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GeoGebra-Assisted Problem-Based Learning for Mathematical Reflective Thinking

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ABSTRACT
Mathematical reflective thinking is an essential component of higher-order thinking that supports conceptual understanding and metacognitive development. Although previous studies have examined Problem-Based Learning (PBL) and GeoGebra separately, limited research has investigated their integrated effect on students' mathematical reflective thinking, indicating a significant research gap. This study aims to investigate the effectiveness of GeoGebra-assisted Problem-Based Learning in improving mathematical reflective thinking among ninth-grade students. The novelty lies in integrating interactive GeoGebra visualization with constructivist PBL and evaluating its effectiveness through pre-test, post-test, N-Gain, and multiple regression analyses within a unified experimental framework. A quantitative quasi-experimental design involving 32 ninth-grade students was employed. The results demonstrated significant improvement in mathematical reflective thinking, with the mean score increasing from 36.53 to 81.03, an average N-Gain of 0.703, and a significant t-test result ($p < 0.001$). Regression analysis indicated that students' perception variables did not significantly predict reflective thinking performance, suggesting a greater contribution from instructional design. Theoretically, this study contributes to technology-enhanced constructivist learning literature. Practically, it provides evidence that GeoGebra-assisted PBL can support mathematics teachers in fostering reflective thinking. Overall, the findings highlight the educational significance of integrating interactive technology and student-centered learning to develop mathematical reflective thinking.

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INTRODUCTION

Mathematical reflective thinking skills are one aspect of higher-order thinking that plays an important role in shaping students' conceptual understanding (Firmansyah et al., 2025). This ability includes an individual's awareness in reviewing their thinking process, analyzing solution strategies, and evaluating mistakes or successes in problem solving. In the context of 21st-century mathematics learning, reflective thinking is an important foundation for the development of metacognitive abilities, critical thinking, and complex problem solving (Kusnandar & Mirza, 2025). Students with good reflective abilities tend to be able to relate mathematical concepts to real-life situations and correct conceptual misunderstandings independently (Nadia, 2025). Therefore, improving mathematical reflective thinking skills is one of the indicators of the success of meaningful mathematics learning processes.

One learning strategy that has great potential in developing reflective thinking skills is Problem Based Learning (Supit & Winardi, 2024). This strategy is oriented towards solving authentic contextual problems, requiring students to think critically, identify relevant concepts, and evaluate the solutions obtained. In the PBL process, students do not only act as recipients of information, but also as discoverers of knowledge through direct learning experiences (Ermawasari et al., 2024). This allows students to reflect on their understanding during the investigation process (Wiseza & Ibermarza, 2025). Theoretically, PBL provides space for students to develop strong metacognitive awareness, as they need to monitor their own thinking steps. Therefore, the application of PBL is considered capable of creating a learning environment conducive to the development of mathematical reflective thinking skills (La'ia & Harefa, 2021).

In addition to learning strategies, another factor that has the potential to improve reflective thinking skills is the use of interactive technology media such as GeoGebra (Putra & Hakim, 2023). GeoGebra is a technology-based learning medium designed to visualize mathematical concepts dynamically and exploratively (Delima et al., 2023). Through GeoGebra, students can directly manipulate geometric and algebraic objects, allowing them to test, prove, and evaluate the relationships between concepts visually (Maryono 2020). This exploration process provides opportunities for students to reflect on their understanding independently, both through observation and logical (Bronkhorst, 2020). Thus, GeoGebra not only functions as a teaching aid but also as a means of stimulating reflective activities in the mathematics learning process (Wassie & Zergaw, 2019).

Previous research provides substantial evidence that Problem-Based Learning (PBL) can support students' higher-order cognitive development. PBL places students in authentic problem situations that require them to identify relevant information, develop solution strategies, evaluate alternatives, and justify their conclusions (Firdaus et al., 2021). These characteristics make PBL theoretically relevant to reflective thinking because students are required not only to solve problems but also to monitor and evaluate their reasoning throughout the problem-solving process (Mostoli et al. 2021). Empirical studies have reported positive effects of PBL on mathematical literacy, critical thinking, problem solving, and other higher-order abilities (Astuti, 2020). However, the existing literature has predominantly emphasized learning outcomes, mathematical literacy, critical thinking, and problem-solving performance, while the specific process through which PBL develops students' mathematical reflective thinking remains less explicitly examined (Sadauskas, 2023). Thus, PBL provides a strong pedagogical foundation for reflective learning, but its specific contribution to mathematical reflective thinking requires further investigation (Noer et al., 2024).

