

The Effect of Problem-Based Learning on Mathematical Problem-Solving: A Meta-Analysis at the Junior Secondary Level

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ABSTRACT

Mathematical problem-solving ability is a fundamental competency in secondary mathematics education; however, many students continue to face significant challenges in mastering this skill. In response, various instructional strategies have been implemented, among which Problem-Based Learning (PBL) has received considerable attention. This study aims to systematically and quantitatively examine the effect of PBL on junior high school students' mathematical problem-solving abilities through a meta-analytic approach. A total of 24 empirical studies published between 2013 and 2024 were rigorously selected based on predefined inclusion criteria. The meta-analysis results indicate that PBL has a large and statistically significant impact on improving students' problem-solving skills, with a mean effect size of 0.89, which falls within the high category. Furthermore, the effectiveness of PBL was found to vary across moderator variables, including implementation duration, assessment instrument type, and grade level. These findings suggest that PBL is an effective instructional strategy for enhancing students' critical thinking and problem-solving capabilities. The study recommends broader and more systematic implementation of PBL in schools, as well as targeted teacher training to support its optimal integration into classroom practice.

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1. INTRODUCTION

Mathematical problem-solving ability is a core competency in secondary education that plays a pivotal role in fostering students' critical and analytical thinking skills. This competency is not only a key indicator of students' academic achievement in mathematics but also essential for preparing them to face real-life

challenges that demand logical reasoning. In the context of the *Merdeka Curriculum* (Indonesian Independent Curriculum), problem-solving is closely associated with the *Profil Pelajar Pancasila* (Pancasila Student Profile), which emphasizes critical and creative reasoning as essential student characteristics (Salsabila & Cahya Mulyaning Asih, 2024). Therefore, the development and implementation of effective instructional strategies to enhance students' problem-solving abilities must be prioritized in mathematics education.

One instructional model that has gained increasing attention for its effectiveness in promoting problem-solving skills is Problem-Based Learning (PBL). This student-centered approach encourages learners to construct knowledge actively through engaging with complex, real-world problems (Suparman et al., 2021). Numerous studies have reported that PBL significantly improves students' conceptual understanding, higher-order thinking skills, and mathematical problem-solving abilities. However, the magnitude of its effectiveness often varies depending on contextual factors such as implementation duration, instructional design, and student characteristics (Anzani & Juandi, 2022; Fardian & Dasari, 2023; Handayani & Lubis, 2024).

A growing body of experimental and quasi-experimental studies has explored the effectiveness of PBL in mathematics instruction, with findings published in both national and international journals. Recent meta-analyses have attempted to synthesize these findings. For instance, Salsabila and Asih (2024) reported a large average effect size of 0.642 for PBL's impact on problem-solving ability. Similarly, Siagian et al. (2023) found moderate to large effect sizes ($g \approx 0.743$) for various mathematical competencies. Another study published in *Symmetry* (2024) revealed a combined effect size of 1.46 for PBL on mathematical reasoning skills in junior secondary students (Frazwanti et al., 2023). Moreover, Anzani and Juandi (2022) reported an effect size of 1.32 for PBL assisted with GeoGebra, especially at the junior high school level. Wahyuni, Katminingsih, and Widodo (2024) synthesized 14 studies and found a very large effect size (1.46; $p < 0.001$), with notable differences between junior high school (1.194) and senior high school (2.008) levels.

Despite these valuable findings, there has yet to be a comprehensive synthesis that systematically consolidates the influence of PBL on mathematical problem-solving specifically for junior high school students. Such a synthesis is critical to address the central question: **To what extent does the PBL model impact the mathematical problem-solving ability of junior high school students?** This study aims to fill this gap through a rigorous meta-analytic approach.

Meta-analysis, as a secondary research method, offers a powerful means of aggregating findings from relevant primary studies and quantifying the overall effect, thereby producing stronger conclusions and broader generalizations (Sinaga & Minarni, 2017). Although meta-analysis has been widely used in mathematics education to evaluate various instructional interventions, studies that specifically

analyze the effect of PBL on the problem-solving abilities of junior high school students remain scarce. Consequently, this research offers a novel contribution by focusing on a specific educational level and synthesizing findings from recent and credible empirical studies.

This study aims to systematically and quantitatively examine the impact of PBL on students' mathematical problem-solving abilities at the junior secondary level. Specifically, it seeks to: (1) identify and select relevant studies that meet inclusion criteria, (2) compute effect sizes for each primary study, and (3) analyze potential moderator variables such as year of publication, research design, and intervention duration that may influence effect size magnitude.

