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The Effect of Problem-Based Learning Models on Students' Mathematical Problem-Solving Ability: A Meta-Analysis

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Abstract: This study aims to analyze the significant influence of the Problem-Based Learning (PBL) model on students' mathematical problem-solving abilities. This meta-analysis includes ten scientific articles comparing the PBL model with conventional teaching methods. The article selection process followed the PRISMA 2020 guidelines to ensure transparency and rigor. Data were analyzed using the Mann-Whitney U test due to the non-normal distribution, and Spearman's Rank Correlation was used to assess the strength of the relationship between PBL and students' problem-solving abilities. The results indicate that the PBL model has a significant and positive impact on students' mathematical problem-solving abilities compared to conventional methods, with a large effect size of r = 0.642. The Spearman's Rank Correlation revealed a strong positive relationship (r_s = 0.782) between the implementation of PBL and the improvement in problem-solving skills. These findings are supported by several factors contributing to PBL's success, including active student engagement, effective teacher facilitation, the use of real-world contexts, and a supportive classroom environment. This study concludes that the PBL model is a highly effective pedagogical approach for enhancing mathematical problem-solving skills. Considering the significant positive effects, this study recommends the widespread adoption of PBL in educational environments to improve students' critical thinking and problem-solving abilities. Further research is needed to explore the long-term impacts of PBL and its application in different educational contexts.

Keywords: problem-based learning, mathematical problem-solving, meta-analysis, mann-whitney u test, spearman's rank correlation.

▪ INTRODUCTION

Education is described as a comprehensive process that aims to develop essential skills such as logical, systematic, and reflective thinking, while fostering both intellectual and non-intellectual aspects such as persistence, confidence, and resilience. It involves preparing individuals not only for academic achievement but also for overcoming challenges, adapting to difficulties, and using those experiences for personal growth (Hutauruk & Priatna, 2017). Furthermore, education emphasizes understanding over memorization, particularly in disciplines like mathematics, which plays a critical role in developing skills necessary for counting, measuring, processing, presenting, and interpreting data. Effective education must foster mastery of mathematical abilities, as these are foundational for academic achievement and career success (Setiawan, Muhtadi & Hukom, 2022).

One of the subjects in school that is certainly part of the educational process is mathematics. According to Gravemeijer et al. (2017), mathematics holds a unique position in the increasingly digitized society, meriting specific attention within the broader push for education. It is essential for preparing students to solve authentic, real-world problems and balance both standard and innovative mathematical approaches, making mathematics a critical skill in the workforce and everyday life. Moreover, Roos (2019) also emphasizes that mathematics is critical in both society and the classroom. To

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succeed academically and in their future personal and professional lives, students must actively engage with mathematics and develop the ability to solve mathematical problems. One of the crucial skills that students need to develop is problem-solving ability, which can be honed through the process of learning mathematics.

Problem-Based Learning (PBL) is deeply rooted in constructivist learning theory, which posits that learners build their understanding through experiences rather than simply absorbing information. This educational theory emphasizes the importance of active learning, where students engage with material in a meaningful way. PBL encourages learners to tackle real-world problems, thereby fostering critical thinking and problem-solving abilities (Savery, 2015). Through PBL, students are encouraged to explore, question, and apply their knowledge in authentic contexts, which aligns with Dewey's principles of experiential learning, where education should be based on practical experience and reflection (Kolb, 1984). Furthermore, PBL aligns with Vygotsky's social constructivism, as it emphasizes collaborative learning environments where students work together to solve problems, allowing them to learn from one another's perspectives and build upon their existing knowledge (Loyens et al., 2011).

In PBL, learners are introduced to real-world problems early in the learning process, encouraging them to actively engage in building their understanding through experience and inquiry. These problems help students identify areas of knowledge they need to develop, leading to critical thinking and collaborative group work to find solutions (Boye & Agyei, 2023). Research has shown that PBL not only enhances problem-solving skills but also fosters deeper engagement with the material, as students take an active role in solving problems. This process not only deepens their understanding but also prepares them for professional environments where teamwork and problem-solving abilities are essential (Hidajat, 2023). Furthermore, PBL has been linked to improvements in cognitive processes, such as reasoning and flexibility in applying strategies. Thus, Problem-Based Learning (PBL) offers an effective framework for improving content knowledge and critical problem-solving abilities in mathematics education.

