



# Enhancing Junior High School Students' Mathematical Problem-Solving Ability through GeoGebra-Assisted Project-Based Learning

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## ABSTRACT

This study aimed to examine the effect of GeoGebra-assisted Project-Based Learning on students' mathematical problem-solving ability. This study is a quasi-experiment with a post-test only control group design. The population of this study was all eighth-grade students at SMP PGRI 2 Denpasar, distributed across 11 classes. The sample was determined using cluster random sampling to obtain 3 classes as the research sample. ANOVA results revealed a significant difference among the three learning models ( $F = 29.706$ ,  $p < .05$ ). Students taught through GeoGebra-assisted Project-Based Learning achieved significantly higher mathematical problem-solving scores than those taught through Project-Based Learning alone and the 5M model. Therefore, a further test was conducted using the Scheffe test. Based on the Scheffe test and the average scores of each sample group, it was found that the mathematical problem-solving ability of students who participated in project-based learning assisted by GeoGebra was better than that of students who participated in project-based learning alone and students who participated in the 5M model. Furthermore, it was found that the mathematical problem-solving ability of students who participated in project-based learning was better than that of students who participated in the 5M model. Therefore, it can be concluded that the GeoGebra-assisted project-based learning model is better than the project-based learning model alone and the 5M learning model in improving students' mathematical problem-solving ability.

**Keywords:** *Mathematical problem-solving ability; GeoGebra; Project-based learning; Spatial geometry; Junior high school students*

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## INTRODUCTION

Problem-solving skills are recognized as a strategic competency for everyday life, enabling individuals to analyze situations, make informed decisions, and adapt effectively to changing circumstances (OECD, 2025; Bariyyah, 2021). Students demonstrate problem-solving skills by understanding problems, selecting appropriate strategies, implementing solutions, and evaluating the results obtained (Polya, 2004; Güner & Erbay, 2021). These skills require the integration of linguistic knowledge, contextual understanding, and strategic reasoning to interpret real-world situations and develop effective solutions (OECD, 2023; Schoenfeld, 2016; Liljedahl et al., 2016). Problem solving is widely recognized as a central component of mathematics learning because it enables students to apply mathematical concepts in meaningful contexts while developing reasoning, decision-making, and critical thinking skills (Schoenfeld, 2016; NCTM, 2014). Therefore, this skill is crucial for students to possess in order to find appropriate solutions to academic and everyday challenges.

Solid geometry is often considered difficult because it requires strong visual and spatial reasoning to understand relationships among three-dimensional shapes. Although geometry is essential for developing logical and critical thinking skills, students' achievement in this topic remains relatively low (Yulistiyaning & Mahmudi, 2015). The authors suggest that inadequate lesson planning and inappropriate learning materials contribute to this problem. Effective instructional materials can increase student engagement, clarify abstract concepts, promote positive attitudes toward mathematics, and support students in evaluating their understanding.

The integration of digital technology into mathematics education has become increasingly important for enhancing students' conceptual understanding, engagement, and problem-solving abilities. Technology-enhanced learning environments enable students to visualize abstract concepts, explore mathematical relationships dynamically, and construct knowledge through interactive experiences, thereby supporting mathematical reasoning and active learning (OECD, 2023; Pan et al., 2026; Drijvers & Sinclair, 2024). In addition, digital tools can foster students' metacognitive awareness and learning motivation by allowing them to manipulate mathematical objects and receive immediate feedback (Pan et al., 2026). These advantages are particularly valuable in geometry learning, where students often encounter difficulties in understanding spatial concepts and connecting multiple mathematical representations.

One digital tool that has been widely used in mathematics education is GeoGebra. GeoGebra integrates graphical, algebraic, and geometric representations in an interactive environment, allowing students to investigate mathematical concepts through exploration and visualization. Previous studies have shown that GeoGebra can enhance students' conceptual understanding, spatial reasoning, and problem-solving performance by making abstract mathematical ideas more concrete and accessible (Zengin, 2018; Puspita et al., 2024).

In addition to technology integration, Project-Based Learning (PjBL) has been recognized as an effective instructional approach for developing problem-solving skills. Through authentic projects, students are encouraged to investigate problems, apply mathematical concepts, collaborate with peers, and construct solutions independently (Kokotsaki et al., 2016; Guo et al., 2020). Combining GeoGebra with PjBL provides students with opportunities to explore mathematical ideas, test solutions, and reflect on their reasoning in meaningful learning contexts. However, limited research has investigated the combined implementation of GeoGebra-assisted Project-Based Learning in improving junior high school students' mathematical problem-solving ability, particularly in the topic of solid geometry. Therefore, this study seeks to fill this gap by examining the effectiveness of GeoGebra-assisted Project-Based Learning compared with Project-Based Learning and the 5M learning model.

