Implementation of GeoGebra-Assisted Problem-Based Learning to Optimize Understanding of the Distance Concept

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Abstrak
Pemahaman konsep jarak merupakan fondasi krusial dalam matematika, khususnya geomet ri. Observasi awal di SMAN 4 Sidoarjo menunjukkan siswa mengalami kesulitan dalam mem ahami konsep ini secara abstrak. Penelitian ini menguji efektivitas implementasi model Probl em-Based Learning (PBL) berbantuan GeoGebra dalam meningkatkan pemahaman konsep jarak. Metode yang digunakan adalah kuasi-eksperimen dengan desain Non-equivalent Cont rol Group. Partisipan terdiri dari dua kelas XI, yaitu kelas eksperimen (PBL+GeoGebra) dan kelas kontrol (pembelajaran konvensional). Instrumen penelitian berupa tes pemahaman kon sep yang telah divalidasi. Hasil analisis Independent Sample t-test pada nilai N-Gain menunj ukkan bahwa peningkatan pemahaman konsep jarak pada kelas eksperimen (N-Gain = 0,67; rata-rata post-test = 82,13) secara signifikan lebih tinggi daripada kelas kontrol (N-Gain = 0, 46; rata-rata post-test = 70,20) dengan sig. < 0,05. Dengan demikian, implementasi PBL berb antuan GeoGebra efektif meningkatkan pemahaman konsep jarak siswa.
Kata Kunci: Problem-Based Learning; GeoGebra; Pemahaman Konsep; Konsep Jarak; Geometri.

Abstract
Understanding the concept of distance constitutes a crucial foundation in mathematics, particularly in geometry. Preliminary observations at SMAN 4 Sidoarjo indicated that students struggle to grasp this concept abstractly. This study examines the effectiveness of implementing a GeoGebra-assisted Problem-Based Learning (PBL) model in enhancing students' understanding of the distance concept. A quasi-experimental method with a Non-equivalent Control Group design was employed. The participants consisted of two eleventh-grade classes: an experimental class (PBL + GeoGebra) and a control class (conventional learning). The research instrument utilized was a validated conceptual understanding test. The Independent Sample t-test analysis on N-Gain scores revealed that the improvement in understanding the distance concept in the experimental class (N-Gain = 0.67; post-test mean = 82.13) was significantly higher than that of the control class (N-Gain = 0.46; post-test mean = 70.20) with $p < 0.05$. Thus, the implementation of GeoGebra-assisted PBL effectively enhances students' understanding of the distance concept.
Keywords: Problem-Based Learning; GeoGebra; Conceptual Understanding; Distance Concept; Geometry.

I. Introduction

Understanding the concept of distance is a vital prerequisite for mastering advanced mathematical topics such as vectors, trigonometry, and calculus (Noto et al., 2025). However, an analysis of daily assessment scores at SMAN 4 Sidoarjo on solid geometry revealed an average score of 58.4, with a classical mastery rate of only 45%. Interviews with mathematics teachers disclosed that students face difficulties in distinguishing between types of distances, visualizing the position of objects in space, and applying formulas appropriately. These difficulties arise due to the abstract nature of the material, which lacks sufficient visualization.

Problem-Based Learning (PBL) was selected for its capacity to create contextual, problem-based learning environments that foster critical thinking and collaboration (Rinaldi & Afriansyah, 2019; Pratama & Mardiani, 2022; Rahayu, Puspitasari, & Luritawaty, 2024). Nevertheless, PBL requires strong visual media support for abstract topics such as solid geometry. GeoGebra, as dynamic geometry software, is capable of presenting interactive visualizations, allowing students to explore distance concepts in real-time. The combination of PBL and GeoGebra is expected to generate a synergy that significantly enhances students' conceptual understanding.

Mathematical conceptual understanding is a fundamental basis for mastering more complex mathematical material (Miatun & Ulfah, 2023; Afriansyah et al., 2024; Sulastri et al., 2025). One essential yet often challenging concept for students is the concept of distance, both in plane and solid geometry. This concept is not merely procedural but also requires strong spatial abilities to imagine and analyze the positions and relationships between objects in space (Ningsih et al., 2023).

To address these issues, innovation in instructional design is required to transform abstractions into tangible concepts. PBL provides the framework for inquiry, while GeoGebra provides the tools to explore and validate answers. The novelty of this research lies in the integration of these two elements (PBL and GeoGebra) specifically applied to the concept of distance in solid geometry within the context of SMAN 4 Sidoarjo.