Several meta-analyses conducted in various educational settings have consistently demonstrated PBL’s positive impact on students' cognitive development, including their problem-solving abilities. Studies by Strobel and van Barneveld (2009) and Walker and Leary (2009) provide substantial evidence that PBL enhances students’ engagement and academic performance across different fields, including mathematics. These findings justify PBL’s growing popularity as a pedagogical approach in both developed and developing countries. In the context of Indonesia, the implementation of Problem-Based Learning (PBL) has also shown a significant effect on students' mathematical abilities. A meta-analysis of studies conducted by Siagian et al. (2023) revealed that the combined effect size of PBL on students' mathematical abilities is 1.147, categorized as a "very high" effect. This demonstrates that PBL is highly effective in improving students' problem-solving skills across various educational settings in Indonesia.

Despite these positive outcomes, it is concerning that the mathematical problem-solving ability of students in Indonesia still needs to improve. This is evident from the 2022 PISA results, where the scores in each assessment subject, namely reading, mathematics, and science, experienced a decline, even though the ranking improved from 2018. Regarding mathematical ability, which is the main focus of the 2022 PISA assessment, Indonesia's average score dropped by 13 points from 379 to 366 (Kemdikbud, 2023). This issue should be the primary focus, aside from merely paying attention to the improved ranking.

Figure 1. Indonesia’s PISA’s score (2009-2022)

Additionally, it was found that students’ problem-solving abilities in mathematics have shown limited improvement (OECD, 2022). It is because students' mathematical problem-solving abilities only showed a slight improvement, and in some cases, had little to no positive impact. This highlights the need for more careful planning, scaffolding, and specific training in problem-solving processes to support their learning (Lonergan, Cumming & O'Neill, 2022). Several factors contribute to these challenges. Teachers often lack clarity on how to effectively implement teaching strategies that promote problem-solving, and they are not given enough opportunities to explore new methods in the classroom. Additionally, the integration of problem-solving techniques, such as those used in PBL, has not been consistently evaluated, which further complicates efforts to improve students' problem-solving abilities (Saad & Zainudin, 2022).

Although PBL has been implemented in various educational settings, comprehensive studies specifically focusing on its impact on mathematical problem-solving skills, particularly in the Indonesia context, remain limited. Most prior research has focused on broader educational outcomes or examined PBL in other subjects, highlighting the need for more in-depth analysis in mathematics education (Simanjuntak & Purwaningsih, 2024). Moreover, research on PBL’s effectiveness in developing countries, including Indonesia, remains scarce, indicating a gap in the literature that warrants further investigation. A systematic review and meta-analysis of existing research is necessary to evaluate PBL’s effectiveness in enhancing mathematical problem-solving abilities in diverse educational settings (Febrianto et al., 2021). This study aims to fill this gap by synthesizing findings from multiple studies to provide evidence of PBL’s effectiveness.

Some other studies that support this are research by Irvan & Muslihuddin (2022) shows that the Problem-Based Learning (PBL) model positively enhances students' problem-solving abilities, particularly improving mathematical skills. Similarly, Suryani et al. (2020) found that the PBL model had a positive impact on students' problem-solving abilities, especially among students with high and medium skill levels, suggesting increased engagement and improved learning outcomes. Additionally, a study by Anam, Sudarwo, & Wiradharma (2020) confirmed that students taught using the PBL model exhibited higher problem-solving abilities compared to those taught with conventional methods.

In this meta-analysis, we aim to systematically analyze the impact of the Problem-Based Learning (PBL) model on students' mathematical problem-solving abilities in Indonesia, synthesizing findings from multiple studies. By providing a comprehensive evaluation of PBL's effectiveness, this study seeks to contribute to the body of knowledge on teaching methodologies that can improve problem-solving skills in mathematics, particularly in the Indonesian context. To achieve the research objectives, this study is guided by three research questions (RQ):

RQ1: Does the Problem-Based Learning (PBL) model have a significant effect on students' mathematical problem-solving abilities compared to conventional teaching methods?
RQ2: What is the effect size of the Problem-Based Learning (PBL) model on students' mathematical problem-solving abilities?
RQ3: How strong is the relationship between the Problem-Based Learning (PBL) model and students' mathematical problem-solving abilities compared to conventional teaching methods?