A parallel body of research demonstrates the potential of GeoGebra as an interactive technology for mathematics learning. GeoGebra enables students to dynamically visualize, manipulate, and explore mathematical objects, thereby supporting conceptual understanding and mathematical reasoning (Delima et al. 2023). Previous studies have reported that GeoGebra can facilitate students' understanding of mathematical concepts, improve mathematical thinking abilities, and support digital literacy (Rahmah & Yahfizham 2024). These findings indicate that dynamic visualization can provide students with opportunities to examine mathematical relationships more directly than static representations (Suciati et al. 2022). Nevertheless, most studies on GeoGebra have focused on conceptual understanding, learning achievement, critical thinking, creative thinking, or digital literacy, rather than explicitly examining how interactive visualization contributes to students' mathematical reflective thinking . Therefore, although GeoGebra offers technological affordances that are theoretically relevant to reflection, its specific role in developing mathematical reflective thinking remains insufficiently established.

More recent research has begun to integrate PBL with technology-supported mathematics learning, including GeoGebra. Sopanda et al. (2022), for example, reported positive learning gains from the integration of GeoGebra and PBL, while Anggana & Putra (2022) demonstrated positive outcomes of problem-based learning in relation to students' digital literacy. These findings suggest that PBL and GeoGebra may provide complementary instructional affordances: PBL creates cognitive demands through authentic problem solving, whereas GeoGebra facilitates dynamic exploration and visualization. However, the existing studies have not sufficiently established whether this combined instructional design specifically enhances mathematical reflective thinking. Moreover, the effectiveness of technology-supported PBL may depend on the design of learning activities and students' ability to engage with the technology (Marcheilla et al., 2025). Consequently, the combined effect of PBL and GeoGebra on mathematical reflective thinking remains an underexplored research area. These findings are also consistent with the broader perspective presented in recent studies published in the Moestopo International Review on Social, Humanities, and Sciences (MIRSHuS), which emphasize that well-designed technology-supported learning environments contribute positively to learning effectiveness and students' cognitive development (Kusparmanto & Yuditha, 2023).

Taken together, the literature suggests three important points. First, PBL has been widely recognized as an approach that promotes higher-order thinking through authentic problem solving, exploration, and evaluation, but its specific relationship with mathematical reflective thinking has received comparatively limited attention. Second, GeoGebra has demonstrated substantial potential for dynamic visualization, conceptual exploration, and mathematical reasoning, yet its contribution to reflective thinking has rarely been examined explicitly. Third, although emerging studies have combined PBL with GeoGebra, there remains limited empirical evidence concerning whether and how their integration supports mathematical reflective thinking. This constitutes the central research gap addressed in the present study. Accordingly, this study investigates the effectiveness of GeoGebra-assisted Problem-Based Learning in improving students' mathematical reflective thinking skills.

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Based on the synthesis of the existing literature, the main research gap is not the lack of evidence supporting PBL or GeoGebra individually, but the limited empirical understanding of their integrated contribution to mathematical reflective thinking. PBL provides students with authentic problems that require exploration, evaluation, and reflection, while GeoGebra provides dynamic visualization and interactive feedback that can facilitate conceptual verification and reflective evaluation. The integration of these affordances may therefore create a learning environment that more systematically supports mathematical reflective thinking. However, this proposition has not been sufficiently examined through an integrated experimental framework. Therefore, this study aims to investigate the effectiveness of GeoGebra-assisted Problem-Based Learning in improving ninth-grade students' mathematical reflective thinking skills. The study is expected to contribute to the theoretical understanding of how technology-supported problem-based learning can facilitate reflective thinking and to provide empirical evidence for the design of interactive, contextual, and student-centered mathematics instruction.

METHOD

The type of research used is a quantitative method with a quasi-experimental design. The purpose of this study is to measure the effect of certain treatments on learning outcomes or specific abilities in a group of subjects that already exist naturally. This study used the independent variables of GeoGebra learning media and Problem Based Learning strategies and the dependent variable of students' mathematical reflective thinking abilities.

The participants were selected using a purposive sampling technique because the selected class had comparable academic characteristics, followed the same mathematics curriculum, and was accessible for implementing the instructional intervention. A total of 32 ninth-grade students participated in this study. This sampling approach was considered appropriate for the quasi-experimental design, where intact classroom groups were maintained during the intervention. The stages of this study are shown in Figure 1.