The results of this meta-analysis are expected to provide a comprehensive synthesis of the effectiveness of PBL at the junior high school level, serving as a valuable reference for teachers, researchers, and policymakers in designing evidence-based instructional strategies. In practical terms, the findings may strengthen the case for implementing contextual learning models that foster students' critical and creative thinking in mathematics classrooms. In the midst of national educational reforms that emphasize active learning and 21st-century skills, this meta-analysis is anticipated to enrich the academic discourse on mathematics instruction and offer empirical evidence to support data-driven decision-making in education.

2. METHOD

2.1 Research Design

This study employed a quantitative research approach using a meta-analytic design. Meta-analysis is a statistical technique that integrates results from multiple empirical studies to estimate the overall effect of a specific intervention. In this context, meta-analysis was used to examine the overall impact of Problem-Based Learning (PBL) on junior high school students' mathematical problem-solving abilities. This method provides a comprehensive overview of the consistency and strength of the relationship across diverse study contexts (Borenstein et al., 2009).

2.2 Inclusion and Exclusion Criteria

To ensure the quality and relevance of the data, the following inclusion criteria were applied:

- Studies were quantitative in nature and conducted between 2013 and 2024.
- The research participants were junior high school students (grades 7 to 9) or their equivalent.
- The intervention applied was Problem-Based Learning (PBL).
- The dependent variable measured was mathematical problem-solving ability.
- The articles reported sufficient statistical data for effect size calculation (e.g., means, standard deviations, sample sizes, or t-values).

The exclusion criteria were as follows:

- Studies that combined PBL with other models without isolating its specific effects.
- Articles that did not contain complete statistical data or were inaccessible.
- Duplicated publications or studies that had not undergone peer review.

2.3 Literature Search Strategy

A systematic literature search was conducted using major academic databases, including ERIC, Scopus, Web of Science, ScienceDirect, and Google Scholar. The search employed various keyword combinations such as “problem-based learning,” “PBL,” “mathematical problem solving,” “junior high school,” “secondary school,” and “meta-analysis.” Boolean operators (AND, OR, NOT) were used to refine and narrow the search results. In addition to electronic searches, manual searches were conducted by screening the reference lists of relevant articles to identify additional eligible studies.

2.4 Data Coding and Extraction

Data from each eligible study were extracted using a standardized coding sheet. The coding covered the following aspects:

- Author(s) and year of publication
- Sample size and demographic characteristics
- Type of research design (true experiment or quasi-experiment)
- Duration of intervention
- Type of assessment used to measure problem-solving skills
- Mean scores and standard deviations of experimental and control groups
- Type of journal (indexed or non-indexed)

To minimize potential bias, two independent coders performed the data extraction process. Inter-coder agreement was assessed, and discrepancies were resolved through discussion and consensus.

2.5 Effect Size Calculation

Effect sizes were calculated using Cohen’s d , which represents the standardized mean difference between the experimental (PBL) and control groups. When direct means and standard deviations were not available, other statistical data such as t or F values were converted to Cohen’s d using established formulas (Lipsey & Wilson, 2001). A positive d value indicates that the PBL model had a favorable effect on mathematical problem-solving ability.

A random-effects model was employed in the analysis to account for variability across studies, including differences in sample characteristics, study settings, and PBL implementation methods.

2.6 Heterogeneity and Moderator Analysis

Between-study heterogeneity was assessed using Cochran’s Q and I^2 statistics. If significant heterogeneity was found, subgroup analyses and meta-regression were conducted to examine the influence of potential moderator variables, including:

- Year of publication
- Duration of intervention
- Type of assessment instrument (open-ended vs. multiple-choice)

- Type of research design (true experiment vs. quasi-experiment)

2.7 Publication Bias Assessment

To assess the risk of publication bias, funnel plots were examined visually for symmetry. Additionally, Egger's regression test was conducted to statistically detect asymmetry, which may suggest the presence of unpublished studies with non-significant results. Symmetrical funnel plots and non-significant Egger's test results would indicate the absence of publication bias.

3. RESULTS AND DISCUSSION

3.1 Characteristics of Included Studies

The final synthesis included 24 empirical studies that met the inclusion criteria. All studies were conducted in Indonesia and employed a quantitative design with samples comprising junior high school students. The total sample size across all studies was 1,456 students, with 748 in the experimental group (who received PBL treatment) and 708 in the control group (who received conventional instruction).

The average duration of the intervention ranged from 4 to 12 sessions. Most studies utilized open-ended problem-solving tests as instruments to assess mathematical problem-solving skills. Several studies also employed scoring rubrics based on Polya's four-step problem-solving indicators: understanding the problem, devising a plan, carrying out the plan, and reviewing the solution.

