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GeoGebra-Assisted Problem-Based Learning: Enhancing Students' Mathematical Problem-Solving Ability

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ABSTRACT

Mathematical problem-solving ability is a crucial competence for students, yet evidence suggests it remains generally low. To address this issue, this study implements GeoGebra-assisted Problem-Based Learning (PBL-GeoG) to enhance students' mathematical problem-solving skills. Using a quantitative approach with a quasi-experimental non-equivalent control group design, the research involved eighth-grade students at a public junior high school in West Bandung Regency during the 2024-2025 academic year. Two classes were selected as samples: class VIII-E as the experimental group receiving the PBL-Geog model and class VIII-C as the control group receiving direct instruction (DI). Data were collected through a validated mathematical problem-solving test and analyzed using IBM SPSS Statistics 23. The results of the independent samples t-test showed a significance value of 0.000 (ρ < 0.05). The findings conclude that the improvement in mathematical problem-solving skills among students taught with the GeoGebra-assisted Problem-Based Learning model is significantly higher than that of students taught through direct instruction.

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1. INTRODUCTION

The NCTM (2000) established five primary standards for mathematics learning that students must master, one of which is mathematical problem-solving ability. This ability is a crucial competency that students must possess when studying mathematics [1], [2]. Mathematical problem-solving refers to an individual's capacity to apply their understanding, knowledge, and skills to find solutions to non-routine problems that lack an immediate solution procedure, thus requiring systematic steps to achieve the desired results [3].

Problem-solving ability is a primary concern in mathematics learning across various countries, functioning not only as a mathematics learning objective but also as an essential ability for making the best decisions in life [4], [5]. This is in line with [6]-[9] who argue, “mathematical problem-solving ability is a matter of concern and needs to be improved so that students' ability to solve mathematical problems related to daily life can develop.” This reveals that mathematical problem-solving ability is important for every student and must be improved so that students are active during the learning process and are able to solve both mathematical and daily life problems with critical, logical, and systematic thinking.

However, the facts in the field show that students' mathematical problem-solving abilities tend to be low and require special attention. Research conducted by [10] at a junior high school in Cikampek reveals that students' mathematical problem-solving abilities remain predominantly low. The study found that a vast majority of students, specifically 84.2%, fall into the low-ability category, whereas only 10.5% demonstrate moderate proficiency, and a mere 5.3% reach a high level of achievement. In addition, the findings of [11] at a junior high school in West Bandung Regency show that “Students' mathematical problem-solving abilities in the high criteria amounted to 8 people with a percentage of 10%, in the moderate category amounted to 42 people with a percentage of 52.5%, and in the low category amounted to 30 people with a percentage of 37.5%.” Furthermore, based on the results of an interview with a mathematics teacher at a public junior high school in West Bandung Regency, it was stated, “the average PSAS mathematics result for eighth-grade students is 51.48, which is still far below the school's minimum mastery criteria (KKM) of 75. This indicates that the mathematical problem-solving ability of students at SMP Parongpong still requires special attention.”

The factors causing the low mathematical problem-solving ability of students are that students often answer directly without paying attention to the completeness of the required elements and make mistakes when using formulas, resulting in answers that do not align with the initial problem; furthermore, although some students can obtain the correct results, they are unable to draw the correct conclusions from those results [11]. In addition, “the cause of the low mathematical problem-solving ability of students is that during the learning process, students' habits do not involve playing a sufficiently active role, so that when learning takes place, there is a lack of opportunity for students to play an active role in developing their problem-solving abilities” [12].

Based on the facts presented, the solution to overcome these problems is to implement a student-centered learning model. Student-centered learning provides opportunities for students to actively and independently construct knowledge through involvement in problem-solving activities [13]. Problem-Based learning is a student-centered learning model. Implementing the Problem-Based Learning model can motivate students to overcome problems, thereby enhancing their problem-solving abilities. Students' learning outcomes when the Problem-Based Learning model is applied are better and more effective in improving students' abilities to solve mathematical problems [14].