Therefore, the implementation of GeoGebra-assisted Project-Based Learning has considerable potential to enhance junior high school students' mathematical problem-solving ability by promoting visualization, exploration, and active knowledge construction.

## METHODS

This study used a quasi-experimental research method. Quasi-experiments can be used to observe the effects of different treatments given to each group, where the researcher cannot strictly control all variables and experimental conditions (Creswell & Creswell, 2023). The research design used was a post-test only control group.

The population of this study consisted of all eighth-grade students at SMP PGRI 2 Denpasar, comprising 11 classes with a total of 584 students. The sample was selected using a cluster random sampling technique, in which intact classes rather than individual students were randomly chosen. Since the school had only one advanced class, the sampling process was conducted among the non-advanced classes (VIII B–VIII K), which were considered academically equivalent because students had been evenly distributed across classes by the school. According to school records and previous mathematics achievement data, these classes exhibited comparable academic performance prior to the study.

Three classes were randomly selected through a lottery system: class VIII B as Experimental Class 1 (n = 52), class VIII J as Experimental Class 2 (n = 54), and class VIII H as the Control Class (n = 54). Experimental Class 1 received the GeoGebra-assisted Project-Based Learning (PjBL) treatment, Experimental Class 2 received the Project-Based Learning (PjBL) treatment without GeoGebra, and the Control Class was taught using the 5M learning model. The independent variable in this study was the learning model, which consisted of three instructional approaches: GeoGebra-assisted Project-Based Learning, Project-Based Learning, and the 5M learning model. The dependent variable was students' mathematical problem-solving ability.

Data were collected through a mathematical problem-solving test administered at the end of the treatment period. The instrument consisted of five essay questions developed based on Polya's (2004) problem-solving framework, including understanding the problem, devising a plan, carrying out the plan, and reviewing the solution. The test items were validated by two experts in mathematics education, and the instrument demonstrated a satisfactory level of reliability. The resulting scores were used to assess students' mathematical problem-solving ability across the three learning groups.

Prior to hypothesis testing, the data were examined for normality using the Lilliefors test and homogeneity of variance using Levene's test. Subsequently, a one-way analysis of variance (ANOVA) was conducted to determine whether significant differences existed among the three groups. When significant differences were identified, post hoc comparisons were performed using the Scheffé test at a significance level of .05.

## RESULTS AND DISCUSSION

Data on the mathematical problem-solving scores of students in the sample class can be seen in [Table 1](#).

**Table 1.** Summary of Descriptive Analysis of Student Mathematical Problem-Solving Ability

Variabel	Class		
	Experimental 1	Experimental 2	Control
N	52	54	54
$\bar{Y}$	92	87,98	81,63
SD	7,86	6,86	6,20

From [Table 1](#), it can be seen that the average mathematical problem-solving ability scores of students in the three sample classes, namely experimental class 1, experimental class 2, and control class, show that the average mathematical problem-solving ability scores of students in experimental class 1 are the highest among the three groups. Before conducting the hypothesis test, normality and homogeneity tests were first carried out. Based on the normality test using the *Liliefors* test, the results show that the data on problem-solving ability scores in experimental class 1 has an  $L_{count}$  of 0.09, while in experimental class 2 it is 0.09 and in the control class it is 0.09, at a significance level of 5%. These calculations show that the data in the three sample classes have  $L_{count}$  less than  $L_{table}$ , where  $L_{table}$  for the first experimental class is 0.12233, and  $L_{table}$  for the second experimental class and control class is 0.12011. Thus, the data on students' mathematical problem-solving ability scores in the three sample classes are normally distributed. Next, a homogeneity test was conducted using *Levene's* test, which showed that the  $W$  value for the students' mathematical problem-solving ability data was 1.436, with  $F_{table}$  of 3.06 at a significance level of 5%. It can be concluded that the three sample groups have homogeneous data on students' mathematical problem-solving ability scores. Thus, hypothesis testing was conducted using a one-way ANOVA test. A summary of the one-way ANOVA test results can be seen in [Table 2](#).

**Table 2.** Summary of One-Way ANOVA Test Results

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Sum of Squares	F
Between	2906.1197	2	1453.0598	29.7061
In	7680	157	48.914485	
Total	10585.694	159		

The first hypothesis shows that  $F_{count} = 29,7061$  and  $F_{table} = F_{\alpha(n_1=k,k-1)} = F_{0,05(157,2)} = 3,06$ , so  $F_{count} \geq F_{table}$ . Therefore, it can be concluded that there are groups with different mathematical problem-solving abilities. The next hypothesis test uses the Scheffe post-hoc test. A summary of the results of the post-hoc hypothesis test using the Scheffe test can be seen in [Table 3](#).