3.2 Overall Effect Size Calculation

Using Cohen's d as the standardized effect size metric, the analysis yielded an overall effect size of:

$$d = 0.87 \text{ (95\% CI = 0.68 - 1.06)}$$

This value falls within the large effect category, suggesting that Problem-Based Learning (PBL) has a statistically significant and substantial impact on students' mathematical problem-solving ability compared to conventional instructional methods. This result reinforces previous research findings that emphasize PBL's effectiveness in enhancing higher-order thinking and deep understanding of mathematical concepts.

3.3 Study Heterogeneity

The heterogeneity analysis produced a Q -value of 94.72 ($p < 0.001$) and an I^2 statistic of 75.3%, indicating a high level of heterogeneity across the included studies. Such heterogeneity reflects variation in implementation context, study design, and sample characteristics. In response to this variability, the random-effects model was applied to better generalize findings, and further moderator analysis was conducted.

3.4 Moderator Analysis

To better understand the sources of heterogeneity, several moderator variables were analyzed:

- Year of Publication: There was no significant difference in effect sizes between studies published before 2019 and those published afterward, indicating a consistent influence of PBL over time.
- Duration of Intervention: Studies that implemented PBL for 8 sessions or more showed a higher effect size ($d = 0.98$) compared to those with less than 8 sessions ($d = 0.71$). This suggests that longer exposure to PBL enhances its effectiveness, possibly due to more opportunities for student engagement, reflection, and deep learning.
- Type of Assessment Instrument: Studies employing open-ended questions with rubric-based scoring (e.g., based on Polya's indicators) yielded larger effect sizes compared to those using multiple-choice instruments. This implies that assessment format may influence the measured effectiveness of PBL, with more authentic and process-oriented tools capturing its benefits more accurately.

3.5 Publication Bias Test

To assess potential publication bias, a funnel plot was visually inspected and Egger's regression test was performed. The funnel plot appeared fairly symmetrical, and the Egger's test yielded $p > 0.05$, indicating no significant evidence of publication bias in the included studies. This supports the robustness of the meta-analytic findings and suggests that the effect size estimates are unlikely to be influenced by selective reporting.

Interpretation and Integration with Prior Studies

The findings of this meta-analysis are consistent with prior research indicating the effectiveness of PBL in improving mathematical problem-solving skills. The large effect size corroborates conclusions drawn by previous meta-analyses (e.g., Salsabila & Asih, 2024; Siagian et al., 2023), while the moderator analysis provides novel insight into how and under what conditions PBL achieves optimal results. The enhanced effect in longer-duration interventions and with rubric-based assessments suggests practical considerations for instructional planning and evaluation.

This evidence-based synthesis reinforces the theoretical foundation of constructivist learning models and their practical application in the Indonesian junior high school context, aligning well with the current educational reform movements under the *Merdeka Curriculum*.

4. Discussion

The findings of this meta-analysis indicate that the Problem-Based Learning (PBL) model exerts a large and statistically significant effect on junior high school students' mathematical problem-solving abilities, as reflected in the overall effect size (**Cohen's $d = 0.87$**). This confirms that PBL is more effective than conventional

instructional methods in enhancing students' capacity to tackle mathematical problems. These results are consistent with prior meta-analyses (e.g., Salsabila & Asih, 2024; Siagian et al., 2023) that have reported the superiority of student-centered learning approaches in promoting higher-order thinking skills such as critical reasoning, conceptual understanding, and self-directed learning.

PBL positions students as active agents in the learning process. Learners are confronted with **ill-structured, contextual problems** that often lack a single correct answer. As a result, students must explore multiple strategies, engage in inquiry, construct their own understanding, and collaborate with peers to reach plausible solutions. In the context of mathematics, this approach is highly relevant because problem-solving involves not only procedural fluency but also **strategic competence, conceptual insight, and metacognitive awareness** (Polya, 1945; Hmelo-Silver, 2004).

An important finding from the moderator analysis is that **the duration of PBL intervention significantly influences its effectiveness**. Studies that implemented PBL for **eight or more sessions** reported greater gains ($d = 0.98$) compared to those with shorter interventions ($d = 0.71$). This supports the notion that deeper learning processes—such as problem exploration, iterative refinement of solutions, collaborative discussion, and reflective thinking—require sufficient instructional time. Without an adequate duration, the learning cycle central to PBL (i.e., inquiry, investigation, synthesis, and presentation) cannot be fully realized. Hence, careful instructional planning, including time allocation and pacing, is vital for maximizing PBL's impact.

Furthermore, the type of assessment instrument emerged as a key moderator. Studies utilizing open-ended problem-solving tests accompanied by structured rubrics based on Polya's four-step framework yielded higher effect sizes than those relying on multiple-choice assessments. This finding is logical, as problem-solving is a multidimensional construct encompassing understanding the problem, devising a plan, executing the strategy, and evaluating results. Multiple-choice tests often fail to capture these processes comprehensively and may not adequately assess students' reasoning or strategic flexibility.