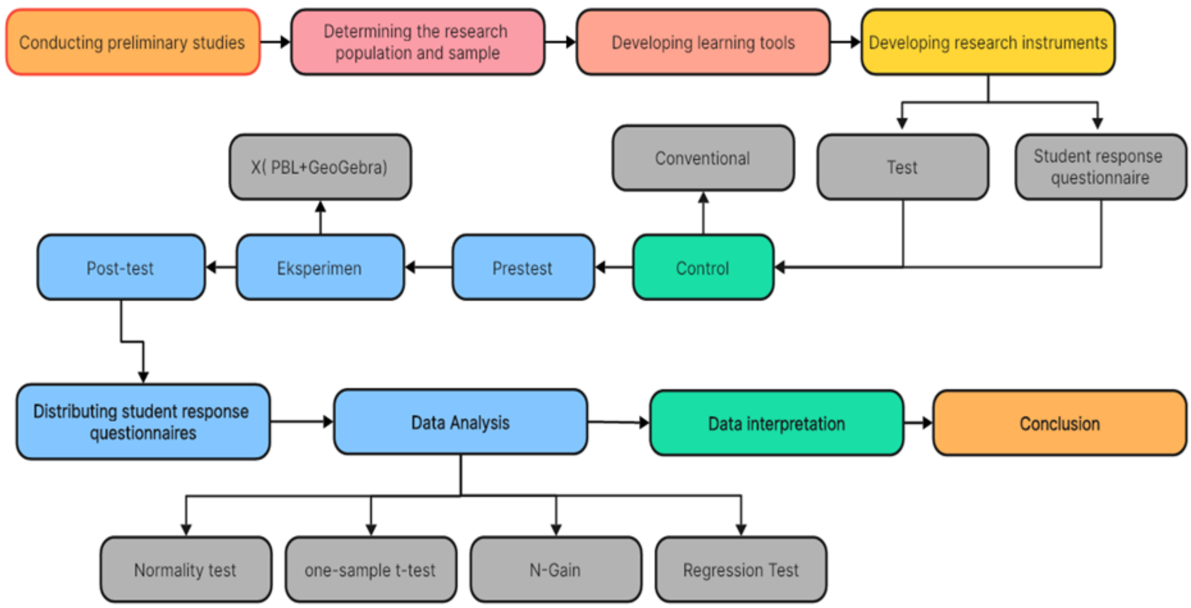

Figure 1. Research Flowchart

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Figure 1 shows the experimental research flow regarding the effect of using GeoGebra media and Problem Based Learning (PBL) strategies on students' mathematical reflective thinking skills. The research began with a preliminary study to identify problems and field needs, then continued with determining the research population and sample so that the research subjects were in line with the objectives to be achieved. After that, the researcher developed learning tools and research instruments, which included tests of reflective thinking skills and student response questionnaires. The next stage was to administer a pretest to the experimental and control groups to determine the students' initial abilities. The experimental group was given treatment in the form of PBL learning assisted by GeoGebra, while the control group used conventional learning. After the treatment was completed, the researcher distributed student response questionnaires to determine their responses to the use of media and learning methods. The collected data were then analyzed using several statistical tests, such as normality tests, independent t-tests, N-Gain tests, and regression tests to determine the differences and effects of the treatment. The final stage involved data interpretation and conclusion drawing to answer the research questions and confirm the research hypothesis.

Mathematical reflective thinking skills encompass various cognitive aspects that demonstrate the depth of students' understanding of mathematical concepts and processes. The indicators of mathematical reflective thinking include: (1) identifying mathematical concepts and/or formulas involved in complex mathematical problems, (2) evaluating/checking the validity of an argument based on the concepts/properties used, (3) drawing analogies from two similar cases, (4) generalizing with reasons (Id et al., 2021), (5) distinguishing between relevant and irrelevant data, (6) interacting with the problem-solving tasks given (Yenni & Sukmawati, 2019), and (7) interpreting a case based on the mathematical concepts involved (Kholid et al., 2020).

