The effectiveness of problem-based learning (PBL) in improving mathematical conceptual understanding and numeracy of grade VIII students

Muhammad Akmal Fadhlur Rohman[1*], Elly Arliani[1]

[1]Department of Mathematics Education, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia
*Correspondence: muhammadakmal.2021@student.uny.ac.id

Abstract: This study aims to examine the effectiveness of the Problem-Based Learning (PBL) model in improving students' mathematical conceptual understanding and numeracy skills at the junior high school level. This research employed a quantitative approach using a quasi-experimental design with a pretest–posttest control group design. The participants consisted of two Grade VIII classes of SMP Negeri 2 Bambanglipuro, with 32 students in each class. The experimental group was taught using the PBL model, while the control group received expository learning. Data were collected through validated and reliable tests of mathematical conceptual understanding and numeracy. Data analysis included the Independent Samples t-test, One-Sample Z Test, One-Sample Proportion Z Test, and N-Gain analysis. The results showed that students in the PBL class achieved an average posttest score equal to or higher than the Minimum Mastery Criterion (MMC = 75) with a mastery proportion of 75%. The N-Gain scores for mathematical conceptual understanding and numeracy were 0.7587 and 0.8218, respectively, which fall into the high category. These findings indicate that the PBL model is effective in enhancing students' mathematical conceptual understanding and numeracy skills.

Keywords:
problem-based learning, mathematical conceptual understanding, numeracy, junior high school

How to Cite: Rohman, M. A. F., & Arliani, E. (2025). The effectiveness of problem-based learning (PBL) in improving mathematical conceptual understanding and numeracy of grade VIII students. *Instructional Media for Mathematics*, *3*(1), 25-39. http://doi.org/10.66161/708562

1. Introduction

Education is a fundamental aspect of national development, as mandated by the 1945 Constitution of the Republic of Indonesia. According to Peterson (2020), education is a process that enables individuals to acquire skills, values, and knowledge to develop their potential and contribute to social life. Education is also defined as a conscious effort to create a learning environment that facilitates the development of students' potential, skills, values, and knowledge (Santrock, 2009). Therefore, education plays a strategic role in shaping high-quality, competitive human resources as the foundation for national progress.

In the process of developing competitive and qualified human resources, mathematics is a compulsory subject that must be learned. Mathematics plays an important role not only as a computational discipline but also as a means of developing logical, analytical, and systematic thinking skills essential to various aspects of life. Ennis (1987) states that mathematics education plays a crucial role in preparing human resources with 21st-century competencies, including analytical competence, interpersonal competence, the ability to take action, information-processing skills, and the ability to manage change. Thus, mathematics education contributes significantly to the development of competitive human resources. Well-standardized mathematics education is expected to produce qualified individuals who can serve as the foundation for national advancement.

Quality education is essential for producing competent generations capable of facing global challenges. In the learning process, instructional methods play a crucial role in determining learning success. Mathematics is often perceived by students as a challenging subject; therefore, strong mathematical conceptual understanding is essential, as it forms the basis for learning other scientific disciplines.

Mathematics is taught at all levels of education, from elementary school to higher education. It is a fundamental science that underlies the development of modern technology and plays a vital role in advancing human thinking. Rapid developments in information and communication technology are strongly supported by advancements in mathematical fields such as number theory, algebra, analysis, probability theory, and discrete mathematics. To master and develop future technologies, a strong foundation in mathematics must be built from an early age. Mathematics learning has essential objectives for students …Hidayat (2017), which are aligned with the Regulation of the Minister of National Education of the Republic of Indonesia Number 58 of 2014, stating that understanding mathematical concepts involves explaining relationships among concepts and applying concepts or algorithms flexibly, accurately, efficiently, and appropriately in problem-solving situations.

One of the common problems in mathematics learning is students' low ability to solve mathematical problems that emphasize conceptual understanding within specific topics. Students who possess good conceptual understanding tend to achieve higher academic performance because they can follow learning activities more easily, whereas students with limited conceptual understanding often experience learning difficulties(Zhang et al., 2022). Low conceptual understanding is, therefore, an important issue that must be addressed. Conventional teaching methods commonly used in schools, such as lectures and routine exercises, are often considered ineffective in improving students' conceptual understanding because they are teacher-centered and provide limited opportunities for active student engagement. As a result, students may feel bored and unmotivated, which ultimately leads to a low level of mathematical conceptual understanding (Marchy et al., 2022).