In addition to implementing the Problem-Based Learning model, other efforts are made to improve students' mathematical problem-solving abilities by using technology-based learning media that can help visualize abstract mathematical concepts. In this digital era, students and teachers can utilize technology in the learning process. The use of technology-based learning media is frequently employed because it is considered more efficient and effective compared to physical teaching aids [15]. One technology-based medium that can be utilized in the mathematics learning process is GeoGebra. GeoGebra is a software program designed to assist teachers in instilling material concepts through attractive images and visualizations [16]. GeoGebra can also assist in mathematics learning by functioning as a medium and tool, particularly for geometry and algebra materials [17]. GeoGebra is highly useful in visualizing mathematical concepts and serves as a means to construct mathematical concepts [18]. By using GeoGebra, students can observe, understand, and attempt to visualize mathematical concepts.

Research developments over the past five years indicate a significant shift toward the integration of dynamic technology within active learning models to address students' low mathematical problem-solving abilities. The Problem-Based Learning (PBL) model has consistently proven effective in enhancing critical thinking skills and mathematical problem-solving performance [19]. However, conventional PBL implementation is often hindered by limitations in visualizing abstract concepts; thus, the integration of GeoGebra software becomes crucial as a tool for independent exploration and verification for students [20]. Previous studies reveal that the use of GeoGebra effectively improves students' self-efficacy and self-regulated learning [21]. Furthermore, there is a significant impact from implementing the GeoGebra-assisted PBL model on mathematical problem-solving, particularly regarding flat-faced three-dimensional shapes [22], [23]. Additionally, the PBL model supported by interactive PowerPoint and GeoGebra has been shown to improve mathematical problem-solving skills [24]. Nevertheless, this study positions itself to strengthen the PBL syntax by optimizing GeoGebra's features to achieve a more measurable and adaptive improvement in problem-solving abilities, aligning with current curricular challenges.

Based on the aforementioned description, this study aims to analyze the improvement of junior high school students' mathematical problem-solving skills through the implementation of the GeoGebra-assisted Problem-Based Learning (PBL) model. This research is expected to offer several significant contributions: providing scientific insights into the effectiveness of the GeoGebra-integrated PBL model within school mathematics instruction; assisting students in transforming abstract mathematical concepts into visual and dynamic representations through GeoGebra-based exploration; fostering systematic problem-solving habits among students through the structured stages of the PBL syntax; and creating a more interactive and engaging learning environment.

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2. METHOD

Research Type

The approach used in this study is a quantitative approach aimed at testing hypotheses from the collected data [25]. The research method employed is a quasi-experiment with a non-equivalent control group design consisting of two classes: an experimental class and a control class. The experimental class is the class that received the GeoGebra-assisted

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problem-based learning (PBL-GeoG) model, while the control class is the class that received the direct instruction (DI) model.

Research Subject

The subjects of this research were 50 eighth-grade students at a public junior high school in Bandung. The research subjects were selected based on purposive sampling, resulting in the selection of class VIII-E and class VIII-C, with 25 students each. Class VIII-E served as the experimental class, and Class VIII-C as the control class. The purpose of this sampling method was to ensure that the research could be conducted effectively and efficiently. Additionally, it aimed to ensure that the selected subjects were well-targeted according to the characteristics required for this study. The objects of this research were mathematical problem-solving ability as the dependent variable and the PBL-GeoG model as the independent variable.

Research Procedure

This research was conducted in three stages: the preparation stage, the implementation stage, and the final stage. In the preparation stage, the researcher designed learning materials based on the PBL-GeoG model for the experimental class and learning materials based on the DI model for the control class. The researcher also drafted, developed, and validated the mathematical problem-solving ability test instruments. Furthermore, the researcher coordinated with the school principal and teachers to request permission to conduct the research at the school. The implementation stage began with the administration of a mathematical problem-solving ability pretest to both the experimental and control classes using the same questions, aimed at identifying and analyzing the students' initial mathematical problem-solving abilities. Subsequently, learning activities were carried out using the PBL-GeoG model for class VIII-E and the DI model for class VIII-C over four meetings covering the topic of linear equations. After the four learning sessions, both classes were given a mathematical problem-solving ability posttest. In the final stage, the researcher collected and analyzed the data to evaluate students' learning outcomes regarding their mathematical problem-solving abilities.