▪ METHOD

Research Design

This study uses a meta-analysis approach to synthesize data from various studies that examine the impact of Problem-Based Learning (PBL) on students' mathematical problem-solving abilities. Meta-analysis is an ideal choice for this research as it provides a statistical technique for systematically combining data from multiple studies to identify overall trends, offering more robust conclusions compared to single studies (Walsh & Downe, 2005). This method is particularly useful when useful when assessing educational interventions like PBL, as it helps mitigate biases and enhances the generalizability of the findings (Marhami, Juandi, & Dasari, 2024). The analysis in this study follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) 2020 guidelines, which have been updated to reflect advancements in systematic review methodology. These guidelines ensure transparency in study selection and reporting (Page et al., 2021).

Search Strategy

The data sources for this study were obtained from multiple academic databases, including Google Scholar, ScienceDirect, and ERIC, using the Publish or Perish 8 application. The use of multiple databases ensures comprehensive coverage of relevant studies. The keywords used were: "problem-based learning", "problem-solving ability", and "mathematics". A total of 100 articles were retrieved, and more rigorous filtering was applied. The filtering process included screening by title, abstract, and full text, followed by manual checking of references to identify additional relevant studies. The following Figure 2 illustrates the stages and procedures used in filtering articles.

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria ensure that only relevant and high-quality studies are analyzed. The selected studies must meet the inclusion criteria as listed in Table 1,

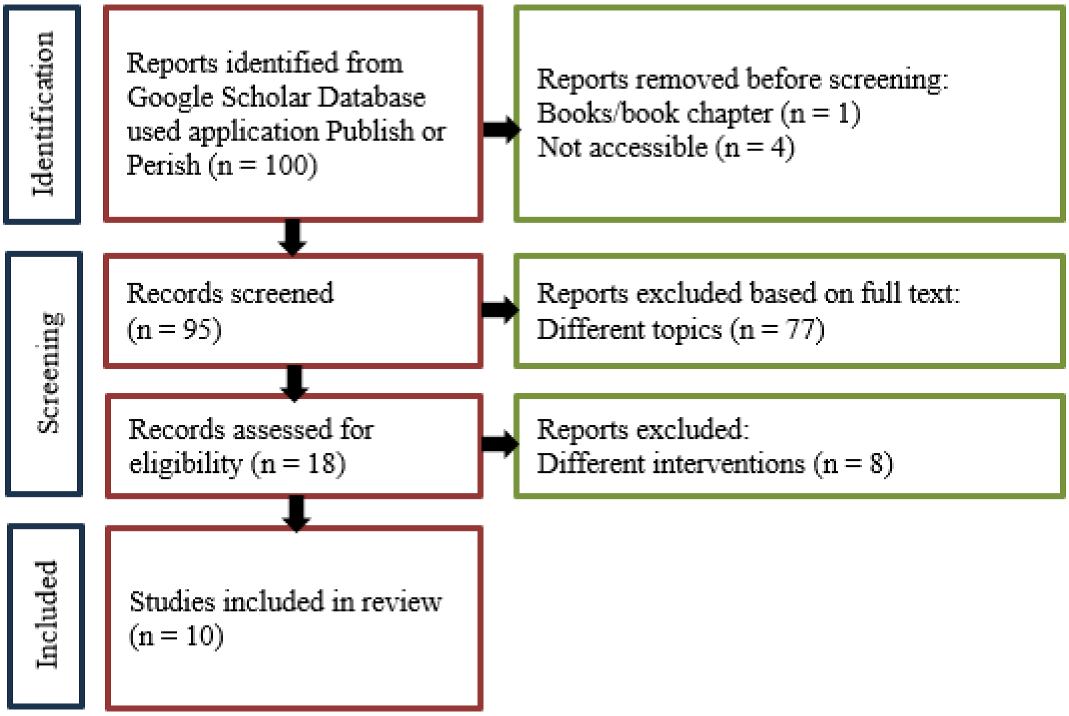

Figure 2. Literature identification process using PRISMA 2020 adapted from page et al. (2021)

which were developed to maintain consistency and rigor in the analysis. This study limited its scope to research conducted in Indonesia to ensure the results are relevant to the local educational context. Since education systems vary significantly across countries, focusing on Indonesia allows the findings to address the specific needs and challenges faced by Indonesia educators and students.