To address these challenges, more innovative and effective learning models are needed. One widely discussed instructional model in education is Problem-Based Learning (PBL). PBL emphasizes problem-solving as the core of the learning process, placing students in situations that encourage them to explore, analyze, and solve meaningful problems (Zaenuri et al., 2020). Through this approach, students become more actively involved and motivated in learning activities. PBL has also been shown to foster mathematical reasoning and constructivist knowledge-building, as students engage in authentic problems that reflect real-world contexts positioning learners as active participants who take ownership of their education (Boye & Agyei, 2023). Research on the effectiveness of PBL in mathematics learning at the junior high school level is particularly important, as this stage represents a critical transition during which students begin to encounter more complex mathematical concepts. Research at the secondary school level has shown that PBL provides practical learning strategies that make mathematics more accessible to students who typically perceive the subject as abstract by situating skill development within collaborative, authentic problem contexts (Arbo & Ching, 2022). Effective instructional approaches at this level can have a significant positive impact on students' conceptual understanding.

This study aims to analyze the effectiveness of the PBL model in improving mathematical conceptual understanding and numeracy skills at the junior high school level. The findings are expected to contribute to mathematics education by providing empirical evidence to support the implementation of innovative and effective instructional strategies and serving as a reference for mathematics teachers in developing better learning practices. Previous studies have demonstrated the potential of PBL in enhancing students' mathematical abilities (Mary & Anastasia, 2013; Purwanti et al., 2021; Suparman et al., 2021; Suratno & Waliyanti, 2023; Ulya et al., 2024). Ramadhani et al. (2020) and Yazar Soyadı (2015) found that PBL effectively improved junior high school students' critical thinking skills, as indicated by significant differences in posttest scores between experimental and control groups. A meta-analysis synthesizing 50 empirical studies with over 5,200 participants demonstrated that PBL significantly enhances students' critical thinking skills compared to conventional instruction, with effect sizes varying by discipline, instructional design, and group size (Boye & Agyei, 2023). Similarly, Hung et al. (2012) and Suratno & Waliyanti (2023) reported that PBL enhanced students' mathematical problem-solving abilities through structured inquiry and group discussions. A quasi-experimental study in Rwanda confirmed that PBL significantly impacted all indicators of learners' problem-solving abilities, including understanding the problem, planning, and executing solution strategies in upper secondary mathematics classrooms (Dorimana et al., 2022). Chen et al. (2020) and Rahmadi et al. (2024) also reported that cognitively oriented PBL increased students' motivation and analytical skills in solving mathematical problems.

However, most previous studies have focused on a single mathematical ability, such as critical thinking or problem-solving. A systematic literature review of HOTS-oriented PBL interventions in mathematics found consistent evidence that PBL improves critical thinking, problem-solving, and creative thinking skills, while also confirming that studies simultaneously examining multiple mathematical competencies within a single PBL intervention remain limited (Aba-Oli et al., 2025). Research that simultaneously examines the effectiveness of PBL on two key competencies mathematical conceptual understanding and numeracy is still limited, particularly in the context of solid geometry topics at the junior high school level. These topics require strong representational skills, spatial visualization, and analytical reasoning, which are closely related to numeracy indicators in the Minimum Competency Assessment (AKM).

Based on these considerations, the relatively low levels of students' mathematical conceptual understanding and numeracy skills, along with the need for instructional models that promote active, meaningful, and contextual learning, highlight the importance of innovation in mathematics education (Zaenuri et al., 2020). The Problem-Based Learning (PBL) model is considered capable of engaging students directly in inquiry and real-world problem-solving activities, thereby encouraging knowledge construction, deeper conceptual understanding, and the application of mathematics in everyday contexts. Therefore, this article examines the effectiveness of the PBL model in improving Grade VIII students' mathematical conceptual understanding and numeracy skills. The objective of this study is to determine whether implementing PBL is more effective than expository learning in enhancing students' mathematical conceptual understanding and numeracy skills.

2. Methods

This study employed a quantitative approach using a quasi-experimental pretest–posttest control group design. The population consisted of all Grade VIII students of SMP Negeri 2 Bambanglipuro. Two classes were selected as samples: Class VIII D as the experimental group and Class VIII C as the control group, each consisting of 32 students. The experimental group received instruction using the Problem-Based Learning (PBL) model, while the control group was taught using an expository learning model. The learning material focused on solid geometry with flat surfaces. Data were collected using tests of mathematical conceptual understanding and numeracy that had been validated by experts and tested for reliability. Data analysis included prerequisite tests (normality and homogeneity tests), an Independent Samples t-test to examine differences between groups, a One-Sample Z test to determine the achievement of the Minimum Mastery Criterion (MMC = 75), a One-Sample Proportion Z Test to examine classical mastery, and an N-Gain analysis to measure the effectiveness of learning improvement.

