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The Effects of GeoGebra-Assisted Problem-Based Learning on Students' Problem-Solving Skills in Solid Geometry

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Abstract
Mathematical problem-solving in solid geometry remains challenging for elementary students, highlighting the need for instruction that actively engages them in reasoning and solution development. Although Problem-Based Learning (PBL), GeoGebra, and their integration have been investigated separately, direct comparisons of these three approaches at the elementary level remain limited. This study compared their effects on fifth-grade students' mathematical problem-solving ability using a quasi-experimental nonequivalent pretest–posttest comparison-group design. The sample comprised 102 students across three conditions: PBL (n = 33), GeoGebra-assisted learning (n = 38), and PBL assisted by GeoGebra (n = 31). Data were collected using a validated and reliable essay-based problem-solving test and analyzed using pretest, posttest, N-Gain, and Kruskal–Wallis procedures. The PBL group achieved the highest posttest mean (50.03) and N-Gain (0.38; moderate), followed by PBL assisted by GeoGebra (41.48; 0.29, low) and GeoGebra-assisted learning (38.71; 0.24, low). The Kruskal–Wallis test revealed a significant difference in improvement among the three groups (p = .005). Overall, PBL showed the greatest descriptive improvement in mathematical problem-solving ability within the study context, although pairwise comparisons are required to establish which specific treatment differences were statistically significant.

Keywords: *Elementary mathematics, GeoGebra, Mathematical problem solving, Problem-Based Learning, Solid geometry.*

I. INTRODUCTION

Mathematics is a fundamental discipline that plays an important role in developing students' logical, critical, systematic, and creative thinking. Beyond its position as a school subject, mathematics provides concepts and methods that are applicable to a wide range of problems encountered in science, technology, economics, and everyday life. Mathematics instruction should therefore extend beyond mastery of concepts and procedures to provide students with opportunities to apply mathematical knowledge meaningfully in real-world situations (Yoga, 2025).

One of the essential competencies to be developed through mathematics instruction is mathematical problem-solving ability. The National Council of Teachers of Mathematics identifies problem solving as an important process standard in mathematics education (Widianti et al., 2024). This competency is also increasingly important because students are expected to address complex and unfamiliar problems that require more than procedural knowledge (Pertiwi et al., 2024). Mathematical problem solving refers to students' ability to use mathematical concepts, principles, and procedures to formulate appropriate solutions to a given problem (Riyanto & Amidi, 2024). According to Polya, as cited in Isrok'atun (2023), problem solving involves four interrelated stages: understanding the problem, devising a solution strategy, carrying out the strategy, and reviewing the solution. These stages require students to identify relevant information, determine appropriate procedures, implement their reasoning accurately, and evaluate the resulting solution.

Accordingly, mathematical problem-solving ability is unlikely to develop optimally through computational exercises alone. Students require learning experiences that actively engage them in interpreting problems, constructing strategies, implementing solutions, discussing alternative approaches, and evaluating their reasoning. Instruction should therefore emphasize not only whether students obtain the correct answer but also how they construct and justify the process used to reach that answer. Such learning experiences are particularly important in elementary mathematics, where students are beginning to establish conceptual and strategic foundations for more advanced mathematical reasoning.

Within elementary mathematics, geometry provides a particularly relevant context for developing problem-solving skills because it requires students to understand spatial relationships and connect abstract mathematical ideas with objects and situations in their environment. Geometry enables students to represent surrounding objects through mathematical forms and provides opportunities to engage in higher-order thinking, including mathematical problem solving (Kusnadi et al., 2025; Maulana, 2025). One important elementary geometry topic is the volume of three-dimensional shapes, which requires students not merely to memorize formulas but also to understand relationships among dimensions, space, and units of volume.

Initial evidence from an interview with a fifth-grade teacher at an elementary school in Kasokandel District indicated that students continued to experience difficulties solving mathematical problems involving the volume of three-dimensional shapes. The difficulties were particularly apparent when students were required to understand contextual problems, identify relevant information, determine an appropriate solution strategy, and formulate conclusions. Similar difficulties have been reported by Yuliyani et al. (2023), who found that students experienced challenges in understanding mathematical word problems and determining appropriate solution strategies. Khoriyani and Nurhakim (2023) further suggested that instruction dominated by formula memorization and procedural exercises provides limited opportunities for students to develop conceptual understanding and problem-solving strategies, particularly when they encounter problems that differ from previously demonstrated examples.