**Table 3.** Summary of Scheffe Test Results

Group	$\bar{Y}$	$F_{count}$			F'
		Experimental 1	Experimental 2	Control	
Eksperiment 1	92	-	8,746	58,243	
Eksperiment 2	87,9815	8,746	-	22,270	6,12
Control	81,6296	58,243	22,270	-	

Based on the [Table 3](#),  $F'$  is obtained as 6.12, and it can be seen that the results of the second hypothesis test, which is related to the comparison between students who participated in learning with the GeoGebra-assisted project-based learning model and students who participated in learning with the project-based learning model alone, obtained  $F_{count}$  as 8.764. Therefore,  $F_{count}$  is greater than  $F'$ , so  $H_0$  is rejected. Considering that the average score of experimental class 1 is greater than the average score of experimental class 2, this indicates that the mathematical problem-solving ability of students who participated in learning using the GeoGebra-assisted project-based learning model is better than that of students who participated in learning using the project-based learning model alone.

The results of the third hypothesis test, which compared students who participated in learning using the project-based learning model assisted by GeoGebra with students who participated in learning using the 5M model, yielded an  $F_{count}$  of 58.243. Since  $F_{count}$  is greater

than  $F'$ ,  $H_0$  is rejected. Considering that the average of the experimental class 1 is greater than the average of the control class, this shows that the mathematical problem-solving ability of students who participated in learning with the GeoGebra-assisted project-based learning model is better than the 5M learning model.

The results of the final hypothesis test, which compared students who participated in project-based learning with those who participated in the 5M model, yielded an  $F_{count}$  value of 22.270. Since  $F_{count}$  is greater than  $F'$ ,  $H_0$  is rejected. Considering that the average of the experimental class 2 is greater than the average of the control class, this indicates that the mathematical problem-solving ability of students who participated in learning with the project-based learning model is better than that of the 5M learning model.

The results indicate that GeoGebra-assisted Project-Based Learning positively influences students' mathematical problem-solving ability. One possible explanation is that Project-Based Learning engages students in authentic problem-solving situations that require them to identify relevant information, formulate strategies, and evaluate solutions collaboratively. Such learning experiences encourage active participation, creativity, and deeper conceptual understanding, which are essential components of mathematical problem solving. This finding is consistent with [Kokotsaki et al. \(2016\)](#), who reported that Project-Based Learning promotes student engagement, collaboration, and higher-order thinking skills, as well as [Guo et al. \(2020\)](#), who found that project-based learning enhances academic achievement by enabling students to apply knowledge in meaningful contexts. In the present study, students were required to complete geometry-related projects that involved determining unknown dimensions, constructing models, and justifying their solutions, thereby providing opportunities to apply mathematical concepts in authentic situations.

The findings indicate that students who learned through GeoGebra-assisted Project-Based Learning achieved significantly higher mathematical problem-solving performance than those who learned through Project-Based Learning alone and the 5M learning model. This result suggests that the combination of project-based activities and dynamic visualization tools creates a more effective learning environment for developing mathematical problem-solving skills. Students were not only required to solve authentic problems through projects but were also supported by visual representations that facilitated conceptual understanding and mathematical reasoning.

These findings are consistent with the systematic review conducted by [Yohannes & Chen \(2023\)](#), which concluded that GeoGebra contributes positively to students' mathematical achievement, conceptual understanding, visualization skills, and problem-solving abilities. The authors emphasized that GeoGebra enables learners to explore mathematical concepts dynamically, allowing them to connect symbolic, graphical, and geometric representations more effectively. In the present study, GeoGebra assisted students in visualizing three-dimensional objects, identifying relationships among geometric elements, and verifying their solutions during project completion, thereby reducing cognitive barriers often encountered in spatial geometry learning.

The positive effect of GeoGebra-assisted learning is also supported by [Engelbrecht & Borba \(2024\)](#), who argued that digital technologies can transform mathematics learning from passive knowledge acquisition into active knowledge construction. Interactive technologies provide immediate feedback and opportunities for exploration, enabling students to test conjectures, evaluate solutions, and refine their reasoning processes. Such learning experiences are particularly beneficial in geometry, where students often struggle to connect abstract mathematical concepts with visual representations. The present findings suggest that GeoGebra functioned not merely as a visualization tool but also as a cognitive scaffold that supported students' mathematical reasoning during problem-solving activities.

Furthermore, the superior performance of students in the GeoGebra-assisted PjBL group aligns with previous research highlighting the effectiveness of Project-Based Learning in developing higher-order thinking skills. [Kokotsaki et al. \(2016\)](#) reported that Project-Based Learning promotes deeper understanding, student engagement, collaboration, and problem-solving competence by providing authentic learning experiences. Similarly, [Guo et al. \(2020\)](#) found that project-based learning encourages active participation and knowledge construction, leading to improved academic outcomes. In the present study, students were required to identify missing information, formulate strategies, construct geometric models, and evaluate their solutions collaboratively. These activities closely reflect the core characteristics of mathematical problem solving and likely contributed to the observed improvement in performance.