The data collection techniques used in this study included tests and questionnaires. Tests were used to determine the results of pre-tests and post-tests on mathematical reflective thinking

The questionnaire technique was used to determine the level of curiosity and response of the students. The research instruments included: (1) Grade 9 junior high school two-variable linear equation system material, (2) 5 pre-test and post-test questions, and (3) student response questionnaires. The stages carried out in this study began with the planning stage and ended with the conclusion. The planning stage involved compiling the research instruments, followed by validation by experts and practitioners. The implementation stage involved collecting data through tests and questionnaires administered to students. The assessment stage involved interpreting the analysis results to answer the research questions and test the hypotheses. The assessment stage included a final data analysis. The final data analysis was based on the pre-test and post-test scores of mathematical reflective thinking, which were analyzed using normality testing, independent t-testing, normalized gain testing (N-Gain), and multiple linear regression testing. The normality of the pre-test and post-test scores was assessed using the Kolmogorov–Smirnov test at a significance level of $\alpha = 0.05$. The test statistic (D) and p-value were examined to determine whether the data deviated significantly from a normal distribution. Quantitative data analysis involved five steps, namely data collection, data examination, data presentation, prerequisite testing and hypothesis testing, and drawing conclusions.

Prior to data collection, all research instruments were evaluated through expert judgment involving mathematics education specialists to establish content validity. Suggestions provided by the validators were incorporated before implementation. Furthermore, the questionnaire instrument was subjected to reliability testing using Cronbach's Alpha, while the test items were reviewed for clarity, relevance, and alignment with the indicators of mathematical reflective thinking. The obtained validity and reliability results indicated that the instruments were appropriate for research purposes. Ethical considerations were observed throughout the research process. Permission to conduct the study was obtained from the school administration prior to data collection. Students participated voluntarily after receiving information regarding the research objectives, and all collected data were treated confidentially and used solely for academic research purposes.

RESULT AND DISCUSSION

In this section, the author presents a series of research findings that aim to evaluate the effectiveness of learning treatments in improving student competence. The analysis was conducted comprehensively through the presentation of quantitative data, which included a comparison of pre-test and post-test scores, a normality test to satisfy the next test step, a comparison using a one-sample t-test, a measurement of effectiveness through the N-Gain calculation, and a multiple linear regression test to determine the effect of independent variables on dependent variables. These three forms of analysis provide complementary information about changes in student abilities before and after the intervention, thereby strengthening the validity of the interpretation. The presentation of data in graphs and tables is intended to clarify the pattern of improvement in learning outcomes and identify the extent to which the learning model affects student achievement. Thus, this section becomes an important basis for assessing the success of the treatment given and understanding its implications for the learning process more broadly. The author presents the pre-test and post-test scores in Figure 2.

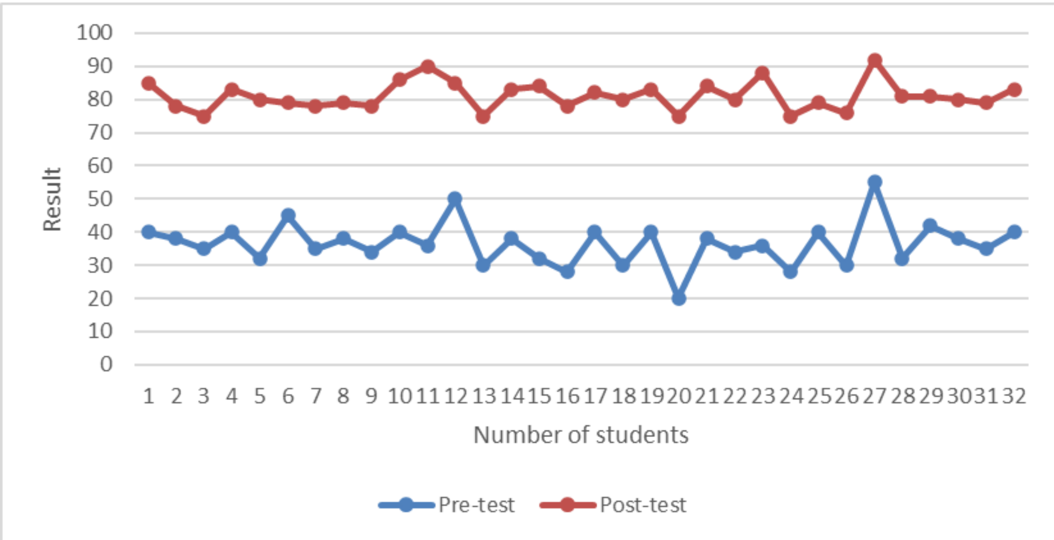

Figure 2. Pre-test and post-test scores

Figure 2 shows a comparison of pre-test and post-test scores for mathematical reflective thinking skills among 32 students after participating in GeoGebra-based learning

