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DEVELOPMENT OF PROBLEM-BASED LEARNING MODEL USING GEOGEBRA TO IMPROVE STUDENTS' MATHEMATICAL CONNECTIONS AND LEARNING MOTIVATION IN ELEMENTARY SCHOOLS

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ABSTRACT

Mathematics education in elementary schools plays a crucial role in fostering students' logical, systematic, and critical thinking skills. However, the prevalence of ineffective instructional approaches, which are often perceived as abstract and mechanistic, remains a significant issue that contributes to students' poor mathematical connection skills and low learning motivation. This study aims to develop a valid, practical, and effective Problem-Based Learning (PBL) model assisted by *GeoGebra software* to enhance the mathematical connection abilities and learning motivation of fifth-grade elementary students. The research employed a quantitative approach utilizing the Research and Development (R&D) method based on the Borg & Gall model. The study involved 23 fifth-grade students at SDIT Ibnu Khaldun. Data were collected using expert validation sheets, mathematical connection ability tests (pretest and posttest), learning motivation questionnaires, and learning implementation observation sheets. The collected data were analyzed using descriptive statistics and non-parametric inferential statistics, specifically the Mann-Whitney tests. The results indicate that the developed learning model meets the high validity criteria, achieving 87.45% from subject matter experts and 88.3% from media experts, and is highly practical with a 92.85% syntax implementation rate. Regarding effectiveness, the results demonstrate a significant improvement in mathematical connection skills (p-value $0.000 < 0.05$), and student learning motivation scores increased significantly from 68.42 to 82.15. In conclusion, the GeoGebra-assisted Problem-Based Learning model is proven to be valid, practical, and effective. This model is highly suitable as an alternative strategy for interactive, contextual, and technology-driven mathematics instruction in elementary education.

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INTRODUCTION

Mathematics education in elementary schools plays a crucial role in fostering students' logical, systematic, and critical thinking skills. One of the primary focal points is mathematical connection ability, which is the capacity to understand the relationships between mathematical concepts, bridge mathematics with other disciplines, and apply these concepts in daily life (Fatimah et al., 2023; Radiusman, 2020; Wahyuni & Prihatiningtyas, 2020). Through mathematical connections, students do not merely learn procedures or formulas mechanically, but also grasp the deeper meaning of concepts, making learning more meaningful (Duha & Harefa, 2024; Hutneriana et al., 2024).

However, in elementary school practice, international studies such as TIMSS and PISA indicate that Indonesian students' ability to associate various mathematical ideas to solve non-routine problems remains low. This is exacerbated by teaching practices that focus on routine exercises and mechanistic procedures (Apriani & Sudiansyah, 2024). This monotonous approach limits students' exploration, leading them to memorize steps without understanding the logical connections between concepts (Mytra & Christi, 2024). Furthermore, presenting abstract material without adequate visualization makes it difficult for students to relate mathematical concepts to real-world situations (Fadilah et al., 2026).

Learning motivation acts as the engine for this connection process. Research shows that high motivation correlates positively with learning outcomes, while lack of motivation hinders the active cognitive engagement required for building mathematical connections. When students fail to see the relevance of mathematics, their motivation to explore conceptual relationships declines significantly (Zakia et al., 2024).

Currently, many students show low motivation due to boredom, resulting in passive participation and poor grades. This is consistent with the researcher's field observations and in-depth interviews, which revealed that students tend to lack enthusiasm when presented with theoretical mathematical materials. Based on these field findings, and supported by preliminary studies, there are three primary factors contributing to low student motivation in mathematics: (1) student capability, (2) the learning environment, and (3) the teacher's pedagogical guidance (Fatmawati, 2021).

Problem-Based Learning (PBL) serves as an effective solution. This model presents contextual problems, encouraging students to investigate, discuss, and construct knowledge independently (Husna et al., 2025; Kusnandar et al., 2025). Real-world problems are essential for enhancing reasoning, logical thinking, and higher-order thinking skills (Samura, 2019). Research demonstrates that applying PBL can improve students' problem-solving abilities and confidence (Susanti et al., 2022).

Furthermore, integrating interactive digital media is essential to bridge abstract material. Without such innovation, limited media can hinder students from exploring concepts deeply, especially when those concepts require dynamic visual representations (Aisyah et al., 2025).