Despite the overall positive effect, this meta-analysis also revealed a **high level of heterogeneity** among the included studies ($I^2 = 75.3\%$). This variation likely reflects differences in the **implementation fidelity, instructional context, teacher experience, student readiness, and available resources**. For example, schools with well-trained teachers and supportive infrastructure may implement PBL more effectively than those with limited professional development opportunities or overcrowded classrooms. These findings highlight the importance of **contextual adaptability** in applying PBL, and they suggest that professional training and instructional support are essential components for successful adoption.

Interestingly, the effect of PBL appeared **consistent across publication years**, indicating that its impact has remained stable over time. This consistency strengthens the case that PBL is not merely a passing trend but a **theoretically grounded and empirically supported pedagogical strategy** with enduring value. The alignment of PBL with the goals of 21st-century education—such as collaboration, critical thinking, and authentic learning—makes it particularly

relevant in the current era of curriculum reform, including Indonesia's **Merdeka Curriculum**.

Practical Implications

The findings of this study carry several practical implications. First, **teacher training programs** should equip educators with the skills needed to design authentic problems, facilitate meaningful classroom discourse, and conduct process-oriented assessment. Second, schools and curriculum developers should ensure that **adequate instructional time** is allocated for PBL to be effective. Finally, the development of **rubrics aligned with problem-solving indicators** is recommended to provide fair and accurate evaluation of students' abilities.

In conclusion, this meta-analysis supports the broader integration of PBL in junior high school mathematics education. Given the increasing emphasis on problem-solving in international assessments such as **PISA**, and its alignment with national education priorities, PBL offers a viable pathway to cultivate students' critical and creative thinking skills. Future research should continue exploring how contextual and pedagogical variables interact to optimize PBL implementation in diverse educational settings.

4. CONCLUSION

Based on a comprehensive meta-analysis of 24 empirical studies conducted between 2013 and 2024, the Problem-Based Learning (PBL) model has been shown to exert a **large and statistically significant effect** on junior high school students' mathematical problem-solving abilities. The overall effect size (**Cohen's $d = 0.87$**) indicates that PBL consistently outperforms conventional instructional methods in developing students' ability to solve mathematical problems. This confirms the pedagogical strength of PBL, which lies in its student-centered nature, its emphasis on inquiry, and its capacity to foster critical thinking and active engagement in solving meaningful and contextual problems.

The findings also revealed that the **effectiveness of PBL is influenced by several moderators**, including the duration of implementation, the type of assessment instruments used, and the alignment of instructional practices with local contextual conditions. The high heterogeneity across studies (**$I^2 = 75.3\%$**) further underscores the importance of thoughtful planning, contextual adaptation, and instructional support when applying PBL in diverse educational environments.

This meta-analysis contributes to the literature by providing an **up-to-date synthesis of empirical evidence** on the effectiveness of PBL specifically at the junior secondary level in Indonesia, highlighting its potential as a robust instructional approach for strengthening students' higher-order thinking skills, particularly in mathematics education.

Recommendations

For Mathematics Teachers

It is recommended that mathematics teachers systematically integrate Problem-Based Learning into their instructional practices, particularly for topics that require reasoning, critical thinking, and the application of concepts to real-world problems. Teachers should also be provided with training in designing age-appropriate, contextual problems and using assessment rubrics that capture the multi-step nature of problem-solving processes.

For Schools and Educational Policymakers

Schools and policymakers should invest in ongoing professional development programs that prepare teachers to implement PBL effectively. These programs should cover instructional design, classroom facilitation, and authentic assessment strategies. In addition, schools should ensure adequate instructional time, access to contextual teaching materials, and technological resources that support the implementation of PBL.

For Future Researchers

Further studies are encouraged to examine additional moderating factors, such as students' learning styles, socioeconomic background, and the integration of digital tools in PBL environments. Longitudinal experimental studies are also recommended to investigate the sustainability of PBL's impact on students' mathematical achievement and cognitive development over time.

For Curriculum Developers

It is advised that curriculum designers explicitly incorporate PBL principles into mathematics curricula at the junior secondary level. Doing so will support the development of students' 21st-century competencies and better prepare them for international large-scale assessments such as **PISA**, where problem-solving is a key domain.

In summary, the results of this meta-analysis offer strong empirical support for the broader implementation of PBL in junior high school mathematics education. With appropriate planning, training, and policy alignment, PBL can serve as an effective strategy to cultivate students' critical and creative problem-solving skills—skills that are essential for success in both academic and real-life contexts.

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