

Implementation of GeoGebra learning media in the problem-based learning model and its effectiveness on students' mathematical reasoning abilities

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Abstract: This research aims to determine the effectiveness of implementing *GeoGebra* in the mathematical learning of linear equations with two variables (LETV) using the Problem-Based Learning (PBL) model on students' mathematical reasoning abilities. This study employs a pre-experimental research design with a one-group pretest-posttest design. The sample for this research consists of one class selected from a total of 4 classes, with 36 students as the experimental subjects. Data were collected using test instruments in the form of pretests and posttests. The instrument is designed to measure mathematical reasoning abilities according to the established indicators. The data obtained will be analyzed using descriptive statistics and inferential statistics. Descriptive statistics are used to describe the scores before and after the intervention. Inferential statistics are used to investigate the effectiveness of implementing *GeoGebra* with the PBL model on students' mathematical reasoning abilities. The test results show that there is a significant difference between the posttest and pretest scores, indicating that the implementation of *GeoGebra* with the PBL model is effective in improving mathematical reasoning skills.

Keywords:

Geogebra, Mathematical reasoning, Problem based learning

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1. Introduction

Mathematical reasoning skills are an important ability that every student must master, especially at the high school level. According to NCTM (2000), the ability to think and reason in mathematics, including making hypotheses and constructing logical, deductive arguments, is crucial, as it serves as a foundation for developing new insights and pursuing further studies. Students with strong mathematical reasoning skills usually find it easier to understand the material than those without (Blanton, M., & Kaput, 2005; English, 2013; Kaur & Lam, 2012). This is in line with the Minister of National Education Regulation Number 22 of 2006 on content standards, which states that the goal of mathematics learning is for students to reason about patterns and properties, perform mathematical manipulations to generalize, construct proofs, and explain mathematical ideas and statements. This goal also aligns with

the general objectives of learning outlined by the National Council of Teachers of Mathematics (NCTM), which include problem-solving processes, reasoning and proof, connections, communication, and representation (NCTM, 2000). The Programme for International Student Assessment (PISA) also evaluates this aspect of reasoning, and its survey results indicate a significant decline in Indonesian students' mathematical reasoning abilities over the past two years (OECD, 2023).

Several existing studies indicate that many students still exhibit low levels of mathematical reasoning (Asdarina & Ridha, 2020; Marian, 2021; Zakiyah et al., 2018). In addition, according to Widyanawati & Firmansyah (2022) and Yanah & Hakim (2022), students' reasoning abilities when solving linear equations with two variables (LETV) problems remain low. There are several difficulties faced by students, such as extracting information from concepts, applying problem-solving methods, and performing mathematical operations (Wahyuni et al., 2023). To enhance mathematical reasoning skills, the appropriate learning model needs to be considered. In the independent curriculum, the learning approach becomes more flexible, providing students with freedom to explore, and the Problem-Based Learning (PBL) model can be an effective choice (Az-zarkasyi & Hindun, 2023). PBL is a learning method that focuses on solving complex and contextual problems while emphasizing students' practical experiences (Wardani, 2023). In line with Kotto et al. (2022), PBL aims to develop students' critical thinking and problem-solving skills. The application of the PBL model creates real-world situations, helping students better understand the material being studied and providing them with the freedom to think critically as they seek solutions to the problems they face. By applying the PBL model, students can better comprehend the subject matter and improve their learning outcomes (Alifiah et al., 2021; Pratama et al., 2023; Wardani, 2023).

The application of learning models can be strengthened by utilizing media in the teaching and learning process. PBL model, supported by learning media such as GeoGebra, provides students with the opportunity to explore their knowledge in solving problems in a more accessible and in-depth manner, thereby enhancing their understanding of the material being taught (Andhini et al., 2023). The GeoGebra media allows students to create simple visualizations of learning concepts, which helps them discover, convey, and create mathematical representations of their ideas (Afhami, 2022). Fazryn et al. (2023) added that the use of GeoGebra in mathematics learning can support the development of cognitive abilities, including critical and creative thinking, as well as communication. Research shows that integrating GeoGebra into mathematics education can significantly enhance students' learning experiences (Aliu et al., 2025). GeoGebra, as dynamic geometry software, can be used as an effective tool in learning through visualization to improve understanding (Saha, 2010).