Software such as *GeoGebra* is a crucial solution for elementary classrooms (Najah & Mandailina, 2024). This technology integration transforms static objects into interactive digital manipulatives (Syarifah & Yasin, 2024). Through *GeoGebra*, students can visualize mathematical concepts dynamically, making exploration easier and more engaging (Aien et al., 2025).

Although the effectiveness of PBL and *GeoGebra* is widely recognized, most previous studies position them separately or partially. PBL implementation is often constrained by limited visualization of abstract materials (Firdaus et al., 2021), while *GeoGebra* is frequently used only as a one-way demonstration tool rather than being embedded in a systematic instructional syntax. Therefore, there is an urgent need to design an instructional model that organically integrates *GeoGebra* into PBL phases to facilitate deep mathematical connections while responding to the fluctuating dynamics of student motivation in elementary schools.

Consequently, this study aims to develop a valid, practical, and effective *GeoGebra-assisted Problem-Based Learning* model to enhance mathematical connection abilities and learning motivation in fifth-grade elementary students. The novelty of this research lies in its instructional syntax, specifically designed to integrate *GeoGebra*'s dynamic features into every phase of Problem-Based Learning, from problem orientation to evaluation.

METHOD

This research employed the *Research and Development* (R&D) method, adapting Borg & Gall's model of development. This approach was chosen to ensure that the product developed went through a systematic process, from needs analysis to implementation, resulting in a valid, practical, and effective product. This research was conducted at SDIT Ibnu Khaldun. The study involved 23 fifth-grade students as subjects. The selection of these subjects was based on the urgent need to enhance students' mathematical connection abilities and learning motivation through instructional innovation in the classroom. The stages involved in this research are shown in the following diagram:

Figure 1. Flowchart of the Borg & Gall Research and Development Procedure.

Research and Information Collecting

This stage includes a preliminary study to map the problem through a needs assessment, a review of relevant literature, and field observations. The goal is to identify gaps between ideal and actual conditions as a theoretical basis for product development.

Planning

Researchers formulate a comprehensive development plan, including establishing research objectives, formulating expected competencies, defining the scope of the material, and developing evaluation instruments. This stage also includes estimating time allocation and operational costs.

Develop a Preliminary Form of Product

This stage focuses on the initial design or prototype of the product (such as a module, learning media, or model). Development is based on the theoretical foundation and plans developed in the previous stage.

Preliminary Field Testing

Trials are conducted on a small scale (in small groups). Data is collected through interviews, observations, or initial questionnaires to gather qualitative feedback on product weaknesses and areas for improvement before broader testing.

Main Product Revision

Based on data from initial field trials, researchers made product refinements. These revisions were essential to ensure the product's substance was more mature and to minimize technical errors before further testing.

Main Field Testing

The revised product is tested on a wider scale. The focus of this stage is to measure the product's effectiveness and feasibility more objectively using standardized instruments.

Operational Product Revision

The results of the main field trials are further analyzed to refine the product. At this stage, operational and technical input from a larger number of test subjects is integrated to improve product quality.

Large-Scale Trial / Feasibility Test (Operational Field Testing)

The product testing phase under real-world conditions (full implementation). Researchers use measurement instruments to demonstrate the product's effectiveness, usability, and usefulness on a broad operational scale.

Final Product Revision

The final refinement step is based on the results of operational trials. These final adjustments aim to ensure that the final product is valid, reliable, and ready for mass use.

Dissemination and Implementation

The final stage is reporting research results, disseminating products through scientific publications, socializing them, or implementing them to users/related agencies, so that the development results can make a real contribution to society.

Data Analysis Techniques

The collected data were analyzed using both descriptive and inferential statistical techniques:

Descriptive Analysis: Employed to describe and summarize the results of the pre-test and post-test, as well as to report validation scores and the level of learning syntax implementation.

Inferential Analysis: Utilized to determine the significant differences in students' abilities before and after the implementation of the developed model. Specifically, the Wilcoxon test was used to analyze paired pre-test and post-test scores, while the Mann-Whitney test was applied to compare the mathematical connection capabilities between the experimental and control groups, due to the non-normal distribution of the experimental data.

RESULTS AND DISCUSSION

Results

The product of this research is a *GeoGebra-assisted problem-based learning* model designed to improve elementary school students' mathematical connection skills and learning motivation. The products developed include the learning model's syntax, learning tools, student worksheets, and interactive *GeoGebra-based learning* media.