3. Results and Discussion

The study began with the administration of a pretest to each sample group. The pretest scores were then used to assess students' initial abilities in both groups. Prior to conducting hypothesis testing for initial ability, prerequisite tests, also known as classical assumption tests, were conducted to ensure that the data met the conditions required for inferential statistical analysis. The purpose of these prerequisite tests was to determine the appropriate statistical procedures, ensure the validity and reliability of the hypothesis-testing results, and minimize bias and errors in data interpretation.

Given that the sample size in each group exceeded 30 students, a normality test was not conducted. According to the Central Limit Theorem, the sampling distribution of the mean tends to approximate a normal distribution when the sample size is sufficiently large ($n > 30$), even if the original data are not perfectly normally distributed. Therefore, the assumption of normality was considered acceptable, and parametric analyses, such as the independent-samples t-test, could be applied. This approach is consistent with the views of Sugiyono (2018) and Ghozali (2016), who state that for large sample sizes, data can be statistically assumed to be normally distributed, and normality testing is not an absolute requirement in data analysis.

Table 1. Results of the Pretest Homogeneity Test

Aspect	Sig.	Conclusion
Based on Mean Pretest Mathematical Conceptual Understanding	0.717	Homogen
Based on Mean Pretest Numeracy Skills	0.542	Homogen

Next, a homogeneity test was conducted. Based on the table above, the significance values (Sig.) of the pretest homogeneity test for mathematical conceptual understanding and numeracy were 0.717 and 0.542, respectively. Since the significance values for the mean pretest for both variables were greater than 0.05, it can be concluded that the pretest data of the experimental and control groups were homogeneous. Subsequently, an Independent Samples t-test was conducted to test the research hypotheses regarding the effect of the instructional treatment on students' learning outcomes. The hypotheses were formulated as follows.

1) Hypotheses for Mathematical Conceptual Understanding

$H_{0_1}: \mu_{1k} = \mu_{2k}$ (There is no effect of the Problem-Based Learning model on the mathematical conceptual understanding of Grade VIII students.)

$H_{1_1}: \mu_{1k} \neq \mu_{2k}$ (There is an effect of the Problem-Based Learning model on the mathematical conceptual understanding of Grade VIII students.)

Where:

μ_{1k} = represents the mean score of the mathematical conceptual understanding of students in the experimental group

μ_{2k} = represents the mean score of the mathematical conceptual understanding of students in the control group

2) Hypotheses for Numeracy

$H_{0_2}: \mu_{1n} = \mu_{2n}$ (There is no effect of the Problem-Based Learning model on the numeracy skills of Grade VIII students.)

$H_{1_2}: \mu_{1n} \neq \mu_{2n}$ (There is an effect of the Problem-Based Learning model on the numeracy skills of Grade VIII students.)

Where:

μ_{1n} = represents the mean numeracy score of students in the experimental group

μ_{2n} = represents the mean numeracy score of students in the control group

The decision rule was determined by comparing the significance coefficient with a significance level of 0.05. If the Sig. (2-tailed) value was greater than 0.05, the null hypothesis H_0 was accepted, and the alternative hypothesis H_1 was rejected. Conversely, if the Sig. (2-tailed) value was less than 0.05, the null hypothesis H_0 was rejected and the alternative hypothesis H_1 was accepted. The results of the Independent Samples t-test are presented in Table 2.

Table 2. Results of the Independent Samples t-Test (Pretest)

Description	T-test for Equality of Means sig. (2tailed)
Pretest Equal Variances Assumed Mathematical Conceptual Understanding	0.754
Pretest Equal Variances Variances Assumed Numeracy Skils	0.840

Table 2 shows that the significance value (2-tailed) in the Equal Variances Assumed row for mathematical conceptual understanding was 0.754. Since this Sig. value was greater than 0.05, the null hypothesis H_{0_1} was accepted, and the alternative hypothesis H_{1_1} was rejected. Therefore, it can be concluded that there was no significant effect of the Problem-Based Learning (PBL) model on the mathematical conceptual understanding of Grade VIII students at the pretest stage.