These challenges indicate the need for an instructional approach that places students in meaningful problem situations and actively involves them in constructing solutions. Problem-Based Learning (PBL) is relevant to this objective because it uses authentic or contextual problems as the starting point for learning. Through PBL, students are encouraged to identify problems, seek relevant information, formulate possible solutions, discuss alternative strategies, and evaluate the solutions they produce. Consequently, students participate not only in acquiring mathematical knowledge but also in developing reasoning, critical thinking, and problem-solving skills (Susino et al., 2023).

Conceptually, the learning processes embedded in PBL are closely related to Polya's problem-solving stages. Problem orientation can facilitate understanding of the problem; investigation and collaborative discussion provide opportunities to devise appropriate solution strategies; the development and presentation of solutions allow students to implement and communicate their reasoning; and reflection encourages them to reconsider the accuracy and appropriateness of their solutions. PBL may therefore provide an instructional structure through which the different stages of mathematical problem solving can be practiced systematically rather than treated as isolated procedural activities.

However, applying PBL to three-dimensional geometry also requires instructional support that enables elementary students to represent and manipulate spatial objects. This is particularly important because abstract representations of three-dimensional shapes and volume can be difficult to understand when presented only through formulas or static illustrations. GeoGebra provides a dynamic mathematical environment integrating geometry, algebra, graphics, and computation (Aulya et al., 2024). Its interactive features enable students to manipulate geometric objects and observe their properties dynamically (Moron et al., 2025). In learning the volume of three-dimensional shapes, GeoGebra can therefore provide visual representations of three-dimensional models, their constituent elements, nets, and relationships involved in the formation of volume.

The integration of PBL and GeoGebra offers a theoretically complementary instructional approach. PBL structures students' engagement with mathematical problems by requiring them to understand the problem, formulate strategies, implement solutions, and reflect on the results, whereas GeoGebra provides dynamic visual representations that may facilitate conceptualization of otherwise abstract geometric relationships. Their integration may therefore enable students to coordinate problem-solving processes with visual-conceptual representations when determining mathematical solutions. Previous evidence supports this possibility. Mulianti et al. (2023) reported that technology-assisted PBL could improve students' problem-solving ability, while Aulya et al. (2024) found that integrating PBL with GeoGebra facilitated engagement with contextual mathematical problems and conceptual understanding. Nevertheless, the potential advantage of integrating these components over using either PBL or GeoGebra separately requires direct empirical comparison.

Previous studies have separately examined PBL, GeoGebra, and technology-supported PBL in mathematics education. PBL has been reported to improve mathematical problem-solving performance compared with conventional instruction (Susino et al., 2023; Ramadisya et al., 2025), while GeoGebra has been used to support geometry learning and mathematical problem solving (Hidayati & Murtiyasa, 2024). Aulya et al. (2024) also reported favorable outcomes for PBL assisted by GeoGebra compared with conventional instruction in learning circle equations. However, the existing studies cited in this study have predominantly compared one instructional approach with conventional or control instruction, rather than directly comparing PBL, GeoGebra, and PBL assisted by GeoGebra within the same empirical design. Furthermore, evidence involving these three conditions specifically in elementary-school instruction on the volume of three-dimensional shapes remains limited. This creates an important comparative research gap because separate studies cannot establish the relative performance of the three instructional conditions when examined within the same learning context.

Accordingly, this study aimed to compare the effects of Problem-Based Learning, GeoGebra-assisted learning, and Problem-Based Learning assisted by GeoGebra on fifth-grade students' mathematical problem-solving ability in learning the volume of three-dimensional shapes. Rather than examining whether each approach is superior to conventional instruction, the study directly compares the three instructional conditions to determine whether students' mathematical problem-solving performance differs across them. Based on the theoretical characteristics of PBL and the visual-representational affordances of GeoGebra, it was hypothesized that a significant difference would exist in mathematical problem-solving ability among students receiving PBL, GeoGebra-assisted learning, and PBL assisted by GeoGebra.