Additionally, GeoGebra empowers students to express their visual and analytical thinking during the learning process and encourages visualization and understanding during instruction (Takači et al., 2015). Arcavi (2003) emphasizes that visualization serves not only as an illustration but also as a fundamental component in reasoning within conceptual learning.

In general, integrating GeoGebra with a flexible teaching approach can offer numerous ways for students to express and understand their learning (Baye et al., 2021). Therefore, this article discusses the implementation of GeoGebra in PBL learning and its effectiveness on students' mathematical reasoning.

2. Methods

2.1 Research Approach

This research employed a quantitative study with a pre-experimental design. According to Creswell & Creswell (2018), pre-experimental research involves a single experimental group with an intervention administered during the experiment. This research design lacks a control group for comparison with the experimental group; thus, it is a one-group pretest-posttest design. This study consists of an independent variable, Problem-Based Learning (PBL) assisted by GeoGebra, and a dependent variable, mathematical reasoning ability. The research measures students' initial abilities through a pretest and their final abilities after the intervention using a posttest. The scores obtained are then used to determine whether there is a significant difference between the scores before and after the intervention.

2.2 Population and Sample

The population of this study consists of students in class X at SMA N 2 Sleman, comprising four classes: X Indraprasta, X Amarta, X Mandaraka, and X Madukara. According to Sugiyono (2013, p. 80), a population is a generalization area that includes objects or subjects with certain qualities or characteristics set for research purposes. The sample in this study was determined using a non-probability sampling technique, specifically purposive sampling. According to Sugiyono (2013, p. 85), purposive sampling is a sampling technique that uses specific criteria; in this study, the sample was selected based on recommendations from the school's mathematics teacher, given that the students in these classes have the necessary resources to support learning with GeoGebra.

2.3 Research Instrument

The data collection instrument in this study used a testing method that consisted of a set of questions to measure the skills, knowledge, and abilities of individuals or groups. The tests used are essay questions on Linear Equation with Two Variables (LETV), including pretests and posttests. The pretest consists of 2 essay questions, administered to students before the learning process and used as a comparison with the results after the treatment. Additionally, the posttest consists of 4 essay questions administered after the learning process to evaluate students' learning outcomes following the implementation of the PBL model assisted by GeoGebra. The tests used in this study were developed using indicators of mathematical reasoning abilities, as follows (see Table 1).

Table 1. Mathematical Reasoning Ability Test Indicators

Indicators	Descriptions
Presenting mathematical statements both orally and in writing	The ability to communicate concepts and ideas clearly and systematically, whether through oral or written means
Formulating conjectures	The ability in critically and analytically thinking processes where students formulate hypotheses and predictions based on available information
Performing mathematical manipulation	The ability to change, organize, or operate mathematical expressions with the aim of solving problems
Constructing proofs and providing justifications for the correctness of solutions	The ability where students develop systematic arguments to support claims with clear reasoning
Drawing conclusions from a statement	The critical thinking ability is where students analyze existing information to produce logical and relevant conclusions

In a study, the use of valid and reliable instruments is an important requirement that cannot be overlooked (Sugiyono, 2013, p. 122). In this research, the validity used is content validity based on expert judgment. Additionally, the validity of this instrument was also tested using SPSS. Based on the results obtained, the product-moment correlation was compared with the table value of 0.232, and the result was found to be valid. Meanwhile, the reliability test used Cronbach's alpha. The results were then compared with the reliability category table according to Arikunto (2009, p. 75) (see Table 2). Based on the Cronbach's alpha reliability values obtained, which are 0.702 for the pretest and 0.698 for the posttest, it can be stated that the instruments used have high reliability.

Table 2. Instrument Reliability Criteria

Criteria	Interpretation
$0,80 < r_{ii} \leq 1,00$	Very High
$0,60 < r_{ii} \leq 0,80$	High
$0,40 < r_{ii} \leq 0,60$	Medium
$0,20 < r_{ii} \leq 0,40$	Low
$0,00 \leq r_{ii} \leq 0,20$	Very Low

2.4 Data Analysis Techniques

The data analysis techniques used are descriptive statistics and inferential statistics. The data collected through the pretest and posttest will be analyzed descriptively first before hypothesis testing. The descriptive analysis includes the mean, variance, standard deviation, maximum, and minimum of the pretest and posttest results. The results of these descriptive statistics can also be used to determine the percentage of achievement of mathematical reasoning indicators and the distribution of mathematical reasoning abilities.