Furthermore, the table indicates that the Sig. (2-tailed) value in the Equal Variances Assumed row for numeracy was 0.840. Because this value was also greater than 0.05, the null hypothesis H_{0_2} was accepted and the alternative hypothesis H_{1_2} was rejected. Thus, there was no significant difference in numeracy skills between the experimental and control groups prior to the implementation of the instructional treatment.

After the initial ability testing, the instructional treatment was administered to each sample group. Class VIII D, which served as the experimental group, received mathematics instruction using the Problem-Based Learning (PBL) model. The PBL implementation in the experimental group followed the following instructional stages: (1) orienting students to the problem by explaining learning objectives, required resources, and motivating students to engage in selected problem-solving activities; (2) organizing students for learning by explaining the learning procedures and assigning tasks; (3) guiding individual and group investigations by assisting students in identifying and developing solutions to the given problems; (4) developing and presenting students' work by facilitating the presentation of their findings; and (5) analyzing and evaluating the problem-solving process by guiding students to reflect on and evaluate the solutions obtained.

Meanwhile, Class VIII C, which served as the control group, received mathematics instruction using an expository learning model. Both groups were taught solid geometry, focusing on flat surfaces, over two instructional meetings. After the instructional treatment, a posttest was administered to both groups to evaluate whether the treatment had an effect and whether the applied learning model was effective in improving students' learning outcomes. The following section presents the analysis of the data collected after the treatment.

Prior to conducting hypothesis testing on the posttest data, prerequisite tests, also known as classical assumption tests, were conducted to ensure the data met the requirements for inferential statistical analysis. The purpose of these prerequisite tests was to determine the appropriate statistical procedures, ensure the validity and reliability of the hypothesis testing results, and minimize bias and errors in data interpretation. The prerequisite test results for this study are presented in Table 3.

Table 3. Results of the Posttest Homogeneity Test

Aspect	Sig.	Conclusion
Based on Mean Posttest Mathematical Conceptual Understanding	0.636	Homogen
Based on Mean Posttest Numeracy Skills	0.592	Homogen

A homogeneity test was conducted on the posttest data. Based on the table above, the significance values (Sig.) of the posttest homogeneity test for mathematical conceptual understanding and numeracy were 0.636 and 0.592, respectively. Since the significance values for the mean posttest for both variables were greater than 0.05, it can be concluded that the posttest data for the experimental and control groups were homogeneous.

Subsequently, an Independent Samples t-test was employed to test the research hypotheses regarding whether the instructional treatment had a significant effect on students' learning outcomes. The hypotheses tested in this stage are presented as follows.

1) Hypotheses for Mathematical Conceptual Understanding

$H_{0_1}: \mu_{1k} = \mu_{2k}$ (There is no effect of the Problem-Based Learning model on the mathematical conceptual understanding of Grade VIII students.)

$H_{1_1}: \mu_{1k} \neq \mu_{2k}$ (There is an effect of the Problem-Based Learning model on the mathematical conceptual understanding of Grade VIII students.)

Where:

μ_{1k} = represents the mean score of the mathematical conceptual understanding of students in the experimental group

μ_{2k} = represents the mean score of the mathematical conceptual understanding of students in the control group

2) Hypotheses for Numeracy

$H_{0_2}: \mu_{1n} = \mu_{2n}$ (There is no effect of the Problem-Based Learning model on the numeracy skills of Grade VIII students.)

$H_{1_2}: \mu_{1n} \neq \mu_{2n}$ (There is an effect of the Problem-Based Learning model on the numeracy skills of Grade VIII students.)

Where:

μ_{1n} = represents the mean numeracy score of students in the experimental group

μ_{2n} = represents the mean numeracy score of students in the control group

The decision rule was determined by comparing the significance coefficient with a significance level of 0.05. If the Sig. (2-tailed) value was greater than 0.05, the null hypothesis $H_0$was accepted and the alternative hypothesis H_1 was rejected. Conversely, if the Sig. (2-tailed) value was less than 0.05, the null hypothesis H_0 was rejected and the alternative hypothesis H_1 was accepted. The results of the Independent Samples t-test are presented in Table 4.

Table 4. Results of the Independent Samples t-Test (Posttest)

Description	T-test for Equality of Mean sig. (2-tailed)
Equal Variances Assumed Mathematical Conceptual Understanding	0.000
Equal Variances Assumed Numeracy Skills	0.000

Table 4 indicates that the significance value (2-tailed) in the Equal Variances Assumed row for mathematical conceptual understanding was 0.001. Since this Sig. value was less than 0.05, the null hypothesis H_{0_1} was rejected and the alternative hypothesis H_{1_1} was accepted. Therefore, it can be concluded that the use of the Problem-Based Learning (PBL) model had a significant effect on the mathematical conceptual understanding of Grade VIII students.