Data Collection

Data collection techniques in this research utilized test instruments. The test instruments used in this study consisted of a pretest and posttest in the form of five essay-type questions to analyze students' mathematical problem-solving abilities. As for the indicators of mathematical problem-solving ability in this research, they include identifying facts systematically, using mathematical concepts in problem-solving, relating mathematical abilities to various contexts, and interpreting problem-solving solutions.

Data Analysis

Quantitative data analysis was used to examine the differences in the improvement of mathematical problem-solving abilities between students who received the PBL-GeoG model and the DI model. Quantitative analysis was conducted using three main stages: 1) descriptive analysis and calculating the improvement in mathematical problem-solving abilities using the normalized gain (N-Gain) formula; 2) testing the required statistical analysis assumptions as a basis for hypothesis testing, namely the normality test for each group and the homogeneity of variance test; and 3) hypothesis testing. The collected data were then processed using IBM SPSS 23.0 for Windows software to perform a test of difference between two means (t-test) on the N-Gain results of the experimental and control classes.

3. RESULTS AND DISCUSSION

3.1. Results

N-Gain analysis was performed after obtaining the pretest and posttest scores of the experimental and control classes with the aim of determining the significance level of the changes that occurred in detail following the administration of the pretest and posttest. The N-Gain data analysis was conducted to determine the improvement in the mathematical problem-solving abilities of students in the experimental class who received the GeoGebra-assisted PBL model and students in the control class who received the conventional learning model.

The results of the N-Gain data processing and analysis using SPSS 23.0 for Windows software are presented in Table 1.

Table 1. Descriptive Statistics of N-Gain Data

	N	Minimum	Maksimum	Mean	Std. Deviation	Variance
PBL-GeoG	25	,52	,72	,5954	,06068	,004
DI	25	,41	,62	,5072	,06724	,005

Based on Table 1, the descriptive analysis results for the average N-Gain data of the PBL-GeoG model class and the DI model class were obtained with a moderate interpretation classification. Furthermore, the standard deviation in both classes is smaller than the mean value of each respective class. This indicates that the data has a tight distribution or is homogeneously distributed. Subsequently, the results of the N-Gain data normality test analysis are presented in Table 2.

Table 2. N-Gain Data Normality Test Output

	Shapiro-Wilk		
	Statistic	df	Sig.
PBL-GeoG	,922	25	,057
DI	,920	25	,050

Based on Table 2, the results of the N-Gain data normality test analysis indicate that the PBL-GeoG class has a significance value of 0.057, and the DI class has a significance value of 0.050. Both classes obtained significance values greater than or equal to 0.05, so H_0 is accepted, and H_a is rejected. Thus, it can be concluded that the N-Gain result data of students in the PBL-GeoG class and the DI class are normally distributed.

Since the PBL-GeoG class and the DI class are normally distributed, the next step is to conduct a homogeneity of variance test. The homogeneity of variance test was performed on the gain index score data of the PBL-GeoG and DI classes using Levene's test at a significance level of 0.05. After the data processing and analysis were conducted, the following calculation results are presented in Table 3.

Table 3. N-Gain Data Homogeneity Test Output

Lavene Statistic	df1	df2	Sig.
,928	1	49	,340

Based on Table 3, the results of the N-Gain data homogeneity test analysis show a significance value of 0.340. Since this significance value is greater than 0.05, H_0 is accepted, and H_a is rejected. Thus, it can be concluded that the N-Gain result data of the students in both classes have homogeneous variances.

The results of the normality and homogeneity tests on the N-Gain data indicate that the data are normally and homogeneously distributed. Based on these findings, a test of difference between two means (t-test) was subsequently conducted using the Independent Sample T-Test with a significance level of 5% (α = 0,05). The results of the N-Gain data t-test analysis are presented in Table 4.