Table 1. Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Literature type	Proceedings and Journal Articles	Editorial, Book Chapters, Review, and Book
Research location	Indonesia	Other country
Research design	Experimental or quasi-experimental	Other method
Intervention	Control group (conventional)	No control group
Outcome	PBL has a positive/significant effect on mathematical problem-solving ability	Another outcome
Year of publication	All years	No exclusion

Data Analysis

In conducting a meta-analysis, it was essential to follow a well-organized and consistent approach as outlined in the protocol. To answer RQ1, the Mann-Whitney U test was employed as the data did not follow a normal distribution. This non-parametric test was chosen because it does not assume normality and is approriate for comparing two independent groups (PBL and conventional methods) in terms of their mathematical problem-solving abilities (Field, 2018). For RQ2, the effect size was calculated using the Z-score obtained from the Mann-Whitney U test output. The formula used is:

$$r = \frac{Z}{\sqrt{N}}$$

Where:
- Z is the Z-score obtained from SPSS results.
- N is the total number of observations.

The effect size helps to quantify the magnitude of the impact of the PBL model on students’ mathematical problem-solving skills. According to Cohen’s benchmarks, an r-value of 0.1 represents a small effect, 0.3 a medium effect, and 0.5 a large effect (Cohen, 2013).

For RQ3, the Spearman’s Rank Correlation was applied to determine the strength of the relationship between the use of the PBL model and students’ problem-solving abilities. This non-parametric measure of correlation is appropriate because the data are ordinal, and the rank correlation helps to assess the direction and strength of association between the two variables (Hauke & Kossowski, 2011). Analyses were conducted using SPSS. The results of these analyses are presented in the following sections, along with detailed interpretations of the findings.

▪ RESULT AND DISSCUSSION

This study identified ten scientific articles discussing the influence of the Problem-Based Learning (PBL) model on students' mathematical problem-solving abilities. The articles included were selected following the PRISMA 2020 guidelines (Page et al., 2021), ensuring transparency in the study selection process. The data from these articles were processed, analyzed, and presented descriptively to assess the effectiveness of PBL.

Table 2. Summary of studies: experiment and control group scores

Author/s	Code	Experiment Group Score	Control Group Score
Amalia, Surya, & Syahputra	A1	88.22	76.38
Astriani, Surya, & Syahputra	A2	76.94	40.75
Mushlihuddin, Nurafifah, & Irvan	A3	82.26	67.51
Darma	A4	79.16	71.49
Hendriana, Johanto, & Sumarmo	A5	35.52	14.21
Nasution, Yerizon, & Gusmiyanti	A6	82.29	70.27
Pohan, Asmin, & Menanti	A7	78.4	71.97
Anam, Sudarwo, & Wiradharma	A8	70.17	21.89
Marchy et al.	A9	78.43	48.12
Ahdhianto & Istiq’faroh	A10	76.73	57.3

Visualization of Data Distribution: Boxplot Analysis

To provide a visual representation of the distribution of problem-solving abilities between the experimental group (PBL) and the control group (conventional methods), a boxplot was created. This visualization helps illustrate the differences in median, interquartile range (IQR), and potential outliers between the two groups.