Furthermore, the table shows that the Sig. (2-tailed) value in the Equal Variances Assumed row for numeracy was also 0.001. Because this value was less than 0.05, the null hypothesis H_{0_2} was rejected and the alternative hypothesis H_{1_2} was accepted. Thus, it can be concluded that the Problem-Based Learning (PBL) model had a significant effect on the numeracy skills of Grade VIII students(Darma et al., 2018). The positive effects on conceptual understanding and spatial reasoning observed in this study align with findings from a quasi-experimental study in Kazakhstan, which reported that PBL significantly improved students' critical thinking, logical reasoning, and decision-making skills in geometry compared to conventional instruction (Tursynkulova et al., 2023).

Subsequently, a One-Sample Z Test was conducted to determine whether the students' average final scores had reached or exceeded the Minimum Mastery Criterion (MMC) of 75 after the instructional treatment. The hypotheses for the One-Sample Z Test were formulated as follows.

$H_0: \mu \leq \mu_0$ (The average final score of students has not reached the Minimum Mastery Criterion)

$H_1: \mu > \mu_0$ (The average final score of students has reached the Minimum Mastery Criterion)

Where:

μ = represents the students' average final score

μ_0 = represents the Minimum Mastery Criterion (MMC)

Table 5. Results of the One-Sample Z Test

Description	Sig. (2-tailed)
Mathematical Conceptual Understanding	0.000
Numeracy Skills	0.000

Based on the results of the One-Sample Z Test presented in Table 5, the Sig. (2-tailed) value for mathematical conceptual understanding was 0.000, and the Sig. (2-tailed) value for numeracy was also 0.000. Since the significance values for both competencies were less than 0.05, the null hypothesis H_0 was rejected and the alternative hypothesis H_1 was accepted for both variables. These results indicate that the students' average final scores in mathematical conceptual understanding and numeracy had reached or exceeded the Minimum Mastery Criterion (MMC) of 75.

After conducting the One-Sample Z Test, a One-Sample Proportion Z Test was subsequently performed to determine whether the proportion of students who achieved learning mastery had reached or exceeded the classical mastery threshold of 75% after the implementation of the instructional treatment. The hypotheses for the One-Sample Proportion Z Test were formulated as follows.

$H_0: p \leq p_0$ (The proportion of students achieving learning mastery has not reached 75%.)

$H_1: p > p_0$ (The proportion of students achieving learning mastery has reached 75%.)

Where:

p = represents the proportion of students in the sample who achieved learning mastery

p_0 = represents the minimum mastery proportion established (0.75)

The results of the One-Sample Proportion Z Test based on the learning mastery data of students in the experimental group are presented in Table 6.

Table 6. Results of the One-Sample Z Test

Description	Exact Sig. (2-tailed)
Mathematical Conceptual Understanding	0.000
Numeracy Skills	0.000

Based on the results of the One-Sample Proportion Z Test presented in Table 6, the Exact Sig. (2-tailed) value for mathematical conceptual understanding was 0.000, and the Exact Sig. (2-tailed) value for numeracy was also 0.000. Since the Exact Sig. (2-tailed) values for both competencies were less than 0.05, the null hypothesis H_0 was rejected and the alternative hypothesis H_1 was accepted for both variables. These results indicate that the proportion of students achieving mastery in mathematical conceptual understanding and numeracy had reached the classical mastery criterion of 75%. This finding is consistent with a study at the junior high school level, which confirmed that PBL implementation significantly enhanced students' mathematical problem-solving skills, with post-intervention scores showing substantial and statistically significant improvement over baseline measures (Apit Dulyapit et al., 2023; Eviliasani et al., 2022; Patunah et al., 2024).

Subsequently, an N-gain analysis was conducted to assess the learning model's effectiveness in improving students' learning outcomes. The results of the N-gain analysis are presented in Table 7 and Table 8.