Table 4. Independent Samples T-Test Output of N-Gain Data

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
N-GAIN	Equal variances assumed	,928	,340	4,921	49	,000	,08818	,01792	,05217	,12420
	Equal variances not assumed			4,911	48,030	,000	,08818	,01796	,05208	,12429

Based on Table 4, the results of the t-test analysis on the N-Gain data show a 2-tailed significance value (Sig. 2-tailed) of 0.000. Since the test of difference between two means for the mathematical problem-solving ability posttest utilized a one-tailed test, the significance value was divided by two, resulting in $\frac{0,000}{2} = 0,000$. Thus, the significance value is less than 0.05, leading to the rejection of H_0 and the acceptance of H_a. Consequently, it can be concluded that the improvement in the mathematical problem-solving abilities of students who received the PBL-GeoG model is significantly higher than that of those who received the DI model.

3.2. Discussion

Based on the research data analysis, Table 4 illustrates that the improvement in mathematical problem-solving abilities of students who received the PBL-GeoG model is higher than that of those who received the DI model. Several factors contributed to this improvement, particularly within the PBL-GeoG learning process. Students were focused on solving contextual problems, which encouraged them to understand the issues, identify essential information within the context of the problem, and formulate resolution strategies through systematic steps. Providing contextual problems in the learning process can significantly influence mathematical problem-solving abilities [26]. This process not only trains students to think logically and systematically but also familiarizes them with being actively involved in solving problems related to daily life [27].

During this process, students were guided to identify the knowns and unknowns of a problem, translate verbal information into mathematical symbols or forms, and model problems into mathematical equations based on the data obtained. Through these stages, students not only understand mathematical concepts theoretically but are also capable of applying them to real-world situations, thereby enhancing their mathematical problem-solving skills. Linking mathematical concepts to real-life situations in learning is vital, as it can improve students' mathematical problem-solving abilities [28]. Furthermore, identifying problems can help students find it easier to resolve issues and ensure that the solutions are correct and appropriate [29]. In addition, [30] and [31] state that "orienting students toward a problem can create experiences that require them to solve problems through structured and systematic steps, aiming to stimulate student interest in problem-solving, which in turn enhances critical thinking and problem-solving skills."

The second factor contributing to the improvement of students' mathematical problem-solving abilities is the use of interactive technology-based learning media, namely GeoGebra. Learning media serve as a tool designed to facilitate students in grasping the material being studied [32]. This media was utilized to strengthen students' conceptual understanding through concrete graphical representations, particularly in comprehending the meaning of the gradient in linear equations. Through GeoGebra, students with low and moderate abilities can understand the concept of gradients easily and comprehensively [33].

Beyond serving as a tool for deeper conceptual understanding, this media also allows students to verify the correctness and accuracy of the linear equation graphs they have drawn manually. This verification process provides students with the opportunity to re-examine the solutions they obtained manually, compare them with the visualization results on the software, and identify any discrepancies that may occur. When a difference is found between the visualized graph and the manual graph, students are encouraged to correct their previous steps and rectify errors. This activity not only reinforces conceptual understanding but also trains students' ability to evaluate the validity of their results based on the given problem context. Thus, the use of technology-based learning media like GeoGebra is not merely a visual aid but also a medium for strengthening students' critical thinking processes to enhance mathematical problem-solving skills. Problem-based learning assisted by the GeoGebra application is capable of encouraging students to think critically, thereby having a positive impact on the improvement of their mathematical problem-solving abilities [34].

The utilization of GeoGebra in mathematics education provides a more meaningful learning experience, particularly when used as a medium to help students understand the concept of gradients. This visualization assists students in comprehending the meaning of a gradient as the slope of a line, especially when comparing lines with positive, negative, zero, or undefined gradients. GeoGebra not only facilitates accuracy in graphing but also reinforces the conceptual understanding of gradients concretely and visually, which positively impacts the improvement of students' analytical skills. The GeoGebra medium helps students obtain a concrete conceptual overview and assists teachers in presenting accurate drawings with precise measurements and slopes for straight lines [35].

The use of GeoGebra enables students to visualize the concept of the gradient of a straight line. This is consistent with [18], [36], [17], which state, “GeoGebra is highly useful in visualizing mathematical concepts and serves as a means to construct mathematical ideas. Through visualization in GeoGebra, the previously abstract concept of a gradient becomes more concrete and understandable, ensuring that students do not merely memorize formulas but also comprehend their underlying meaning deeply.” Furthermore, GeoGebra is utilized as a tool to verify the correctness of graphs created in student worksheets by directly comparing students' manual sketches with more accurate digital graphs.