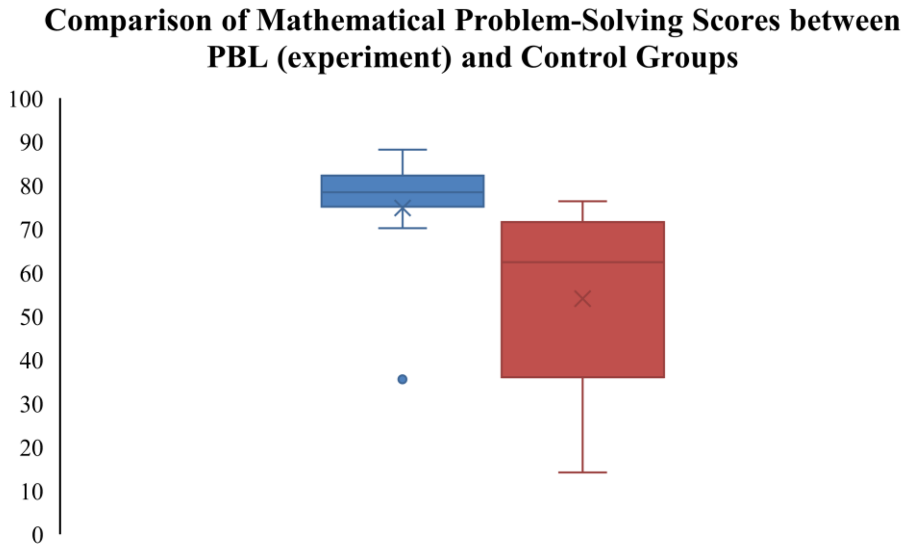

Figure 3. Boxplot

The boxplot clearly shows a difference in the median scores, with the PBL group exhibiting higher central values compared to the control group. Furthermore, the interquartile range (IQR) for the PBL group is narrower, indicating less variability in students' performance compared to the control group. Additionally, outliers in the experiment group suggest that some students performed significantly lower than their peers. This visual representation reinforces the upcoming findings from the statistical analysis, which will be discussed below.

RQ1: Does the Problem-Based Learning (PBL) model have a significant effect on students' mathematical problem-solving abilities compared to conventional teaching methods?

Based on the analysis of the 10 selected articles, the results show that the Problem-Based Learning (PBL) model generally has a positive and significant effect on students' mathematical problem-solving abilities compared to conventional teaching methods. However, despite these promising findings, further research is needed to explore the extent to which PBL is effective in improving students' mathematical problem-solving skills. Therefore, a statistical analysis is required to test whether the PBL model has a significant impact on students' mathematical problem-solving abilities. The statistical analysis employed in this study is non-parametric, specifically the Mann-Whitney U test, due to the non-normal distribution of the data.

Before conducting the main analysis, the data were first tested for normality test. The normality test was performed using the Shapiro-Wilk test, which is appropriate for small sample sizes. From Table 3, the results of this test indicated that the p-value was less than 0.05, meaning the data did not meet the assumption of normal distribution. As a result, since the data did not follow a normal distribution and the assumptions for a parametric test (t-test) were not met, the analysis proceeded with the non-parametric Mann-Whitney U test, which is an ideal alternative for comparing two independent groups when parametric assumptions are violated (Havlicek & Peterson, 1974).

Table 3. Normality test result

	Tests of Normality		
	Shapiro-Wilk		
	Statistic	df	Sig.
skor	0.832	20	**0.003**
a. Lilliefors Significance Correction			

Given that the data were not normally distributed, the following hypotheses were tested to assess the significance of the difference between the groups:

H0: There is no significant difference between the mathematical problem-solving abilities of students taught using PBL and conventional methods.

H1: There is a significant difference between the mathematical problem-solving abilities of students taught using PBL and conventional methods.

Table 4. Mann-whitney U test result

Test Statistics[a]	
	skor
Mann-Whitney U	12.000
Wilcoxon W	67.000
Z	-2.873
Asymp. Sig. (2-tailed)	**0.004**
Exact Sig. [2*(1-tailed Sig.)]	.003[b]
a. Grouping Variable: kelas	
b. Not corrected for ties.	

Based on Table 4, the results of the Mann-Whitney U test indicated a p-value of less than 0.05, leading to the rejection of the null hypothesis (H0). This demonstrates that there is a significant difference in the mathematical problem-solving abilities between students taught using the Problem-Based Learning (PBL) model and those taught using conventional methods.