II. METHOD

This study employed a quantitative approach using a quasi-experimental nonequivalent pretest–posttest comparison-group design to compare three instructional treatments. Participants were fifth-grade students from three elementary schools implementing the Kurikulum Merdeka during the second semester of the 2025/2026 academic year. The groups were selected purposively based on grade level, curriculum, and a minimum class size of 30 students. The first group comprised 33 students from SDN Ranjiwetan I who received Problem-Based Learning (PBL), the second comprised 38 students from SDN Jatimulya II who received GeoGebra-assisted learning, and the third comprised 31 students from SDN Kasokandel I who received PBL assisted by GeoGebra, resulting in a total sample of 102 students. All groups completed a pretest, received three instructional sessions on the volume of three-dimensional shapes, and subsequently completed a posttest. To minimize instructional variation, all treatments were delivered by the same researcher using equivalent learning objectives, content, instructional duration, and assessment instruments; the primary difference among groups was the instructional treatment. Baseline analysis of pretest scores using the Kruskal–Wallis test indicated no statistically significant difference among the three groups ($p = .387$), suggesting relatively comparable initial mathematical problem-solving performance.

Mathematical problem-solving ability was measured using a seven-item essay test developed according to Polya's four problem-solving indicators: (1) understanding the problem, (2) devising a solution plan, (3) carrying out the plan, and (4) reviewing the solution. Each problem contained prompts representing these four processes and addressed the volume of three-dimensional shapes, including cubes, rectangular prisms, and triangular prisms. The instrument was reviewed by three elementary school teachers experienced in mathematics instruction and subsequently pilot-tested. Item validity, reliability, difficulty level, and discrimination were examined before the instrument was administered in the main study. The instrument was considered suitable for use after meeting the established validity criteria and demonstrating reliability above .70.

Table 1. Blueprint of the Mathematical Problem-Solving Test

No.	Learning Indicator	Polya's Problem-Solving Indicators	Item
1	Solve problems involving the volume of a cube	Understanding the problem; devising a plan; carrying out the plan; reviewing the solution	1

2	Solve problems by comparing the volumes of a rectangular prism and a cube	Understanding the problem; devising a plan; carrying out the plan; reviewing the solution	2
3	Solve problems involving the volume of a partially filled rectangular prism	Understanding the problem; devising a plan; carrying out the plan; reviewing the solution	3
4	Solve problems involving the volume of a rectangular prism and determine whether sufficient space is available	Understanding the problem; devising a plan; carrying out the plan; reviewing the solution	4
5	Solve problems involving the volume of a rectangular prism	Understanding the problem; devising a plan; carrying out the plan; reviewing the solution	5
6	Solve problems involving the volume of a triangular prism	Understanding the problem; devising a plan; carrying out the plan; reviewing the solution	6
7	Determine the height of a rectangular prism from a known volume	Understanding the problem; devising a plan; carrying out the plan; reviewing the solution	7

Data were analyzed using SPSS 16.0. The Shapiro–Wilk and Levene tests were used to examine normality and homogeneity of variance, respectively. Within-group pretest–posttest differences were analyzed using a paired-samples t-test for normally distributed data or the Wilcoxon signed-rank test when normality was not satisfied. Between-group differences were examined using one-way ANOVA when parametric assumptions were met or the Kruskal–Wallis test otherwise. N-Gain scores were calculated to quantify improvement in mathematical problem-solving ability across the three groups. Differences in N-Gain among treatments were subsequently examined using the Kruskal–Wallis test, followed by Dunn–Bonferroni post-hoc comparisons when a significant omnibus difference was identified. Epsilon squared (ε^2) was calculated as the effect-size measure to estimate the magnitude of between-group differences.