The third factor contributing to the improvement of students' mathematical problem-solving abilities is the implementation of the PBL-GeoG model, which emphasizes the process of independent investigation and information gathering or group discussions to resolve contextual problems. Students are capable of drawing graphs independently using GeoGebra [17]. In this context, students are provided with scaffolding questions that prompt them to engage in purposeful investigations based on the provided guidelines. This instructional support is designed to sharpen students' critical thinking, enabling them to become adept at navigating complex problems. Through these investigative activities, students transition from passive recipients of knowledge to active seekers and processors of information. This shift significantly bolsters their critical and analytical capabilities, as they are required to devise resolution strategies, filter pertinent information, verify data accuracy, and integrate their findings into a cohesive solution, all of which are fundamental components of mathematical problem-solving proficiency. Furthermore, engaging in exploration and systematic data collection deepens their conceptual understanding; once a viable solution is identified, students execute it methodically according to a structured plan and appropriate procedures [37].

Based on the aforementioned description, the mathematical problem-solving abilities of students who received the PBL-GeoG model are superior to those who received the DI model. At the beginning of the learning process using the PBL-GeoG model, students are required to understand contextual problems, plan solutions, engage in discussions, execute solution plans, present the results of their solutions, and analyze and evaluate the problem-solving process. Through the PBL-GeoG model, students are allowed to explore a problem, allowing them to become accustomed to contextual challenges that can enhance their mathematical problem-solving skills. By implementing the PBL-GeoG model, the improvement in students' mathematical problem-solving abilities is higher than that of students in the DI model. The process through which students solve problems using PBL-GeoG is more effective than the process used by students under the DI model [38], [39].

4. CONCLUSION

Based on the data analysis and hypothesis testing, the improvement in the mathematical problem-solving abilities of junior high school students who received the

Problem-Based Learning model assisted by GeoGebra (PBL-GeoG) is significantly higher than that of those who received the Direct Instruction (DI) model. The PBL-GeoG model is highly suitable for mathematics education, particularly in honing students' problem-solving skills across various proficiency levels. The primary strength of this model lies in its ability to actively involve all students according to their respective capacities and potentials. For high-ability students, PBL-GeoG encourages critical thinking, the exploration of alternative solutions, and the formulation of in-depth mathematical arguments. These students are also given opportunities to develop more complex resolution strategies, making the learning experience more meaningful.

Meanwhile, students with lower abilities can remain actively involved through collaborative and explorative activities. By utilizing a real-world problem-based approach, they can learn through group discussions, receive peer assistance, and build self-confidence by expressing their opinions and presenting their results. Activities such as discussing, observing, and gradually developing simple strategies help lower-ability students build their thinking and problem-solving skills in a slow yet directed manner. Furthermore, students feel that their contributions are valuable, enabling them to participate effectively in solving complex problems.

The findings of this study have significant implications for classroom instructional practices, where the integration of GeoGebra within the PBL syntax is proven to strengthen students' cognitive processes in mathematical problem-solving. GeoGebra serves not merely as a visual aid but as a self-verification medium that encourages students to evaluate and correct their problem-solving steps. This fosters a deeper conceptual understanding, particularly regarding the topic of straight-line equations. Despite these effective results, this study is subject to certain limitations, including its specific focus on straight-line equations and a research subject pool limited to a particular group of students. Furthermore, the effectiveness of GeoGebra in this research is highly dependent on the availability of school technological facilities and the students' initial proficiency in operating the software.

This study contributes as a reference for innovative learning models relevant to the demands of the *Kurikulum Merdeka* in enhancing students' mathematical problem-solving abilities. For future development, it is recommended that subsequent researchers expand the application of the PBL-GeoG model to topics with high levels of abstraction and examine its influence on affective aspects, such as growth mindset or math anxiety. Furthermore, the development of instructional media in the form of digital student worksheets directly integrated with GeoGebra’s interactive features is highly encouraged to optimize self-regulated learning and provide students with a more structured exploratory experience.

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