Table 6. Results of the N-Gain Analysis for Mathematical Conceptual Understanding

	N-Gain Value of The Experimental Group	N-Gain Value of The Control Group
Mean	0.7587	0.5872
Category	High	Moderate
Minimum	0.53	0.33
Maximum	0.93	0.75

Table 7. Results of the N-Gain Analysis for Numeracy Skills

	N-Gain Value of The Experimental Group	N-Gain Value of The Control Group
Mean	0.8218	0.5916
Category	High	Moderate
Minimum	0.67	0.38
Maximum	1.00	0.82

Based on the N-gain analysis, the experimental group, which received mathematics instruction using the Problem-Based Learning (PBL) model, was found to be effective in improving both mathematical conceptual understanding and numeracy skills, with average N-gain scores of 0.7587 and 0.8218, respectively. Meanwhile, the control group, which received mathematics instruction using an expository learning model, was classified as moderately effective in improving both mathematical conceptual understanding and numeracy skills, with average N-gain scores of 0.5872 and 0.5916, respectively. The high N-gain scores obtained by the experimental group further indicate that PBL not only improves mathematical performance but also builds foundational competencies findings that resonate with a mixed-methods quasi-experimental study showing PBL significantly enhanced critical thinking ($F = 104.833$, $p < 0.05$) and collaborative skills among students compared to conventional teaching (Rehman et al., 2023).

These results indicate that the N-gain scores of the experimental group were higher than those of the control group. The higher learning mastery achieved by PBL students in this study is further supported by quantitative evidence that students' confidence, perceived value of mathematics, and intrinsic motivation are significantly shaped by engagement in problem-based learning environments, all of which are known to directly influence achievement outcomes (Nugroho et al., 2025; Nugroho & Septianisha, 2025; Zamir et al., 2022). Therefore, it can be concluded that implementing the Problem-Based Learning (PBL) model in mathematics instruction effectively enhanced both the mathematical conceptual understanding and the numeracy skills of Grade VIII students. These results are consistent with a comprehensive meta-analytic review which confirmed that PBL yields significant positive effects on problem-solving skills across mathematical and non-mathematical domains, with consistent evidence supporting its effectiveness at various educational levels (Masitoh & Fitriyani, 2018; Nugroho et al., 2025; Yuhana & Fajari, 2025). The overall pattern of results, significant group differences, achievement of mastery criteria, and high N-gain values reflects an instructional model that effectively supports knowledge construction, a finding aligned with international evidence showing PBL's consistent positive impact on mathematical achievement and mastery across different cultural and educational contexts (Ahdhianto et al., 2020; Dorimana et al., 2022)

4. Conclusion

This study found that the Problem-Based Learning (PBL) model is effective in improving eighth-grade students' mathematical conceptual understanding and numeracy skills. Students in the PBL class showed significantly better posttest results compared to those in the expository class. Their average scores reached the minimum mastery criterion, and the proportion of students achieving mastery met the classical mastery threshold. Furthermore, the improvement in both competencies was classified as high in the PBL class, while only moderate in the expository class. Thus, PBL is superior to expository learning in enhancing these two competencies.

This study was limited to a single topic (solid geometry with flat surfaces) and a single grade level (VIII), so the findings cannot be generalized broadly. Future research should extend similar studies to other mathematical topics and educational levels. Researchers are also encouraged to combine PBL with other approaches such as contextual learning or project-based learning, and to examine additional variables including learning motivation, creativity, and critical thinking skills.

Declarations

Author Contribution	:	MAFR: Conceptualization, Writing - Original Draft, Editing, and Visualization; EA: Writing - Review & Editing, Formal analysis, Methodology.
Funding Statement	:	The authors received no financial support for the research, authorship, and/or publication of this article
Conflict of Interest	:	The authors declare no conflict of interest.
Additional Information	:	-

References

Aba-Oli, Z., Koyas, K., & Husen, A. (2025). Higher-order thinking skills-oriented problem-based learning interventions in mathematics: A systematic literature review. *School Science and Mathematics*, *125*(3), 214–231. https://doi.org/10.1111/ssm.12676

Ahdhianto, E., Marsigit, M., Haryanto, H., & Nurfauzi, Y. (2020). Improving Fifth-Grade Students’ Mathematical Problem-Solving and Critical Thinking Skills Using Problem-Based Learning. *Universal Journal of Educational Research*, *8*(5), 2012–2021. https://doi.org/10.13189/ujer.2020.080539

Apit Dulyapit, Yayat Supriatna, & Fanny Sumirat. (2023). Application of the Problem Based Learning (PBL) Model to Improve Student Learning Outcomes in Class V at UPTD SD Negeri Tapos 5, Depok City. *Journal of Insan Mulia Education*, *1*(1), 31–37. https://doi.org/10.59923/joinme.v1i1.10