III. RESULTS AND DISCUSSION

A. Results

1. Descriptive Analysis of Pretest and Posttest Scores

Descriptive analysis was conducted to examine changes in mathematical problem-solving scores across the three instructional groups: **Problem-Based Learning (PBL), GeoGebra-assisted learning, and PBL assisted by GeoGebra**. Table 2 presents the minimum, maximum, and mean scores obtained before and after the interventions.

Table 2. **Descriptive Statistics of Pretest and Posttest Scores**

Instructional Group	Test	Minimum	Maximum	Mean	Mean Difference
PBL	Pretest	5	45	18.88	31.15
	Posttest	18	99	50.03	
GeoGebra	Pretest	5	29	19.50	19.21
	Posttest	15	62	38.71	
PBL assisted by GeoGebra	Pretest	3	52	17.90	23.58
	Posttest	18	96	41.48	

The pretest means were relatively close across the three groups, ranging from 17.90 to 19.50. GeoGebra-assisted learning recorded the highest initial mean (19.50), followed by PBL (18.88) and PBL assisted by GeoGebra (17.90). As established by the baseline analysis reported in the Method section, these differences were not statistically significant ($p = .387$), indicating no evidence of significant baseline differences in mathematical problem-solving performance among the groups.

Posttest scores increased in all three groups, although the magnitude of change varied. The PBL group achieved the highest posttest mean (50.03), followed by PBL assisted by GeoGebra (41.48) and GeoGebra-assisted learning (38.71). The corresponding raw mean increases were 31.15, 23.58, and 19.21 points, respectively. Descriptively, therefore, the PBL group demonstrated the largest pretest–posttest improvement. However, these raw-score differences alone do not establish whether the magnitude of improvement differed significantly among the three treatments; this was examined subsequently through N-Gain and between-group inferential analyses.

Despite the increase across all groups, the highest posttest mean was only 50.03, suggesting that students' overall mathematical problem-solving performance remained limited after the interventions. Analysis across Polya's problem-solving indicators further showed that carrying out the solution plan remained comparatively difficult. Students appeared better able to identify the problem and formulate an initial strategy than to accurately translate that strategy into the calculations required to solve problems involving the volume of three-dimensional shapes. This pattern indicates that improvement in overall scores did not necessarily reflect equivalent development across all components of mathematical problem solving.

The difficulty in carrying out a solution plan was particularly evident in tasks requiring students to coordinate several procedural steps, such as selecting an appropriate formula, relating the given information to the required quantity, performing calculations accurately, and verifying whether the resulting answer was consistent with the problem context. Thus, although the descriptive results indicate improvement following each instructional treatment, they also reveal persistent difficulties in translating problem-solving plans into accurate mathematical procedures. The comparative effectiveness of the three treatments therefore requires consideration of the subsequent inferential and N-Gain analyses rather than posttest means alone.

2. Within-Group Pretest–Posttest Differences

Within-group analyses were conducted to determine whether students' mathematical problem-solving performance changed significantly from pretest to posttest. The Shapiro–Wilk test was first applied to determine the appropriate statistical procedure. A paired-samples t-test was used when both measurements satisfied the normality assumption, whereas the Wilcoxon signed-rank test was used when this assumption was not met.

Table 3. Normality and Within-Group Difference Tests

Instructional Group	Test	Minimum	Maximum	Mean	Mean Difference
PBL	Pretest	5	45	18.88	31.15
	Posttest	18	99	50.03	
GeoGebra	Pretest	5	29	19.50	19.21
	Posttest	15	62	38.71	
PBL assisted by GeoGebra	Pretest	3	52	17.90	23.58
	Posttest	18	96	41.48	

The PBL and GeoGebra groups satisfied the normality assumption ($p > .05$ for both pretest and posttest scores); therefore, paired-samples t-tests were applied. Both groups showed statistically significant pretest–posttest differences ($p < .001$). In contrast, the PBL assisted by GeoGebra group did not satisfy the normality assumption (pretest, $p = .010$; posttest, $p = .001$), and the Wilcoxon signed-rank test likewise identified a significant difference between pretest and posttest scores ($p < .001$). These results demonstrate that mathematical problem-solving scores changed significantly from pretest to posttest in all three instructional groups. Considered together with the descriptive results, in which posttest means were higher than pretest means across all groups, the findings indicate significant improvement following each instructional treatment. However, these within-group tests do not establish which treatment produced the greatest improvement; between-group analysis of the magnitude of change is required for that conclusion.