The developed learning model integrates the stages of problem-based learning into mathematics activities and is supported by *GeoGebra*. This model encourages students to understand mathematical concepts through contextual problem presentations, group discussions, concept exploration using interactive media, and reflection on learning outcomes. The following figure illustrates the interface and interactive features of the GeoGebra media utilized during the implementation phase:

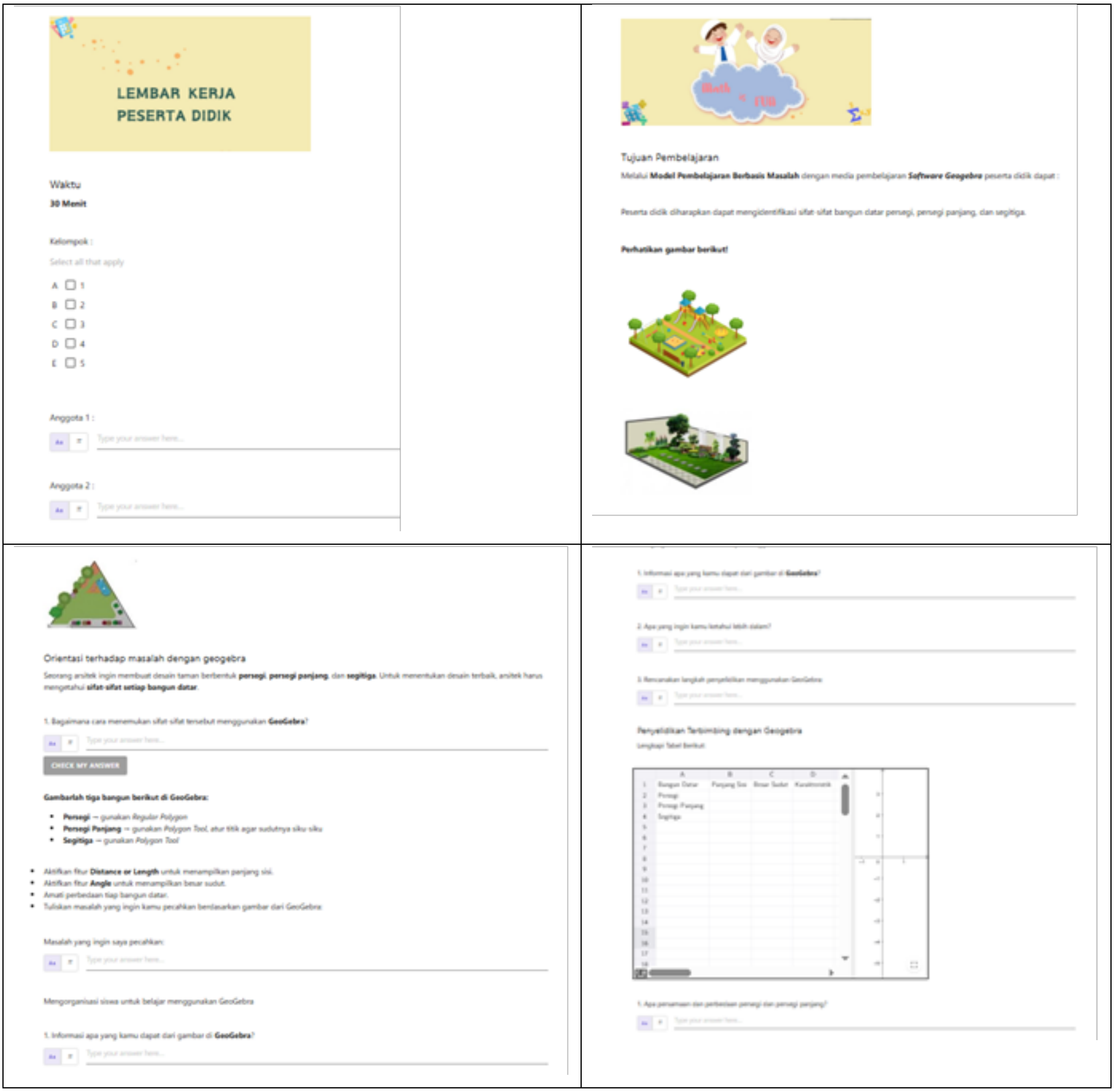

Figure 2. *GeoGebra* Interactive Media Interface Used in the Classroom.

