneous dual-view interface, known as multiple representations. In the software environment, the Algebra View and the Graphics View are interconnected dynamically. Whenever a student alters a geometric object or a point position in the Graphics View, the corresponding algebraic equation in the Algebra View updates instantly. This synchronized change helps students grasp the foundational essence of analytic geometry: that every geometric configuration possesses a unique algebraic identity. This vivid visual connection strengthens students' capacity for constructing proofs, allowing them to verify theoretical assertions visually before translating them into formal symbolic expressions.

Despite the positive statistical outcomes, the implementation of GeoGebra in the classroom encountered certain operational challenges. Reflecting on the instructional process within the experimental class, technical constraints such as varying hardware capabilities of student devices and unstable school internet connections required initial adjustments. Students who were unfamiliar with the digital interface of GeoGebra needed additional orientation time to master basic functions, such as generating circles from specific coordinates or using the perpendicular line tool accurately.

Consequently, the successful cultivation of mathematical reasoning through digital tools depends heavily on the technological pedagogical content knowledge of the educator. The teacher must serve as a focused facilitator who guides students toward the mathematical essence of the visualizations rather than letting them get distracted by the software's interface. Without explicit guidance, technology integration risks becoming a superficial digital exercise devoid of higher-order thinking skills. This reality underscores why structured student worksheets designed for GeoGebra exploration are essential for linking technology with logical reasoning.

In contemporary education, mathematics instruction extends beyond preparing students for academic examinations; it focuses on developing adaptive skills and critical thinking dispositions. The integration of GeoGebra within the experimental group stimulated the development of the 4Cs, which are critical thinking, creativity, communication, and collaboration. When students worked in small groups to solve contextual problems involving tangent lines, they were pushed to think critically to navigate the digital workspace efficiently.

Communicating graphical findings to peers also refined the students' mathematical communication skills. They learned to explain why a line touches or intersects a circle by utilizing the objective visual evidence provided on screen. This collaborative process directly supports the development of critical thinking and independent problem-solving characteristics as outlined in modern educational frameworks. Therefore, integrating dynamic geometry software into secondary education is no longer just an innovative alternative but a necessary approach to creating meaningful mathematics classrooms.

The results of this study demonstrate that the integration of GeoGebra software into the topic of circle tangent line equations yields a significant positive impact. The striking disparity in outcomes between the two classes is influenced by GeoGebra's capacity to transform abstract geometric concepts into dynamic and interactive visualizations. Through object manipulation features, students' in the experimental group could visually and directly explore the relationships between parameter changes in circle equations and the resulting positions of tangent lines. The improvement in the experimental class was particularly evident in the indicators of constructing proofs and drawing conclusions. Dynamic visualization allowed students' to independently verify their conjectures, unlike the control class, which relied solely on routine procedures without the support of robust visual representations.

The enhancement of mathematical reasoning ability in the experimental group occurred because the utilization of GeoGebra provided a more interactive and contextualized learning experience. Through the application, students' could directly manipulate mathematical objects, thereby acquiring a deeper understanding of conceptual connections. In the topic of circle tangent lines, for example, students' could alter the position of a point on the circle and dynamically observe how the corresponding tangent line equation adjusted. This activity helped students' grasp the relationship between geometry and algebra, which was previously abstract. This aligns with the perspective of Nur Hamidah et al. (2020), who asserted that dynamic visualization in GeoGebra is capable of helping students' understand abstract concepts through more tangible and engaging representations.

This improvement was driven not only by the deployment of visual media but also by a shift in students' learning paradigms from passive to active. GeoGebra enables students' to engage in autonomous exploration, test various possibilities, and receive immediate feedback from the generated visual representations. This process fosters autonomous knowledge construction, wherein students' do not merely receive information but also verify and reflect upon their own understanding.

Furthermore, the findings of this study reinforce the view that mathematical reasoning develops when students' are engaged in activities that compel them to think critically and logically. According to Hendriana et al. (2017), reasoning capacity encompasses activities such as formulating conjectures, performing manipulations, constructing arguments, and drawing conclusions. GeoGebra supports all four activities by allowing students' to explore diverse possibilities, test hypotheses, and construct arguments based on the outcomes of their explorations.