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Students' mathematical reasoning abilities in this study are categorized as very high, high, moderate, low, or very low. The assessment categories for students' mathematical reasoning abilities are determined based on the scoring guidelines (Vebrian et al., 2021). In this study, the intervention is considered effective if there is an improvement in scores from the pretest to the posttest and the scores fall within the moderate category.

Table 3. Categories of Mathematical Reasoning Ability Levels

Categories	Achievement of mathematical reasoning ability
Very High	$85 < x \leq 100$
High	$75 < x \leq 85$
Moderate	$60 < x \leq 75$
Low	$54 < x \leq 60$
Very Low	$x \leq 54$

The inferential test used is the one-way paired-samples t-test. This test can be used to determine whether the average posttest score exceeds the pretest score. If there is a significant difference between the posttest and pretest in this one-way test, it can be stated that the PBL model with GeoGebra media is effective in improving students' mathematical reasoning abilities.

3. Results and Discussion

3.1 Students' mathematical reasoning abilities

Mathematical reasoning ability was measured using a descriptive test consisting of 2 pretest and 4 posttest questions. A description of the pretest and posttest scores is shown in Table 4. There is an increase in scores from pretest to posttest, from the previous one with an average of 63.86 to 85.86.

Table 4. Description of research data

Description	Pretest	Posttest
Number of students (n)	36	36
Ideal highest value	100	100
Ideal lowest value	0	0
Highest value	91	100
Lowest value	27	66
Average	63,86	85,86
Variance	284,52	85,26
Standard deviation	16,86	9,23

In Table 4, the lowest student score before the intervention was 27, and the highest was 91. Meanwhile, after the intervention, namely the provision of PBL models with

GeoGebra media, there was an increase; the lowest score of students became 66, with the highest score of 100. This increase in scores indicates that the intervention or treatment given to students has an effect. The results of the test of students' mathematical reasoning ability are influenced by five indicators that have previously been presented in Table 1. The following is the percentage of achievement of each mathematical reasoning indicator.

Table 5. Percentage of Achievement of Mathematical Reasoning Indicators

Description	Pretest	Posttest
Present mathematical statements orally or in writing	94%	98,8%
Formulating conjectures	67%	83,7%
Performing mathematical manipulation	93%	96,9%
Constructing proofs and providing justifications for the correctness of solutions	45%	83,7%
Drawing conclusions from a statemen	54%	83,7%

Based on Table 5, the percentage of achievement in mathematical reasoning indicators increased after receiving an intervention in the form of a PBL model using *GeoGebra* media. The largest increase occurred in the indicator for compiling evidence and providing reasons for the correctness of the solution, at 38.7%. In contrast, the smallest increase was in the indicator for making conjectures, at 16.7%. Overall, the results of the intervention showed improvement, as evidenced by higher posttest achievement percentages than pretest achievement across all indicators tested. This means that the interventions given effectively improve mathematical reasoning skills.

The results of the mathematical reasoning ability test are then classified according to the intervals set in Table 3, namely very high, high, medium, low, or very low. This classification also serves to measure the effectiveness of learning. The following are the results of the classification of students' mathematical reasoning skills.

Table 6. Distribution of mathematical reasoning ability values

Description	Pretest	Posttest
Present mathematical statements orally or in writing	94%	98,8%
Formulating conjectures	67%	83,7%
Performing mathematical manipulation	93%	96,9%
Constructing proofs and providing justifications for the correctness of solutions	45%	83,7%
Drawing conclusions from a statemen	54%	83,7%

Based on Table 6, the number of students increased from pretest to posttest. Prior to the intervention, 10 students were in the very low classification, 3 in the low classification, 13 in the medium classification, 7 in the high classification, and 3 in the very high classification. This shows that there are 36.1% of students are still below the expected classification. After the intervention, there was an increase in scores: 22 students were in the very high classification, 7 in the high, 7 in the medium, and none in the low or very low classification. Before the intervention, 23 students (63.8%) were at the expected qualification; after the intervention, this increased to 36 students (100%), all in the minimum moderate classification.

3.2 Implementation of GeoGebra in PBL and its effectiveness

The purpose of this study is to determine the effectiveness of implementing GeoGebra within the PBL model. Based on the results of the paired-samples t-test, the implementation of GeoGebra within the PBL model is effective in improving students' mathematical reasoning skills. The implementation of GeoGebra in PBL is considered effective because it meets the previously set learning effectiveness criteria, namely, an increase from pretest to posttest scores.