This conclusion aligns with previous research highlighting the effectiveness of problem-based learning (PBL) as a pedagogical approach in various educational contexts. Based on the meta-analysis conducted by Suparman, Juandi, & Tamur (2021), the implementation of problem-based learning (PBL) significantly enhances students' mathematical problem-solving skills in Indonesia. This suggests that PBL is an effective approach for improving students' abilities to solve mathematical problems, encouraging mathematics teachers and educators to adopt this instructional strategy in their classrooms.

Another study that reached a similar conclusion is the research by Suparman, Yohannes, & Arifin (2021), where their meta-analysis found that the implementation of the Problem-Based Learning (PBL) model had a significant positive impact on the mathematical problem-solving abilities of junior high school students in Indonesia. These findings also emphasize the importance for educators to adopt innovative teaching strategies like PBL, as it facilitates a deeper understanding and application of mathematical concepts.

RQ2: How large is the effect of the Problem-Based Learning (PBL) model on improving students' mathematical problem-solving abilities?

Based on the findings from RQ1, which demonstrate that the Problem-Based Learning (PBL) model significantly improves students' mathematical problem-solving abilities, the next step is to determine the effect size of this impact. Understanding the magnitude of the effect is crucial, as it not only quantifies the strength of the relationship between PBL and problem-solving skills but also provides a clearer picture of how effective PBL is compared to conventional teaching methods. Measuring the effect size allows educators and policymakers to assess the practical significance of PBL, ensuring that its implementation leads to meaningful improvements in student outcomes, and guiding decisions on the adoption of this instructional model in various educational contexts. In the context of the Mann-Whitney U-tets, effect size can be quantified using the correlation coefficient (r), calculated with the formula:

$$r = \frac{Z}{\sqrt{n}}$$

Where Z represents the standardized Z-score , and n denotes the total number of observations. The negative r values do not need to be worried about because effect size are usually interpreted based on their magnitude, not their positive or negative direction (Tomczak, 2014). Using Cohen's benchmarks, we can categorize the magnitude of the effect size to better understand how substantial the influence of PBL is on student outcomes.

Table 5. Cohen's benchmarks of r

Value of r	Interpretation
$r < 0.3$	Small
$0.3 \leq r < 0.5$	Medium
$r \geq 0.5$	Large

Using the formula for effect size, where the value of Z is -2.873 (from Table 4) and the sample size n is 20 (number of experiment classes and control classes), we can calculate the effect size. Substituting the values into the formula, we get:

$$r = \frac{-2.873}{\sqrt{20}} = \frac{-2.873}{4.472} \approx -0.642$$

This result shows an effect size of approximately -0.642. Ignoring the negative sign, the r-value indicates a large effect according to Table 5. It suggests that the PBL model has a strong influence on the students' mathematical problem-solving abilities when compared to conventional methods.

Building on this, the large effect size demonstrates that the PBL model is statistically significant and practically impactful in enhancing students' mathematical problem-solving skills. This strong influence indicates that students who engage with PBL are likely to develop deeper problem-solving abilities compared to those taught with traditional methods. Such a large effect size underscores the importance of adopting PBL in educational settings, as it provides substantial evidence that this teaching strategy can yield meaningful improvements in students' cognitive abilities.

These findings are consistent with other studies that have explored the effect size of PBL on problem-solving abilities. For instance, Musna et al. (2021) reported an effect size of 1.092, demonstrating a similar strong influence of PBL. Additionally, Dochy et al. (2003) found a combined effect size of 0.460 in their meta-analysis, further validating the robustness of PBL as an effective instructional strategy. While the values vary slightly, all studies point to the significant benefits of PBL in improving educational outcomes, particularly in mathematics education.

RQ3: How strong is the relationship between the Problem-Based Learning (PBL) model and students' mathematical problem-solving abilities compared to conventional teaching methods?

To answer RQ3, Spearman's Rank Correlation was chosen to determine the strength of the relationship between the implementation of the PBL model and the improvement in students' problem-solving abilities. Spearman's correlation is appropriate for this analysis because the data is ordinal and does not meet the assumptions of normality required for parametric tests like Pearson's correlation (Ali Abd Al-Hameed, 2022). Since the data in this study does not follow a normal distribution, this method is the most suitable for analyzing the association between the PBL model and problem-solving abilities.