Nevertheless, the results of this study are not entirely aligned with some previous researches. A study conducted by Villaroza et al. (2023) demonstrated that while the utilization of GeoGebra increased student activity and interest in learning, it did not produce a significant difference in learning outcomes compared to conventional instruction. This discrepancy indicates that the effectiveness of GeoGebra is highly dependent upon how the media is integrated into the instructional process. If GeoGebra is utilized merely as a demonstration tool without actively involving the students', its impact on mathematical reasoning ability will be suboptimal.

Conversely, the results of this study concur with the findings of Nuralam et al. (2024), which stated that the use of GeoGebra combined with active learning approaches, such as problem-based learning, is capable of significantly enhancing mathematical reasoning ability. This is attributed to the involvement of students' in problem-solving processes that demand critical thinking, analysis of interconceptual relationships, and logical argument construction.

Meanwhile, the results in the control class demonstrated a lower rate of improvement. This was due to the conventional instructional approach, which remains teacher-centered, leaving students' to primarily receive explanations and replicate sample problems. This instructional model tends to cause students' to focus on procedures without understanding the underlying conceptual meaning. Consequently, mathematical reasoning ability—which requires logical argumentation—does not develop optimally. This condition is consistent with the findings of Purcell & Varberg (2003), who noted that without the aid of visual representations, students' tend to experience difficulties in comprehending analytic geometry concepts and rely heavily on formula memorization.

In addition to exerting a positive influence on learning outcomes, the utilization of GeoGebra also enhanced student motivation and engagement during instruction. Students' became more interested because they could learn through exploration rather than being subjected solely to lecture-based methods. The interactive learning environment encouraged students' to actively ask questions, attempt alternative solutions, and engage in peer discussions. This indicates that learning becomes more meaningful as students' do not merely solve problems but construct knowledge autonomously. This finding is aligned with constructivist theory, which emphasizes the vital importance of active student involvement in building understanding.

This study also demonstrates that utilizing technology in mathematics instruction can address 21st-century demands, which emphasize the vital importance of mastering higher-order thinking skills (HOTS). Through GeoGebra, students' are trained to think critically, analyze interconceptual relationships, and structure arguments systematically.

These skills are critical for confronting complex problems in real-world contexts. The findings of this study do not merely treat GeoGebra as a visual tool but as a vehicle to develop mathematical reasoning ability based on specific indicators. This study does not solely measure general learning improvements but analyzes how GeoGebra supports students' cognitive processes in formulating conjectures, executing mathematical manipulations, and drawing logical conclusions. Additionally, this study focuses on the topic of equations of tangent lines to a circle, which possesses tight interconnections between geometric and algebraic concepts, thereby offering a novel contribution to the domain of technology-based mathematics instruction.

Nonetheless, this study possesses several limitations. First, the sample size used was relatively small as it involved only two classes; hence, the research findings cannot be broadly generalized. Second, the scope of the examined material was limited to the equations of tangent lines to a circle, whereas mathematical reasoning ability is equally vital to investigate across other mathematical topics. Third, constraints regarding technological infrastructure at the school posed a challenge to the optimal implementation of GeoGebra, given that not all students' possessed access to adequate devices.

Based on these limitations, future research should be sustained and is recommended to be conducted with a broader scope, both in terms of sample size, educational levels, and variations in mathematical learning topics. Furthermore, subsequent studies could examine the integration of GeoGebra with specific instructional models to obtain a more comprehensive understanding regarding its effectiveness in enhancing students' mathematical reasoning ability.

CONCLUSION AND SUGGESTIONS

This study concludes that the utilization of GeoGebra software is significantly more effective in enhancing high school students' mathematical reasoning ability in the topic of equations of tangent lines to a circle compared to conventional methods. This is substantiated by the calculated t-value of 5.13 > critical t-table value of 2.018, alongside a mean score improvement in the experimental class (4.41) that far surpassed that of the control class (2.73). GeoGebra functions as a cognitive bridge that transforms abstract concepts into dynamic visualizations, thereby reinforcing students' capacities to formulate conjectures, perform mathematical manipulations, and draw logical conclusions. As a suggestion, mathematics teachers are encouraged to integrate GeoGebra with active learning models to optimize students' digital literacy and mathematical reasoning. For future researchers, it is recommended to expand the sample scope and explore the effectiveness of GeoGebra across other mathematical topics that share similar characteristics of geometric abstraction.

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