3. N-Gain Analysis

N-Gain analysis was conducted to quantify the magnitude of improvement in students' mathematical problem-solving ability relative to the maximum possible improvement. The results for the three instructional groups are presented in Table 4.

Table 4. N-Gain of Mathematical Problem-Solving Ability

Instructional Group	Mean N-Gain	Category
PBL	0.38	Moderate

GeoGebra	0.24	Low
PBL assisted by GeoGebra	0.29	Low

All three groups demonstrated positive N-Gain scores, although the magnitude of improvement differed descriptively. The PBL group achieved the highest mean N-Gain (0.38), classified as moderate, followed by PBL assisted by GeoGebra (0.29) and GeoGebra-assisted learning (0.24), both classified as low. Thus, the descriptive results indicate that PBL produced the greatest proportional improvement in mathematical problem-solving performance, whereas adding GeoGebra to PBL did not result in a higher N-Gain than PBL alone. Whether these differences were statistically significant was subsequently examined through between-group inferential analysis.

To identify which components of mathematical problem solving showed the greatest improvement, N-Gain scores were also calculated for each of Polya's four indicators.

Table 5. N-Gain by Mathematical Problem-Solving Indicator

Problem-Solving Indicator	PBL	Category	GeoGebra	Category	PBL + GeoGebra	Category
Understanding the problem	0.35	Moderate	0.03	Low	0.23	Low
Devising a solution plan	0.67	Moderate	0.46	Moderate	0.50	Moderate
Carrying out the plan	0.23	Low	0.18	Low	0.22	Low
Reviewing the solution	0.48	Moderate	0.24	Low	0.23	Low

The indicator-level analysis revealed a consistent pattern across the three groups. Devising a solution plan showed the greatest improvement, reaching moderate N-Gain levels in PBL (0.67), GeoGebra (0.46), and PBL assisted by GeoGebra (0.50). In contrast, carrying out the plan remained in the low category across all treatments, with N-Gain values of 0.23, 0.18, and 0.22, respectively. The PBL group additionally demonstrated moderate improvement in understanding the problem (0.35) and reviewing the solution (0.48), whereas these indicators remained in the low category in the other two groups. Overall, the descriptive pattern suggests that students improved more strongly in formulating solution strategies than in accurately executing those strategies.

4. Between-Group Differences

A Kruskal–Wallis test was conducted to examine differences in mathematical problem-solving performance across the three instructional groups. The nonparametric procedure was selected because the normality assumption was not satisfied for all groups.

Table 6. Kruskal–Wallis Test of Pretest and Posttest Scores

Measurement	Kruskal–Wallis *p*	Interpretation
Pretest	.387	Not significant
Posttest	.008	Significant

The pretest scores did not differ significantly among the PBL, GeoGebra, and PBL assisted by GeoGebra groups ($p = .387$), providing further evidence that the groups had relatively comparable baseline mathematical problem-solving performance. In contrast, a significant between-group difference was identified for the posttest scores ($p = .008$). Descriptively, the PBL group obtained the highest posttest mean (50.03), followed by PBL assisted by GeoGebra (41.48) and GeoGebra-assisted learning (38.71). However, the significant omnibus Kruskal–Wallis result indicates only that at least one group differed from another; it does not identify the specific pairs responsible for the difference.

To provide a more appropriate comparison of improvement across treatments, the N-Gain scores were subsequently analyzed. Because the N-Gain distributions did not satisfy the normality assumption in all three groups, the Kruskal–Wallis test was used.