Spearman's correlation coefficient measures both the strength and direction of the relationship between two variables, with values ranging from -1 to +1. A coefficient close to +1 indicates a strong positive relationship, where an increase in one variable is associated with an increase in the other. Conversely, a coefficient close to -1 indicates a strong negative relationship, where an increase in one variable is associated with a decrease in the other. A coefficient near 0 suggests no significant relationship between the variables (Ali Abd Al-Hameed, 2022).

Table 6. Spearman's rank correlation

Correlations				
			experiment	**control**
Spearman's rho	experiment	Correlation Coefficient	1.000	.782**
	control	Correlation Coefficient	.782**	1.000
****. Correlation is significant at the 0.01 level (2-tailed).**				

Based on Table 6, the result of the Spearman correlation test in this study yielded a coefficient of r = 0.782, indicating a strong positive association between the use of the PBL model and improved problem-solving skills. According to Spearman's scale, near to +1 indicate a strong positive association, meaning that as the use of PBL increases, so does the students' ability to solve mathematical problems. This further validates the effectiveness of the PBL approach in enhancing students' cognitive and problem-solving skills.

Educational Impact

Based on the analysis of the ten selected articles, Problem-Based Learning (PBL) has been shown to significantly enhance students' mathematical problem-solving abilities through various influencing factors. Central to this effectiveness is the active engagement of students, which promotes collaboration and critical thinking as they tackle real-world problems. The role of the teacher is equally important; effective facilitation enables educators to guide students through complex inquiries and discussions, thereby enhancing their problem-solving strategies.

Additionally, authentic contexts related to students' daily lives foster deeper understanding and retention of mathematical concepts. A supportive classroom environment that encourages questioning and interaction further enriches the learning experience, allowing students to build confidence in their abilities.

Motivation also emerges as a critical factor impacting student engagement and success in PBL environments. Students with higher motivation are more likely to actively participate and take initiative in collaborative learning. The structured phases of PBL, which include problem analysis and collaborative investigations, play a vital role in developing students' problem-solving skills. By emphasizing student-centered learning and promoting higher-order thinking, PBL not only improves cognitive abilities but also cultivates essential soft skills, such as communication and teamwork.

These findings suggest that Problem-Based Learning (PBL) is a multifaceted and effective approach for enhancing mathematical problem-solving abilities. The large effect size observed in this study, coupled with the strong positive correlation between PBL and problem-solving abilities, underscores the practical significance of adopting PBL in educational settings. This instructional model offers a promising strategy for improving student outcomes and should be considered by educators and policymakers aiming to promote deeper mathematical understanding and problem-solving proficiency among students.

▪ CONCLUSION

This meta-analysis provides clear evidence that the Problem-Based Learning (PBL) model significantly enhances students' mathematical problem-solving abilities when compared to conventional teaching methods. The findings from ten selected studies reveal that PBL not only improves problem-solving skills but also leads to higher engagement and a deeper understanding of mathematical concepts.

The effect size calculated from the Mann-Whitney U test demonstrated a large influence of PBL on students' problem-solving abilities, underscoring the strong impact of this instructional approach. Additionally, Spearman's Rank Correlation showed a strong positive relationship between the implementation of PBL and improved problem-solving skills, further confirming the effectiveness of this model.

Several factors contribute to PBL's success in enhancing students' abilities. These include the active engagement of students, effective facilitation by teachers, the use of real-world contexts, and a supportive classroom environment. Motivation and collaborative learning also play critical roles in increasing students' success in PBL environments, with students demonstrating higher problem-solving skills when given opportunities to work together and explore complex problems.

In conclusion, the evidence presented in this study suggests that PBL is a highly effective pedagogical model for improving mathematical problem-solving skills. Given the strong positive effects observed in various studies, PBL should be widely adopted by educators and policymakers as an essential approach to foster higher-order thinking and problem-solving proficiency in students. Future research should continue to explore the long-term impacts of PBL and investigate how it can be adapted to different educational contexts to further enhance its benefits.

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