Before being tested with students, the developed product was first validated by material and media experts to assess the feasibility of the learning model.

Results of validation by material experts

Table 1. Teaching Material Validation Results

Rated aspect	Validator 1	Validator 2	Validator 3	Total Score	SMI	Percentage Score	Criteria
Contents	14	16	14	44	48	91.6	Valid
Linguistics	13	13	15	41	48	85.4	Valid
Presentation	7	5	8	20	24	83.3	Valid
ICT used	14	14	15	43	48	89.5	Valid
Total	48	48	52	**148**	**168**	**87.45**	**Valid**

Based on the table from the three validators, the percentages for each score fall within the valid category. All aspects of the final score fall within the valid category, so the final score percentage is 87.45%, which is considered valid under the Teaching Materials criteria.

Media expert validation results

Table 2. Media expert validation results

Rated aspect	Validator 1	Validator 2	Validator 3	Total Score	SMI	Percentage Score	Criteria
Quality and completeness of learning media	19	20	17	56	60	93.3	Valid
Effective and efficient in learning	18	19	18	55	60	91.6	Valid
Suitability of learning media with related elements	7	6	5	18	24	75	Valid
Accessibility and ease of use and management	19	20	17	56	60	93.3	Valid
Total	63	65	57	**185**	**204**	**88.3**	**Valid**

The table from the three validators shows that the percentages for each score fall within the valid category. All aspects of the final score fall within the valid category, so the final score percentage is 88.3, which is considered valid for learning media and worthy of being tested.

Descriptive Statistical Analysis

Table 3. Descriptive Statistics Mathematical Connection Ability

	N	Minimum	Maximum	Mean	Standard Deviation
Pre-Test Experiment	23	29	93	62.22	11,281
Post-Test Experiment	23	80	100	86.22	5,469
Pre-Test Control	26	55	79	67.31	7,287
Post-Test Control	26	70	88	80.58	4,717
Valid N (listwise)	23				

The descriptive statistics showed a significant difference in the average increase in mathematical connection ability scores between the experimental and control groups. The average post-test score for the experimental group increased by 24.00 points from 62.22 to 86.22, while the control group increased by 13.27 points from 67.31 to 80.58. This provides an initial indication that the *GeoGebra based Problem Based Learning* model intervention is more effective at improving students' mathematical connection abilities.

Normality Test

Table 4. Normality Test Results

	Class	Kolmogorov-Smirnova Statistics	df	Sig.	Shapiro-Wilk Statistics	df	Sig.
Student Learning Outcomes	Pre-Test Experiment	.180	23	.051	.877	23	.009
	Post-Test Experiment	.173	23	.073	.880	23	.010
	Pre-Test Control	.129	26	.200*	.949	26	.224
	Post-Test Control	.139	26	.200*	.943	26	.159

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The results of the Shapiro-Wilk normality test show that the pre-test and post-test data in the control class have p-values above 0.05 (0.224 and 0.159, respectively), so they are considered normally distributed. In contrast, the pre-test and post-test data in the experimental class have significance p-values below 0.05: 0.009 and 0.010, respectively. This indicates that the data for the experimental class is not normally distributed. Because the normality requirements for the experimental class data are not met, hypothesis testing to see the effectiveness of the *Problem-Based Learning* model will use non-parametric statistics.

Independent Hypothesis Test

Table 5. Independent Hypothesis Test Results

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Nilai	Equal variances assumed	2.160	.148	-3.877	47	.000	-5.640	1.455	-8.567	-2.713
	Equal variances not assumed			-3.841	43.797	.000	-5.640	1.468	-8.600	-2.681

The analysis of the independent samples t-test presented in Table 5 indicates that the data variances are homogeneous, with a significance value of 0.148 on Levene's Test for Equality of Variances. Therefore, the hypothesis testing was based on the 'equal variances assumed' row. The calculation results show a t-value of -3.877 with 47 degrees of freedom (df). The obtained significance value (2-tailed) is 0.000, which is less than 0.05. Consequently, the null hypothesis H_0 is rejected and the alternative hypothesis Ha is accepted, indicating a statistically significant difference between the mean scores of the experimental and control groups, with a mean difference of -5.640.