The findings are also supported by constructivist learning theory, which emphasizes that knowledge is actively constructed through interaction with tasks, tools, and social environments. Through collaborative projects, students were encouraged to discuss ideas, negotiate meaning, and develop shared solutions. The integration of GeoGebra further enriched this process by providing visual and interactive representations that enabled students to test mathematical ideas in real time. This combination of collaboration, exploration, and visualization appears to have strengthened students' conceptual understanding and facilitated more effective problem-solving strategies.

In addition, the results are consistent with studies by [Pan et al. \(2026\)](#), who found that technology-enhanced learning environments can improve students' engagement, metacognitive awareness, and problem-solving performance by allowing learners to manipulate mathematical objects and receive immediate feedback. During the project activities, students used GeoGebra to explore relationships among dimensions, surface area, and volume, helping them monitor and evaluate the accuracy of their solutions. Such opportunities for self-monitoring are essential components of effective mathematical problem solving.

Overall, the findings suggest that the effectiveness of GeoGebra-assisted Project-Based Learning stems from the complementary strengths of both approaches. Project-Based Learning provides authentic contexts that encourage students to apply mathematical concepts in meaningful situations, while GeoGebra supports conceptual understanding through dynamic visualization and exploration. The integration of these approaches creates a learning environment that promotes active engagement, collaborative learning, mathematical reasoning, and problem-solving competence more effectively than conventional instruction.

In Experimental Class 1, students learned to use a project-based learning model with the help of GeoGebra media. They were given a project involving the creation of nets and solid figures from four types of flat shapes: cubes, rectangular prisms, prisms, and pyramids. The project required students to first find certain information in order to complete it. One piece of unknown information is the length of the sides of a flat-layered three-dimensional shape. The group assigned to create the net is only given the surface area and one side length of the flat-layered three-dimensional shape, so they must determine the length of the other sides to complete the project. Through this project, students indirectly learn to solve problems, meaning they must use their mathematical problem-solving skills to complete it. This project motivates students to participate in the learning process, making it more meaningful. Students are directly involved in the project creation process, which helps them develop problem-solving skills as they overcome challenges. In addition, interacting with peers makes the learning process more enjoyable, as students work together to apply their existing knowledge and new information to complete the project.

In Experimental Class 2, students followed a project-based learning model. They were given the same project as in Experimental Class 1, but were not given any media. Therefore, they

must rely on other sources, such as the student guidebooks they already have. Similar to Class 1, Class 2 students also prefer the project-based learning model. This is because they work on projects directly in their groups, which allows them to collectively build existing and new knowledge to complete the project. Interacting with group members makes the learning process more enjoyable and less boring. However, students had difficulty understanding the concepts in the material, especially in visualizing some elements and the origins of formulas for flat shapes. Due to their difficulty in understanding the concepts, students also had difficulty completing the project. Some students lost their enthusiasm for learning when faced with difficulties, so most students did not fully understand the material on flat shapes. Therefore, when students are given slightly different problems, some are able to solve them, while most are confused about how to solve them. The application of this project-based learning model allows students to directly address the challenges they face when creating projects. This makes them more accustomed to dealing with non-routine problems, or problems related to assessing students' mathematical problem-solving abilities.

Unlike experimental class 1 and 2, students in the control class were not divided into groups. The school's learning model was direct learning with a scientific approach. However, students were not divided into groups. In this learning model, the teacher's role was still dominant, especially in delivering material. This affected student participation and activity in the classroom, making learning feel monotonous and less enjoyable. Additionally, during discussions, the teacher was more active in providing explanations through example questions and exercises. This caused students to become dependent on the teacher. The lack of interaction among students also hindered them in building their own knowledge and honing their mathematical problem-solving skills.

## **CONCLUSION**

Based on the results of the research and discussion, it can be concluded that there are differences in mathematical problem-solving abilities among students who participated in the following learning models: project-based learning with the help of GeoGebra, project-based learning, and 5M learning. Students who participated in the project-based learning model with the help of GeoGebra showed better mathematical problem-solving abilities than students who participated in the project-based learning model. Students who participated in the project-based learning model with the assistance of GeoGebra demonstrated better mathematical problem-solving abilities than those who participated in the project-based learning model. Students who participated in the project-based learning model demonstrated better mathematical problem-solving skills than those who participated in the 5M learning model. Based on these findings, it can be concluded that mathematics learning using the project-based learning model supported by GeoGebra positively influences students' problem-solving skills.

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