The implementation of GeoGebra in mathematics education is effective in improving students' understanding. Using a visual representation of a function, students can manipulate the GeoGebra slider to create various points located on that function (see Figure 1). This process not only stimulates the data in the GeoGebra window but also transforms that data into information ready for processing in working memory (Karadag & McDougall, 2011). In addition, GeoGebra empowers students to articulate their visual and analytical thinking during the learning process and encourages their visualization and understanding (Takači et al., 2015).

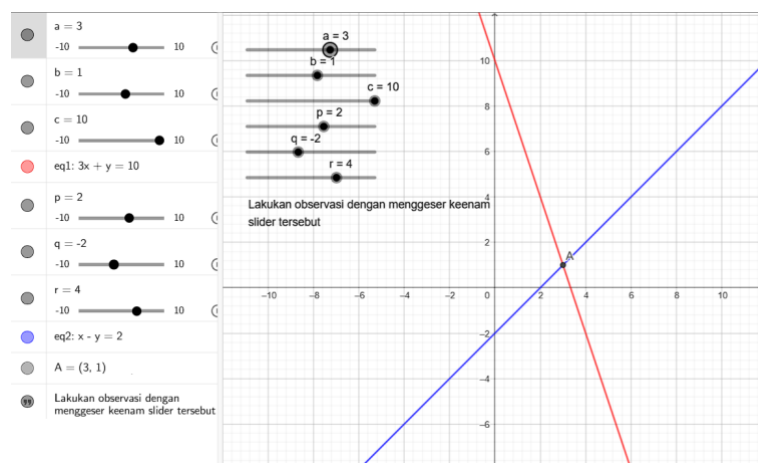


Figure 1. Visual representation of two linear functions

Research shows that GeoGebra software has a significant impact on students' math skills compared to traditional learning. GeoGebra effectiveness studies show that this device is more effective under certain conditions and that differences in education levels do not affect the magnitude of GeoGebra's effect on students' mathematical abilities, so GeoGebra is recommended for use in JHS, SHS, and colleges (Juandi et al., 2021). According to Saha et al. (2010), GeoGebra software can be used as an effective tool for learning through visualization to improve students' learning and understanding. Another study by Aliu et al. (2025) reports that students who use GeoGebra show better conceptual and procedural understanding, improved problem-solving abilities, and higher levels of engagement than students who do not use GeoGebra.

Table 7. Distribution of Mathematical Reasoning Ability Values

Data	t	df	Significance
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			One-Sided p	Two-Sided p
Pretest & Posttest	-8.901	35	<0.001	<0.001

Based on the results of the paired sample t-test (sig one tailed) in Table 7, a significance value was obtained $< 0,001 < \alpha = 0,05$ and a value of $t |-8,901| > t_{table} = 1,690$ which means rejected H_0 . Thus, implementing GeoGebra in PBL for LETV material effectively improves students' mathematical reasoning skills. The results of this study are consistent with the findings of Dewi (2023), and Muchlis et al. (2023) Orozco & Morales-Morgado (2017), which indicate that students' mathematical reasoning improves after implementing GeoGebra in PBL learning. The implementation of GeoGebra in PBL can improve students' mathematical reasoning skills, as seen by the increase in the average post-test score from 63,86 to 85,86. In general, it can be concluded that students can present mathematical statements in oral and written form, propose conjectures, perform mathematical manipulations, compile evidence, provide reasons for the correctness of solutions, and draw conclusions from statements.

4. Conclusion

Based on the results of this study, it can be concluded that implementing GeoGebra within the Problem-Based Learning (PBL) model effectively improves students' mathematical reasoning abilities on the topic of linear equations with two variables (LETV). This effectiveness is evidenced by the significant increase in students' posttest scores compared to their pretest scores, as well as the results of the paired-samples t-test, which indicate a statistically significant difference. Furthermore, improvements were observed across all indicators of mathematical reasoning, including formulating conjectures, performing mathematical manipulation, constructing proofs, and drawing conclusions. In addition, integrating GeoGebra into the PBL model helps students visualize abstract mathematical concepts, thereby facilitating deeper understanding and enhancing their engagement in the learning process. The use of dynamic and interactive media enables students to explore mathematical ideas more meaningfully and develop higher-order thinking skills. Therefore, the combination of GeoGebra and PBL can be considered an effective and innovative approach to improving students' mathematical reasoning skills and overall learning experience.

Declarations

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Additional Information : -

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