Arbo, J. B., & Ching, D. A. (2022). Problem-Based Learning Approach in Developing Mathematical Skills. *International Journal of Science, Technology, Engineering and Mathematics*, *2*(1). https://doi.org/10.53378/352873

Boye, E. S., & Agyei, D. D. (2023). Effectiveness of problem-based learning strategy in improving teaching and learning of mathematics for pre-service teachers in Ghana. *Social Sciences & Humanities Open*, *7*(1), 100453. https://doi.org/10.1016/j.ssaho.2023.100453

Chen, O., Retnowati, E., & Kalyuga, S. (2020). Element interactivity as a factor influencing the effectiveness of worked example–problem solving and problem solving–worked example sequences. *British Journal of Educational Psychology*, *90*(S1), 210–223. https://doi.org/10.1111/bjep.12317

Darma, I. K., Candiasa, I. M., Sadia, I. W., & Dantes, N. (2018). The effect of problem based learning model and authentic assessment on mathematical problem solving ability by using numeric ability as the covariable. *Journal of Physics: Conference Series*, *1040*, 012035. https://doi.org/10.1088/1742-6596/1040/1/012035

Dorimana, A., Uworwabayeho, A., & Nizeyimana, G. (2022). Enhancing Upper Secondary Learners' Problem-solving Abilities using Problem-based Learning in Mathematics. *International Journal of Learning, Teaching and Educational Research*, *21*(8), 235–252. https://doi.org/10.26803/ijlter.21.8.14

Ennis, R. H. (1987). *Critical thinking and the curriculum. Thinking skills instruction: Concepts and techniques*. Springer.

Eviliasani, K., Sabandar, J., & Fitriani, N. (2022). Problem-Based Learning Assisted by GeoGebra to Improve Students' Mathematical Understanding. *AL-ISHLAH: Jurnal Pendidikan*, *14*(1), 85–98. https://doi.org/10.35445/alishlah.v14i1.1092

Ghozali, I. (2016). *Aplikasi analisis multivariate dengan program IBM SPSS*. Badan Penerbit Universitas Diponegoro.

Hidayat, W. (2017). *Konsep dasar pembelajaran matematika*. Refika Aditama.

Hung, C. M., Hwang, G. J., & Huang, I. (2012). A project-based digital storytelling approach for improving students' learning motivation, problem-solving competence and learning achievement. *Educational Technology and Society*, *15*(4), 368–379. https://www.jstor.org/stable/jeductechsoci.15.4.368

Marchy, F., Murni, A., Kartini, K., & Muhammad, I. (2022). The Effectiveness of Using Problem-Based Learning (PBL) in Mathematics Problem-Solving Ability for Junior High School Students. *AlphaMath : Journal of Mathematics Education*, *8*(2), 185. https://doi.org/10.30595/alphamath.v8i2.15047

Mary, & Anastasia. (2013). Supporting Student Self-Regulated Learning in Problem- and Project-Based Learning. *Interdisciplinary Journal of Problem-Based Learning*, *7*(2), 127–150. http://10.0.30.91/1541-5015.1339%5Cnhttp://search.ebscohost.com/login.aspx?direct=true&db=eue&AN=90663292&amp%5Cnlang=ko&site=ehost-live

Masitoh, L. F., & Fitriyani, H. (2018). Improving students' mathematics self-efficacy through problem based learning. *Malikussaleh Journal of Mathematics Learning (MJML)*, *1*(1), 26. https://doi.org/10.29103/mjml.v1i1.679

Nugroho, H., Desti, D., Kismiantini, K., & Setyaningrum, L. (2025). Integrating GeoGebra into Project-Based Learning to Improve Students ' Problem-Solving Skill on Circle Topic. *Proceedings of the 8th International Symposium on Mathematics Education and Innovation (ISMEI 2024)*, 35–54. https://doi.org/10.2991/978-2-38476-434-1

Nugroho, H., & Septianisha, N. I. (2025). Improving Students' Mathematical Representation Skills in Systems of Linear Equations in Two Variables Through Geogebra-Based STEM Approaches: A Quasi-Experimental Study. *Jurnal Pendidikan Matematika Dan IPA*, *16*(1), 67–81. https://doi.org/10.26418/jpmipa.v16i1.78553

Patmara, R., Wahyudin, A., & Susilaningsih, E. (2020). Implementation of Problem-Based Learning Model with Ethnomathematics Nuance Towards Students' Problem-Solving Ability and Mathematics Anxiety. *Journal of Primary Education*, *9*(2), 188–196. https://journal.unnes.ac.id/sju/index.php/jpe/article/view/31350