Table 7. Between-Group Comparison of N-Gain Scores

Instructional Group	Mean N-Gain	Shapiro–Wilk *p*	Distribution
PBL	0.38	.021	Non-normal

GeoGebra	0.24	.299	Normal
PBL assisted by GeoGebra	0.29	.001	Non-normal

Kruskal–Wallis test: p = .005

The analysis revealed a statistically significant difference in N-Gain among the three instructional groups (p = .005). The PBL group demonstrated the highest mean N-Gain (0.38), followed by PBL assisted by GeoGebra (0.29) and GeoGebra-assisted learning (0.24). These findings indicate that the magnitude of improvement in mathematical problem-solving ability differed significantly across the three instructional conditions. Descriptively, the greatest improvement occurred in the PBL group.

However, the significant Kruskal–Wallis result does not yet establish that PBL significantly outperformed each of the other two treatments individually. Pairwise Dunn–Bonferroni post-hoc comparisons, as specified in the Method section, are required to determine whether the significant difference occurred between PBL and GeoGebra, PBL and PBL assisted by GeoGebra, GeoGebra and PBL assisted by GeoGebra, or more than one pair. The corresponding epsilon-squared (ε^2) should also be reported to indicate the magnitude of the overall between-group effect.

B. Discussion

The findings showed that all three instructional conditions were followed by improvements in students' mathematical problem-solving ability, although the magnitude of improvement varied. The PBL group obtained the highest mean N-Gain (0.38; moderate), followed by PBL assisted by GeoGebra (0.29; low) and GeoGebra-assisted learning (0.24; low). The Kruskal–Wallis analysis further indicated a significant difference in improvement among the three groups (p = .005). These findings suggest that the instructional approach influenced the extent to which students' problem-solving performance developed, with the strongest descriptive improvement observed in the PBL group. This pattern supports previous evidence that appropriate instructional strategies and technology-supported representations can contribute to mathematical problem solving (Muthia et al., 2024; Nabilah & Siregar, 2023).

The stronger improvement observed in the PBL group may be explained by the close alignment between PBL activities and Polya's problem-solving processes. Students were required to engage with contextual problems, identify relevant information, formulate solution strategies, discuss possible procedures, present their reasoning, and reflect on the resulting solutions. Classroom observations also indicated that students gradually became more active in identifying information, discussing solution procedures, and justifying their answers. Such activities provide repeated opportunities to practice problem solving as a reasoning process rather than merely applying predetermined formulas. This interpretation is consistent with previous studies reporting positive contributions of PBL to mathematical problem solving and other higher-order thinking skills (Ningrum et al., 2023; Alghifari et al., 2023; Restudila et al., 2023; Ramadisya et al., 2025).

Nevertheless, improvement was not uniform across Polya's four indicators. Devising a solution plan showed the strongest improvement across all groups, with N-Gain values of 0.67 for PBL, 0.46 for GeoGebra, and 0.50 for PBL assisted by GeoGebra. In contrast, carrying out the plan remained low across the three conditions (0.23, 0.18, and 0.22, respectively). This pattern suggests that students became better at determining how a problem could be solved but continued to experience difficulty translating their strategies into accurate mathematical procedures. Problems involving the volume of three-dimensional shapes require students to coordinate conceptual understanding, formula selection, relevant information, and numerical operations. Consequently, developing an appropriate strategy does not necessarily guarantee successful execution, particularly when several procedural steps must be coordinated.

GeoGebra provided a different form of instructional support. Its dynamic representations enabled students to observe and manipulate three-dimensional objects, potentially making geometric relationships more accessible than static representations. Such visualization is particularly relevant to elementary geometry, where students may benefit from concrete and manipulable representations when constructing spatial concepts (Qomariah, 2025). This is consistent with Hidayati and Murtiyasa (2024), who emphasized the contribution of GeoGebra to geometry learning through interactive visualization. However, the GeoGebra group recorded the lowest overall N-Gain (0.24). The indicator-level findings suggest that visualization alone was insufficient to provide systematic practice across all stages of problem solving, particularly the execution of solution procedures. Thus, GeoGebra may be more appropriately understood as a representational tool that supports mathematical reasoning rather than as a substitute for an explicit problem-solving strategy.