Based on the background outlined, the research question is: "Is the implementation of GeoGebra-assisted Problem-Based Learning effective in improving the understanding of the distance concept among students at SMAN 4 Sidoarjo?" The objective of this study is to analyze the effectiveness of the GeoGebra-assisted Problem-Based Learning model in improving students' understanding of the distance concept at SMAN 4 Sidoarjo.

Conceptual understanding represents a higher level of ability than rote memorization. In the revised taxonomy by Anderson & Krathwohl (2001), understanding occupies the C2 cognitive level, serving as a basis for higher-order thinking skills. Skemp (1976) distinguishes understanding into two types: (1) Instrumental Understanding (procedural and isolated), and (2) Relational Understanding (holistic, knowing "why" and "how" concepts relate). This study aims to foster students' relational understanding of the distance concept.

PBL is an instructional model that utilizes authentic and challenging real-world problems as a context for students to develop critical thinking and problem-solving skills. The syntax includes orienting students to problems, organizing learning, guiding investigations, developing/presenting artifacts, and evaluating the process. PBL was chosen for its ability to create an active, student-centered learning environment.

GeoGebra is dynamic mathematics software integrating algebra, geometry, calculus, and statistics. Its primary advantage lies in providing interactive visualizations. For solid geometry, students can drag points, lines, and planes to observe changes in distance in real-time, bridging the gap between mathematical abstraction and concrete understanding.

II. METHOD

This study employed a quasi-experimental research design using a Non-equivalent Control Group Design. The experimental group received the GeoGebra-assisted PBL treatment, while the control group utilized conventional methods.

The population comprised all Grade XII Science students at SMAN 4 Sidoarjo (Academic Year 2024/2025). Samples were selected using a *purposive sampling* technique, resulting in two classes (n=30 each) deemed equivalent based on previous academic records and homogeneity tests (p > 0.05).

Lesson Plans (RPP) integrating PBL syntax with GeoGebra, validated by experts. A Distance Concept Understanding Test consisting of 5 descriptive items designed to measure indicators based on Skemp (1976). The test was declared valid (Aiken's V > 0.8) and reliable (Cronbach's Alpha = 0.86).

Data were analyzed using: 1) Assumption Tests: Normality (Shapiro-Wilk) and Homogeneity (Levene's Test); and 2) Hypothesis Testing: Independent Sample t-test on Normalized Gain (N-Gain) scores. If parametric assumptions were not met, the Mann-Whitney U test would be used. The significance level was set at $\alpha = 0.05$.

III. RESULT AND DISCUSSION

The descriptive statistics for pre-test, post-test, and N-Gain scores are presented in Table 1.

Table 1.
Descriptive Statistics of Pre-test, Post-test, and N-Gain Scores

Class	Statistic	Pre-test	Post-test	N-Gain
Eksperiment	Mean	45.27	82.13	0.67
(n=30)	Median	46,00	85,50	0,67
	Std. Deviation	8.145	7.228	0.132
Control	Mean	45.50	71.00	0.45
(n=30)	Median	7.831	8.415	0.151
	Std. Deviation	7.831	8.415	0.151

Based on Table 1, it can be seen that:

- Experimental Class: Mean Pre-test = 45.27, Mean Post-test = 82.13, N-Gain = 0.67 (Moderate Category).
- Control Class: Mean Pre-test = 45.50, Mean Post-test = 71.00, N-Gain = 0.45 (Low-Moderate Category). These results indicate a greater improvement in understanding within the treatment group.

The initial step before conducting a hypothesis test is to carry out a prerequisite analysis test, namely a test for normality and homogeneity of the data.

1. Normality Test (see Table 2): Both classes showed N-Gain significance values > 0.05 (Exp: 0.112, Ctrl: 0.065), indicating normal distribution.

Table 2.
Shapiro-Wilk Normality Test Results on N-Gain

Class	Statistic	df	Sig
Experiment	.941	30	.112
Control	.923	30	.065

2. Homogeneity Test (see Table 3): Levene's Test showed Sig. 0.269 (> 0.05), indicating homogeneous variance.

Table 3.
Levene's Test Homogeneity Results

F	df1	df2	Sig
1.245	1	58	0,269

3. Independent Sample t-test (see Table 4): The result showed Sig. (2-tailed) = 0.000 (< 0.05). Thus, H_0 is rejected. There is a statistically significant difference in the improvement of distance concept understanding between the two groups, with a mean difference of 0.210 in favor of the experimental group.