Patunah, S., Herman, T., & Hasanah, A. (2024). The Enhancement of Mathematical Problem-Solving Skills among Junior High School Students Using Problem-based Learning. *Jurnal Pendidikan MIPA*, *25*(3), 1067–1079. https://doi.org/10.23960/jpmipa/v25i3.pp1067-1079

Peterson, A. (2020). Character education, the individual and the political. *Journal of Moral Education*, *49*(2), 143–157. https://doi.org/10.1080/03057240.2019.1653270

Purwanti, D., Zaenuri, ∗, & Asikin, M. (2021). Problem Solving Ability in the Learning Model of Problem-Based Learning based on Ethnomathematics. *Journal of Primary Education*, *10*(1), 113–120. https://journal.unnes.ac.id/sju/index.php/jpe/article/view/34303

Rahmadi, J., Wahyu, Y., & Oktari, V. (2024). Implementation of creative problem-solving model with RME approach on mathematics problem-solving ability. *Jurnal Elemen*, *10*(1), 43–54. https://doi.org/10.29408/jel.v10i1.19788

Ramadhani, R., Farid, F., Lestari, F., & Machmud, A. (2020). Improvement of Creative Thinking Ability through Problem-Based Learning with Local Culture Based on Students' Gender and Prior Mathematics Ability. *Al-Jabar : Jurnal Pendidikan Matematika*, *11*(1), 61–72. https://doi.org/10.24042/ajpm.v11i1.4961

Rehman, N., Zhang, W., Mahmood, A., Fareed, M. Z., & Batool, S. (2023). Fostering twenty-first century skills among primary school students through math project-based learning. *Humanities and Social Sciences Communications*, *10*(1), 424. https://doi.org/10.1057/s41599-023-01914-5

Santrock, J. (2009). *Educational Psychology*. Jakarta: Salemba Humanika.

Sugiyono. (2018). *Metode penelitian pendidikan: Pendekatan kuantitatif, kualitatif, dan R&D*. Alfabeta.

Suparman, S., Yohannes, Y., & Arifin, N. (2021). Enhancing Mathematical Problem-Solving Skills of Indonesian Junior High School Students through Problem-Based Learning: a Systematic Review and Meta-Analysis. *Al-Jabar : Jurnal Pendidikan Matematika*, *12*(1), 1–16. https://doi.org/10.24042/ajpm.v12i1.8036

Suratno, J., & Waliyanti, I. K. (2023). The Integration of GeoGebra in Problem-Based Learning to Improve Students' Problem-Solving Skills. *International Journal of Research in Mathematics Education*, *1*(1), 63–75. https://doi.org/10.24090/ijrme.v1i1.8514

Tursynkulova, E., Madiyarov, N., Sultanbek, T., & Duysebayeva, P. (2023). The effect of problem-based learning on cognitive skills in solving geometric construction problems: a case study in Kazakhstan. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1284305

Ulya, H., Sugiman, Rosnawati, R., & Retnawati, H. (2024). Technology-based learning interventions on mathematical problem-solving: a meta-analysis of research in Indonesia. *International Journal of Evaluation and Research in Education* , *13*(1), 292–301. https://doi.org/10.11591/ijere.v13i1.26380

Yazar Soyadı, B. B. (2015). Creative and Critical Thinking Skills in Problem-based Learning Environments. *Journal of Gifted Education and Creativity*, *2*(2), 71–71. https://doi.org/10.18200/jgedc.2015214253

Yuhana, Y., & Fajari, L. E. W. (2025). Cross-disciplinary effects of problem-based learning on problem-solving skills in mathematics and beyond: A comprehensive meta-analysis and bibliometric. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(11), em2732. https://doi.org/10.29333/ejmste/17345

Zaenuri, Imam, F., & Nugroho, S. E. (2020). The effectiveness of problem based learning (PBL) model with ethnomatematics to improve mathematics literation ability of high school students. *Journal of Physics: Conference Series*, *1567*(2), 022086. https://doi.org/10.1088/1742-6596/1567/2/022086

Zamir, S., Yang, Z., Wenwu, H., & Sarwar, U. (2022). Assessing the attitude and problem-based learning in mathematics through PLS-SEM modeling. *PLOS ONE*, *17*(5), e0266363. https://doi.org/10.1371/journal.pone.0266363

Zhang, F., Wang, H., Bai, Y., & Zhang, H. (2022). A Bibliometric Analysis of the Landscape of Problem-Based Learning Research (1981–2021). *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.828390