An important finding was that PBL assisted by GeoGebra did not produce greater improvement than PBL alone, despite the theoretical complementarity of problem-based investigation and dynamic visualization. The combined group achieved an N-Gain of 0.29 compared with 0.38 in the PBL group. Observations during implementation provide several plausible explanations. Some students were still adapting to GeoGebra, several were less confident during presentations, and smartphone use occasionally became a source of distraction. Moreover, GeoGebra was used primarily to visualize geometric concepts rather than being systematically embedded throughout all stages of problem solving. Consequently, students had to simultaneously engage with the PBL process, operate the application, and interpret its visual representations. For elementary students, these concurrent demands may have divided attention and increased cognitive demands during learning. Therefore, the present findings should not be interpreted as evidence that integrating GeoGebra with PBL is inherently less effective; rather, they highlight the importance of student readiness, technological familiarity, classroom management, and instructional integration in determining the value of technology-supported PBL.

The comparative design provides an additional contribution to the existing literature. Previous studies have reported positive outcomes for PBL or GeoGebra, frequently by comparing one intervention with conventional instruction (Ramadisya et al., 2025; Hidayati & Murtiyasa, 2024). The present study instead directly compared PBL, GeoGebra-assisted learning, and PBL assisted by GeoGebra within the same research framework. The results indicate that adding a technological component does not automatically produce greater learning gains than a well-structured pedagogical approach. Rather, technology appears most valuable when its functions are explicitly aligned with the cognitive processes required by the learning task.

These findings should nevertheless be interpreted within the limitations of the study. The three groups were drawn from different schools without random assignment, meaning that school and student characteristics may have influenced the outcomes despite the absence of significant baseline differences ($p = .387$). The intervention was also limited to three instructional sessions, which may have been insufficient for students to become proficient in both mathematical problem solving and GeoGebra use. Furthermore, although the Kruskal–Wallis test showed a significant overall difference in N-Gain ($p = .005$), this omnibus result alone does not establish which specific pairs of groups differed significantly. Pairwise post-hoc results are therefore required before concluding that PBL statistically outperformed either of the other treatments. Future studies should employ stronger group controls, longer intervention periods, and more systematic integration of GeoGebra across the PBL stages to clarify the comparative effectiveness of these approaches.

IV. CONCLUSION

This study demonstrated significant differences in the improvement of mathematical problem-solving ability among students receiving Problem-Based Learning (PBL), GeoGebra-assisted learning, and PBL assisted by GeoGebra in learning the volume of three-dimensional shapes ($p = .005$). The PBL group achieved the highest mean N-Gain (0.38; moderate), followed by PBL assisted by GeoGebra (0.29; low) and GeoGebra-assisted learning (0.24; low), indicating that PBL produced the greatest descriptive improvement within the study context. Nevertheless, the relatively modest posttest performance suggests that students' mathematical problem-solving ability still requires further development. These findings provide comparative empirical evidence regarding the three instructional approaches; however, interpretation should consider that the treatments were implemented in different schools without random assignment. Future research should employ stronger experimental controls, preferably including PBL, GeoGebra, PBL assisted by GeoGebra, and a control group, with longer interventions and, where feasible, randomization within comparable school settings to establish more robust evidence of their relative effectiveness.

CONFLICT OF INTEREST

The authors report no competing interests that could have affected the conduct, analysis, interpretation, or reporting of this study.

AUTHOR CONTRIBUTIONS

Nelyan Setia Zehanara *was responsible for the study conceptualization, research design, instrument preparation, implementation of the instructional treatments, data collection, statistical analysis, and initial manuscript preparation.* ***Maulana*** *contributed to the methodological development, supervision of the research process, interpretation of the results, and critical revision of the manuscript.* ***Isrok'atun*** *contributed to the theoretical and methodological framework, evaluation of the research instruments and procedures, interpretation of the findings, and substantive review of the manuscript. All authors participated in refining the final manuscript, approved the version submitted for publication, and accept responsibility for the integrity of the work.*

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES

Generative AI tools were used only during manuscript preparation to assist with language editing, sentence refinement, and improvement of academic readability. No AI tools were employed to generate or modify research data, perform statistical analyses, determine research findings, or make scientific interpretations. The authors independently examined and revised all AI-assisted text and retain full responsibility for the accuracy, originality, and integrity of the published work.

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