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and Problem Based Learning strategies. In general, it appears that pre-test scores were relatively low and varied, indicating that the students' initial abilities were not yet optimal. In contrast, the post-test scores appear to have increased consistently across all students and are in a higher range with more stable variations. The striking distance between the two curves reflects a significant increase in ability after the treatment was given. This pattern indicates that the integration of GeoGebra as a visualization tool and the application of PBL, which emphasizes the process of exploration and reflection, have contributed positively to the overall development of students' mathematical reflective thinking skills. To provide a more comprehensive understanding of the pattern of score changes in both classes, descriptive statistical data from the pretest and post-test in the experimental class are presented in Table 1.

Table 1. Descriptive Statistics

Problem Based Learning	Test	
	Pre-test	Post-test
N	32	32
Mean	36,53	81,03
Standard Deviation	6,594	4,327
Varians	43,483	18,723
Minimum	20	75
Maximum	55	92
Range	35	17

Table 1 shows a very clear increase in students' ma thematical reflective thinking skills after participating in GeoGebra-assisted Problem Based Learning. The pre-test average score of 36.53 with a standard deviation of 6.594 indicates that the students' initial abilities were still in the low category and had a fairly varied score distribution. After the treatment was given, the post-test average increased significantly to 81.03 with a smaller standard deviation of 4.327, indicating that in addition to an increase in scores, the distribution of students' scores also became more homogeneous. The variance decreased from 43.483 in the pre-test to 18.723 in the post-test, reinforcing the finding that the differences in ability between students became smaller after the learning process took place. In addition, the minimum score increased from 20 to 75, while the maximum score rose from 55 to 92, indicating that improvements occurred across the entire range of student abilities, both in the lowest and highest categories. The narrowing range of scores from 35 on the pre-test to 17 on the post-test also illustrates that student learning outcomes became more uniform. Overall, the data provides empirical evidence that the application of GeoGebra-assisted Problem Based Learning is effective in improving and stabilizing students' mathematical reflective thinking skills. To ensure that the data meets the basic assumptions in inferential statistical testing, a normality test was conducted on both variables. The results of the normality test are presented in Table 2.

Table 2. Data Normality Test for Pretest and Posttest

Class	Data	Statistics	Df	Sig.	Description
Control	Pretest	0,174	32	0,014	Not normally
Experiment	Posttest	0,129	32	0,189	Normal

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Table 2 presents the results of the Kolmogorov–Smirnov normality test for the pre-test and post-test scores of mathematical reflective thinking in the experimental class. The pre-test yielded a significance value of 0.014 ($p < 0.05$), indicating that the null hypothesis of normality was rejected. Therefore, the pre-test scores did not meet the normality assumption at the $\alpha = 0.05$ significance level. In contrast, the post-test yielded a significance value of 0.189 ($p > 0.05$), indicating that there was insufficient evidence to reject the null hypothesis of normality. Thus, the post-test scores were considered normally distributed. These results indicate that the normality assumption was not fully satisfied for both measurement occasions, and therefore, the subsequent statistical analyses should be interpreted with consideration of the non-normal distribution of the pre-test scores. The results of the t-test (one sample test) are presented in Table 3.

Table 3. Result of the t-test (one sample t-test)

One sample t Test	Post-test
N	32
Mean diff	36,53
Siginificance (Two-sided p)	<0,001
Df	32
t	8,013
Lower	4,52
Upper	7,61

Table 3 shows the results of the one-sample t-test that the students' post-test scores have a significant difference compared to the reference value (test value) of 75. A t-value of 8.013 with a degree of freedom (df) of 31 resulted in a significance value for both one-tailed and two-tailed tests of $p < 0.001$. Because the p-value is much smaller than the significance threshold $\alpha = 0.05$, it can be concluded that the post-test mean is statistically above the reference value. The mean difference of 6.063 with a 95% confidence interval between 4.52 and 7.61 indicates that the improvement in students' abilities after the treatment is consistent and not accidental. These findings indicate that Problem-Based Learning supported by GeoGebra media has a significant positive effect on improving students' mathematical reflective thinking skills. To obtain a more in-depth picture of the level of improvement, an N-Gain calculation was then performed to assess the extent of improvement in students' abilities from the pretest to the posttest, as presented in Table 4.