Mann Whitney test

Table 6. Mann-Whitney Test Results

	Class	N	Mean Rank	Sum of Ranks
Learning outcomes	Control Class	26	18.46	480.00
	Experimental Class	23	32.39	745.00
	Total	49		

	Learning outcomes
Mann-Whitney U	129,000
Wilcoxon W	480,000
Z	-3,429
Asymp. Sig. (2-tailed)	.001

a. Grouping Variable: Class

Based on the Ranks table, the experimental class has a Mean Rank of 32.39, which is much higher than the control class's 18.46. This indicates that, overall, the achievement of students in the experimental class in mathematical connection skills is better than that of the control class.

Data from the learning observation sheet results

Table 7. Learning observations resultsa

Meeting	Total score	Percentage	Criteria
1	79		
2	77		
3	77		
4	78	92.85%	Excellent
5	78		
6	79		
Total	**468**		

Based on this data, it can generally be said that the implementation of learning according to the learning steps using the Problem-Based Learning model reached 92.85%. The implementation of learning using the developed tools is categorized as excellent.

Data from the results of the learning motivation questionnaire

Table 8. Learning Motivation Questionnaire Results

Number of students	Average initial motivation	Average final motivation	Category
23	68.42	82.15	High

Based on Table 8, students' learning motivation increased after participating in learning using the GeoGebra-assisted Problem-Based Learning model. This is evident from the lower average score of students' learning motivation before learning compared to the average score after learning. This increase indicates that implementing problem-solving activities and using interactive media can increase students' interest and engagement in the mathematics learning process. Thus, the applied learning model positively influences students' motivation to learn.

Based on the results of expert validation, limited trials, and extensive trials, the final syntax of the GeoGebra-assisted Problem-Based Learning model used in this study was obtained. This syntax was designed to facilitate students' understanding of mathematical concepts through problem-solving activities supported by interactive *GeoGebra* visualizations. The final syntax of the developed learning model is presented in Figure 3.

Figure 3. Geogebra-assisted Problem Based Learning Syntax

Discussions

The results of the study indicate that implementing the *Problem-Based Learning* (PBL) model, assisted by *GeoGebra* software, has a significant positive impact on the mathematical connection skills and learning motivation of fifth-grade elementary school students. The success of this intervention was empirically demonstrated through a series of inferential statistical tests that showed the experimental class outperformed the control class.In intra-group effectiveness testing using the Independen test, the null hypothesis H_0 states that there is no significant difference between the pre-test and post-test results in the experimental class.

However, the analysis results show an Asymp. Sig. (2-tailed) value of 0.000. Because the significance value is much smaller than the specified significance level ($0.000 < 0.05$), the statistical decision taken is to reject H_0 and accept H_a. This rejection of H_0 clearly confirms a significant increase in students' mathematical connection abilities after receiving treatment using the *GeoGebra-based* PBL model. To compare groups, a Mann-Whitney test was conducted with H_0 stating that there is no significant difference in mathematical connection achievement between the control and experimental classes. The results of this statistical test produce an Asymp. Sig. (2-tailed) value of 0.001.

Considering that the value of $0.001 < 0.05$, then H_0 is rejected and H_a is accepted, which confirms that the achievement of mathematical connection ability of experimental class students (with Mean Rank of 32.39) is significantly better than the control class (with Mean Rank of 18.46). The rejection of H_0 scientifically demonstrates that the developed learning model is highly effective at helping students connect mathematical concepts. Theoretically, the rejection of H_0 and acceptance of H_a is due to the dynamic visual support from *GeoGebra* integrated into the PBL syntax. Traditional instruction often burdens students' cognitive abilities because the material is presented in an abstract, monotonous manner.

This encourages students to focus on memorizing mechanical formulas without truly understanding their underlying meaning (Harahap, 2023). Our finding aligns with Harahap's perspective, confirming that shifting away from such traditional methods towards problem-based models effectively reduces cognitive load and enhances student focus. Using *GeoGebra* software, initially rigid mathematical concepts can be transformed into interactive, dynamic digital elements (Sumartini et al., 2023).