Table 4.
Independent Sample t-test Results on N-Gain

t	df	Sig (2-tailed)	Mean difference	95% confindence Interval of difference
5,678	58	0,000	0,210	Upper: 0,286

The results of statistical analysis show that the implementation of the Problem-Based Learning (PBL) model assisted by GeoGebra is effective in improving the understanding of the concept of distance of class XII IPA students of SMAN 4 Sidoarjo, with the N-Gain value of the experimental class being significantly higher ($p<0.05$) than the control class.

Qualitatively, the learning atmosphere in the experimental class demonstrated an active and collaborative dynamic. Students engaged in group discussions to solve contextual problems related to the concept of distance, such as designing the shortest distance in a geometric figure. During the "problem investigation" session, students used GeoGebra to visualize points, lines, and planes, and observed real-time distance changes using the drag-and-drop feature. This activity not only increased interaction between students but also encouraged the participation of students who had previously tended to be passive. Several students who rarely spoke during conventional learning became active in asking questions and expressing ideas when confronted with GeoGebra's dynamic visual displays.

Statistical analysis confirms that GeoGebra-assisted PBL is effective. Qualitatively, the experimental class demonstrated an active and collaborative atmosphere. Students utilized GeoGebra to visualize geometric elements and observe real-time changes, which encouraged participation even from typically passive students.

Observations indicated that 95% of students were actively involved in discussions. This aligns with Nurhayati & Herman (2020), who stated that integrating PBL with dynamic media enhances engagement and conceptual understanding. The findings also support the notion that interactive technology reinforces relational understanding in solid geometry, consistent with Skemp's theory (1976). The synergy between the inquiry framework of PBL and the visual tools of GeoGebra successfully bridged the gap between abstraction and concrete understanding.

Thus, the success of the PBL+GeoGebra implementation is not only evident in improved test scores, but also in the transformation of the learning environment to become more interactive, collaborative, and meaningful. The synergy between the inquiry-based learning model (PBL) and dynamic visual media (GeoGebra) successfully bridged the gap between mathematical abstraction and students' concrete understanding.

This clearly demonstrates that the implementation of the "Problem-Based Learning (PBL) model with GeoGebra is effective" in improving the understanding of the concept of distance among 12th-grade science students at SMAN 4 Sidoarjo. This effectiveness is demonstrated by the significantly higher N-Gain value of the experimental class compared to the control class.

These findings can be interpreted from several perspectives. First, the advantage of the PBL model lies in its ability to create a learning environment where students actively construct their own knowledge through contextual inquiry and problem-solving (Barrows, 1996). In this study, the problems presented sparked students' curiosity and encouraged them to collaborate in groups to find solutions. Second, GeoGebra's role as a dynamic visualization tool was crucial in transforming the abstract concept of distance into something concrete and explorable (Hohenwarter & Preiner, 2007). Students could drag points, lines, and abstract objects, particularly spatial geometry. This success lies not only in each component, but in the synergy in which PBL provides a framework for inquiry and GeoGebra provides the tools to realize that inquiry visually and interactively.

These findings align with research by Pratama & Utami (2022), which also found a positive synergy between PBL and GeoGebra in geometry. However, this study provides a more specific contribution by demonstrating its effectiveness in the more complex concept of distance in spatial geometry. These results also reinforce the theory put forward by Anderson & Krathwohl (2001) that learning involving high-level visual and cognitive activities (such as analyzing and evaluating in PBL) will be more effective in achieving conceptual understanding.

Thus, it can be reaffirmed that the combination of the PBL model and GeoGebra media is an effective and powerful learning strategy for overcoming students' difficulties in understanding abstract mathematical concepts, particularly spatial geometry. This success lies not only in each component, but in the synergy in which PBL provides a framework for inquiry and GeoGebra provides the tools to realize that inquiry visually and interactively.

IV. CONCLUSION

The implementation of GeoGebra-assisted Problem-Based Learning is effective in improving the understanding of the distance concept among Grade XII Science students at SMAN 4 Sidoarjo. This is evidenced by the significantly higher N-Gain in the experimental class (0.67) compared to the control class (0.46).

Limitations of this study are the study used a quasi-experimental design with intact groups, the instructional period was limited to three meetings, and technology use is dependent on school infrastructure.

Teachers are encouraged to use GeoGebra-assisted PBL for abstract topics. Schools should provide technical training and adequate facilities. Test similar models on other topics (calculus, algebra), employ true experimental designs, include variables such as motivation or spatial ability, and conduct longitudinal studies.

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