Table 4. N gain test results

Result	N	Minimum	Maximum	Mean	Std. Deviation
N-Gain score	32	0,62	0,84	0,7030	0,05559
N-Gain persen	32	61,54	84,38	70,2969	5,55936

Table 4 shows the results of the N-Gain analysis, which indicate that the improvement in students' mathematical reflective thinking skills after participating in Problem-Based Learning supported by GeoGebra is in the effective category. The N-Gain scores ranged from 0.62 to 0.84 with an average of 0.7030 and a standard deviation of 0.05559, indicating that most students experienced an increase in ability in the moderate to high category with relatively small inter-individual variation. Furthermore, N-Gain in percentage form ranged from 61.54% to 84.38% with an average of 70.2969% and a standard deviation of 5.55936. These results confirm that the learning applied not only produced consistent improvements but also had an even impact on all students. Thus, the N-Gain data provides empirical evidence that the integration of GeoGebra in the Problem-Based Learning model can significantly and effectively improve mathematical reflective thinking skills. Furthermore, multiple linear regression tests were conducted to determine the effect of independent variables on dependent variables. To determine this, several things are considered in multiple linear regression testing, namely the model summary to show the strength and quality of the regression model as a whole, the ANOVA table to measure whether the regression model has a simultaneous significant effect, and the coefficients table to show the partial effect of each variable. Before conducting multiple linear regression analysis, several classical assumption tests were performed to ensure the appropriateness of the regression model. These included normality, linearity, multicollinearity, and homoscedasticity tests. The results indicated that the data fulfilled the required assumptions for regression analysis; therefore, the regression model was considered appropriate for examining the relationship between the independent and dependent variables. The model summary is shown in Table 5.

Table 5. Model Summary of the Multiple Linear Regression Analysis

Model summary				
Model	R	R square (R^2)	Adjusted R^2	Std. Error of the estimate
1	0,282	0,080	0,016	4,425

Table 5 explains that an R value of 0.282 indicates that the simultaneous relationship between the independent variables and the dependent variable is in the weak category. Furthermore, the R Square value of 0.080 indicates that the model is only able to explain 8% of the variation in the dependent variable, while the remaining 92% is influenced by factors outside this research model. When adjusting for the number of predictor variables, the Adjusted R Square value drops to 0.016, which means that the model's ability to explain the actual data variation is very low. On the other hand, the Standard Error of the Estimate value of 4.425 indicates a relatively high level of prediction error, so that the accuracy of the model in predicting the value of the dependent variable is not yet optimal. Therefore, this table illustrates that the regression model used has limited explanatory power and a fairly high level of prediction error. Next, to measure whether the regression model as a whole is significant, namely whether X1 and X2 simultaneously affect Y, this will be shown in Table 6.

Table 6. Results of the ANOVA Test

ANOVA						
Model		Sum of Square	df	Mean Square	F	Sig.
1	Regression	45,233	2	22,617	1,255	,300[b]
	Residual	522,642	29	18,022		
	Total	567,875	31			

Table 6 explains that the Sum of Squares Regression value is 45.233 with degrees of freedom (df) = 2, resulting in a Mean Square Regression of 22.617. This value is compared with the Mean Square Residual of 18.022 (from the Sum of Squares Residual of 522.642 with df = 29) to produce a calculated F value of 1.255. This F value is accompanied by a significance value (Sig.) of 0.300, which is greater than the significance threshold of 0.05. The meaning of these numbers shows that the variation explained by variables X1 and X2 is only a small portion compared to the residual variation not explained by the model, so the model does not show high predictive power. The interpretation is that simultaneously, X1 and X2 do not have a significant effect on Y, so the hypothesis stating that there is a significant effect together cannot be accepted. To clarify the results and assess the effect of each independent variable on the dependent variable partially, it will be shown in Table 7.