Supporting this notion, research by Septian (2022) highlights that the integration of *GeoGebra* into student-centered learning models significantly enhances students' mathematical connection abilities by allowing them to actively explore, visualize, and resolve complex mathematical problems. Furthermore, research by Putra et al. (2021) emphasizes that integrating *GeoGebra* into mathematics learning empowers students to dynamically visualize complex mathematical shapes, fosters positive attitudes, and provides precise manipulation tools that significantly outperform traditional drawing instruments.

Furthermore, the findings from the literature review by Siregar (2025) confirm that the consistent use of *GeoGebra* has proven effective in transforming abstract mathematical materials into visual and interactive representations, thereby strengthening students' conceptual understanding and cognitive skills across various educational levels This corroborates the research of Sumartini et al., who identified dynamic visualization as the cornerstone of instructional effectiveness in mathematics.This not only makes it easier for students to map interconnections between concepts but also motivates them to apply mathematical principles to real-world situations (Rahmi, 2024). Our data, which shows an increase in student motivation from 68.42 to 82.15, mirrors Rahmi's findings that interactive media acts as a primary catalyst for student engagement.

Furthermore, the implementation of our *GeoGebra* assisted PBL model aligns with the broader perspective on mathematical connectivity widely discussed in contemporary literature. As Hatisaru (2023) emphasizes, successful mathematics instruction relies heavily on a teacher's ability to weave mathematical connections such as linking various representations, properties, and real-world contexts rather than merely sticking to isolated formulas or procedures. This is strongly supported by Boye and Agyei (2023), whose findings demonstrate that problem-based learning strategies significantly improve mathematics teaching and learning outcomes by actively engaging pre-service teachers in learner-centred, small-group activities and collaborative discourse. Moreover, as highlighted in the comprehensive review by Schukajlow et al. (2023), fostering positive emotions and student motivation through innovative instructional methods such as interactive media and dynamic visualization is crucial for driving deep cognitive engagement and conceptual understanding in mathematics classrooms. This is where *GeoGebra*'s dynamic visualization plays a crucial role as a bridge, enabling students to systematically transition between algebraic, graphical, and tabular forms, thereby fostering a much deeper conceptual understanding, much like the high-quality instructional practices reviewed by Hatisaru

This fact strongly supports the research findings of Azizah et al. (2024), which showed that the use of information and communication technology (ICT) based on real-world problems is more effective in optimizing in-depth cognitive engagement compared to commonly practiced instructional methods. Psychopedagogically, these results align with Jean Piaget's constructivist perspective.This theory emphasizes that students construct understanding independently through the processes of assimilation and accommodation when they interact directly with real objects and manipulatives.

By using *GeoGebra* as a cognitive tool, students can explore and manipulate mathematical structures independently. This activity strengthens students' thinking frameworks in establishing strong and substantial mathematical connections, which is consistent with the findings of Astrilia et al. (2025) regarding the critical role of student autonomy in building robust connections. The positive impact of the rejection of H_0 on cognitive abilities was linear with the development of students' affective aspects.The integration of GeoGebra into the PBL phases successfully revolutionized the guidance process, in which the teacher acts as a facilitator, and students are positioned as active subjects investigating real-world problems.

Challenging problem-solving activities combined with interactive media have proven effective in triggering students' curiosity. Overall, the acceptance of this research hypothesis provides strong confirmation that the combination of PBL and *GeoGebra* is an effective, cutting-edge solution for improving the quality of mathematics learning processes and outcomes in elementary schools.

CONCLUSION

The findings of this study confirm that the implementation of the *GeoGebra-assisted Problem-Based Learning* (PBL) model significantly enhances the mathematical connection abilities and learning motivation of fifth-grade elementary school students. Empirical evidence demonstrates that this model outperforms the commonly practiced instructional methods, as indicated by the significant improvement in student performance. By integrating dynamic visualization and real-world problem-solving, the model effectively reduces cognitive load and fosters deeper mathematical connections.

Furthermore, the increase in student motivation confirms that *GeoGebra-assisted* learning creates a more engaging and active environment, successfully positioning the teacher as a facilitator and students as independent investigators. Given these positive outcomes, future research should explore the effectiveness of this model across diverse mathematical topics and grade levels to ensure its generalizability, while also examining the long-term retention of concepts. Additionally, future studies could investigate the readiness of teachers in integrating such digital tools and explore the efficacy of alternative interactive software to provide a broader comparative analysis of ICT-based learning in elementary education.

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