Table 7. Results of the Coefficients test

Coefficients[a]						
		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	60,050	14,388		4,174	<,001
	X1	,263	,178	,263	1,475	,151
	X2	,067	,126	,096	,537	,595

Table 7 explains that the constant value is 60.050 with t = 4.174 and significance < 0.001, which means that when X1 and X2 are zero, the baseline value of Y is 60.050. The regression coefficient for X1 is 0.263 with a standard error of 0.178, a t-value of 1.475, and a significance value of 0.151, indicating that X1 has a positive partial effect on Y (as indicated by the positive coefficient), but this effect is not significant because the p-value is greater than 0.05. Meanwhile, the regression coefficient for X2 is 0.067 with a standard error of 0.126, a t-value of 0.537, and a significance value of 0.595, which means that X2 also has a very small and insignificant positive effect on Y. The standardized Beta values indicate the relative strength of each variable's influence, with Beta X1 at 0.263 having a greater influence than X2 Beta X2 at 0.096, although both remain insignificant. The interpretation is that neither X1 nor X2 has a significant partial effect on Y, so the partial hypothesis stating that each variable has an effect on Y cannot be accepted. Thus, the regression model shows that the variation in Y cannot be meaningfully explained by X1 and X2 individually.

The findings of this study indicate that the implementation of GeoGebra-assisted Problem Based Learning significantly improves students' mathematical reflective thinking skills. The average score increased from 36.53 to 81.03, accompanied by a decrease in variance and standard deviation, indicating that in addition to an overall improvement in skills, student learning outcomes also became more stable and homogeneous. This empirical evidence is in line with the view that the application of the PBL model is effective in improving students' cognitive learning outcomes in the subject of work and energi (Gusman et al., 2023). Setiawi & Suparta, (2021) also emphasized that students' ability to solve problems and think critically using the PBL model with the help of Geogebra was better than those who followed conventional learning F = 1917.095 and Sig. = 0.000; ρ <0.05. Another study also found that Geogebra has a positive, effective, and superior impact on improving students' mathematical abilities in the mathematics learning process (Nzaramyimana et al., 2021). Thus, the combination of PBL and GeoGebra has been proven to significantly and consistently improve students' mathematical abilities. From the perspective of constructivist learning theory, the improvement in mathematical reflective thinking can be understood through the sequence of authentic problem solving, exploration, evaluation, and reflection facilitated by Problem-Based Learning (PBL). In PBL, students are confronted with contextual and challenging mathematical problems that require them to identify relevant information, formulate strategies, and explore possible solutions. This process encourages students to move beyond simply obtaining an answer toward examining whether their strategies and conclusions are mathematically appropriate. Thus, the PBL mechanism can be represented as: authentic problem → exploration → evaluation → reflection. Through this sequence, students are encouraged to monitor their reasoning, identify errors, compare alternative strategies, and justify their conclusions, which are core processes of mathematical reflective thinking.

GeoGebra complements this process by providing dynamic visualization and interactive manipulation of mathematical objects. Students can modify representations, observe changes in mathematical relationships, receive immediate visual feedback, and verify whether their conjectures are consistent with the underlying mathematical concepts. The mechanism can therefore be understood as: dynamic visualization → manipulation → immediate feedback → conceptual verification → reflection. Rather than functioning merely as a presentation tool, GeoGebra provides an exploratory environment in which students can test and revise their mathematical reasoning. This interactive process supports reflection because students can compare their initial assumptions with the observed representations and subsequently evaluate or revise their understanding.

The theoretical contribution of the present study lies in the interaction between these two mechanisms. PBL provides the cognitive demand through authentic problem solving and requires students to evaluate their reasoning, whereas GeoGebra provides dynamic representations and immediate feedback that make mathematical relationships more observable and testable. Consequently, the integration of PBL and GeoGebra creates a complementary learning process in which students encounter a problem, explore possible solutions, visualize and manipulate mathematical relationships, evaluate the consistency of their reasoning, and reflect on the resulting solution. This interaction provides a plausible explanation for why the GeoGebra-assisted PBL intervention was associated with substantial improvement in students' mathematical reflective thinking.

The N-Gain analysis shows an average increase of 0.7030 or 70.30%, which is in the moderate to high category, indicating that learning has a strong and consistent impact on students. The low standard deviation shows that most students experienced improvements at relatively the same level. These findings are in line with the results of research by Rohmah et al. (2022), which states that the PBL learning model on students' critical thinking skills has a high Effect Size criterion, and when the average of the PBL learning model is sought, the average Effect Size value is 1.47 (high effect). Furthermore, the t-test results showing a p-value < 0.001 confirm that the post-test improvement did not occur due to chance but was a the post-test mean was significantly higher than the reference value of 75, in line with the views of Hafizah et al. (2024), who emphasize that the application of the PBL model with metacognitive reflection is effective in improving students' critical thinking skills and learning outcomes. These findings are also consistent with the opinion of Fajriati & Putra, (2023), who stated that video learning media meets the criteria of validity, practicality, and effectiveness, making it suitable for use in learning. With the consistency between the descriptive results, t-test, and N-Gain, it can be concluded that the learning strategy applied was successful in significantly improving reflective thinking skills.

Although there was a significant increase in student ability, the regression results showed that variables X1 and X2 did not have a significant effect, either simultaneously or partially, on Y, as indicated by an R Square value of only 0.080. The low explanatory power of this model indicates that most of the variability in reflective thinking ability is influenced by factors other than the questionnaire variables used. This condition is in line with the findings of Araujo et al. (2025), which explain that perception-based instruments often have low predictive power for actual cognitive performance. In addition, Hafeez (2021) study shows that practical and newly developed learning approaches must be applied to student learning outcomes in critical thinking and high-level communication skills. In line with this, research by Bhat et al., (2022) shows that instructional design and work context factors have a significant contribution to learning transfer and training completion. Therefore, the results of this study confirm that the improvement in students' reflective abilities mainly comes from the quality of the PBL-GeoGebra-based learning process, not from the perceptual variables measured through questionnaires.

The findings show that the application of GeoGebra-assisted Problem Based Learning resulted in a significant increase in mathematical reflective thinking skills, as reflected in the increase in the average score from 36.53 to 81.03, accompanied by a decrease in variance and standard deviation, indicating higher learning outcome stability. Inferential analysis through t-tests and an N-Gain of 0.7030 or 70.30% confirms that this improvement is a direct effect of the learning treatment. These results show that the combination of active learning strategies and interactive visual media is effective in developing students' higher-order cognitive abilities. However, the regression results with an R^2 of 0.080 indicate that the questionnaire variables do not have a strong predictive power on students' reflective achievements, so that the improvement is more accurately attributed to the quality of the learning process itself. Structured instructional design, exploratory activities, and dynamic visual support are the main factors that drive the improvement in reflective thinking skills. The integration of appropriate strategies and media enables a more effective and equitable learning experience for all students. This confirms that the quality of learning is highly dependent on how the process is designed to optimize the cognitive potential of students. Thus, the application of PBL with the support of GeoGebra has been proven to significantly and consistently improve reflective thinking skills.

CONCLUSION

The results of the study show that the application of GeoGebra-assisted Problem Based Learning has proven effective in improving students' mathematical reflective thinking skills. This is reflected in the increase in average scores, decrease in variance and standard deviation, and N-Gain scores that show a consistent and significant improvement in most students. The t-test analysis confirms that these changes are a direct effect of the quality of the learning process, which integrates exploration, reflection, and the use of interactive visual media. However, regression results show that student perception variables through questionnaires do not have a significant effect on reflective thinking skills, so that improvement is more influenced by the quality of learning design and implementation than by individual psychological factors. Therefor, the effectiveness of GeoGebra-assisted PBL lies in the learning process itself, which is able to consistently encourage high-level cognitive development.

Future studies are recommended to involve larger and more diverse samples from different educational levels and regions to improve the generalizability of the findings. In addition, future research may incorporate other variables, such as learning motivation, self-efficacy, digital literacy, or metacognitive awareness, to better explain variations in students' mathematical reflective thinking skills. Further investigations using longitudinal or mixed-method approaches are also recommended to provide a more comprehensive understanding of how GeoGebra-assisted Problem-Based Learning influences students' reflective thinking development over time.

Practically, the findings suggest that mathematics teachers may adopt GeoGebra-assisted Problem-Based Learning as an instructional strategy to foster students' mathematical reflective thinking through interactive exploration, visualization, and collaborative problem solving. The integration of digital technology with student-centered pedagogy also provides valuable guidance for curriculum developers and schools seeking to enhance higher-order thinking skills in mathematics classrooms. This study has several limitations. First, the sample consisted of only 32 students from a single school, which limits the generalizability of the findings. Second, the research focused on short-term learning outcomes without examining the long-term retention of mathematical reflective thinking skills. Third, the regression model included only questionnaire variables, leaving other influential factors unexplored. Future research is recommended to involve larger and more diverse samples across different educational contexts, incorporate additional cognitive and affective variables such as self-efficacy, metacognitive awareness, and digital literacy, and employ longitudinal or mixed-method approaches to provide a more comprehensive understanding of how GeoGebra-assisted Problem-Based Learning influences students' mathematical reflective thinking over time.

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