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Problem-Based Learning Model On Students’ Mathematical Ability: A Meta-Analysis

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Mathematical ability is a core competence that students must master and develop 19 in mathematics education. One instructional model considered effective for enhancing this competence is ProblemBased Learning (PBL), which positions students at the center of learning by engaging them in solving contextual and meaningful problems. Through these activities, students are encouraged to strengthen key mathematical skills, including conceptual understanding, reasoning, and problem-solving. 9 This study aims to comprehensively analyze the impact of the PBL model on students’ mathematical abilities in Indonesia through a meta-analytic approach. A total of 30 studies were systematically reviewed following PRISMA guidelines. Data analysis was conducted using JASP to calculate the pooled effect size, the heterogeneity level, the forest plot, the funnel plot, and the potential publication bias. The meta-analysis produced a summary effect size of 1.132 (95% confidence interval: 0.873–1.390), indicating a large effect. The heterogeneity index (I^2=83.26%) showed substantial differences across studies; therefore, a random-effects model was employed. Although the funnel plot showed slight asymmetry, the Fail-Safe N value of 9.29>1 indicated that publication bias did not substantially affect the results. Overall, the findings confirm that PBL has a significant and consistent positive effect on students’ mathematical abilities across various educational levels in Indonesia.

Keywords: High-Order Thinking Meta-Analysis Problem Solving Problem-Based Learning Mathematical Ability

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1. INTRODUCTION

Mathematics is a fundamental discipline that plays a strategic role in developing students’ logical, analytical, systematic, and critical thinking skills. Kilpatrick et al. [1] view that mathematics fosters mathematical proficiency through conceptual understanding, procedural fluency, and adaptive reasoning. This is also supported by the NCTM [2], which emphasizes that mathematics learning should encourage students to think logically, critically, and strategically through meaningful problem-solving activities. Across all educational levels, mathematics serves as the foundation for mastering 19 science and technology [3]. However, in reality, Indonesian students' mathematical abilities remain relatively low. According to international assessments such as the Programme for International Student Assessment (PISA), Indonesian students' performance in mathematics falls below the OECD average [4]. This phenomenon indicates that mathematics instruction continues to face challenges in fostering higher-order thinking skills, particularly problem-solving and logical reasoning. One factor likely contributing to low mathematics achievement is the predominance of teacher-centered instructional approaches [5], [6], [7]. Such approaches often position students as passive recipients of information, with learning activities focused on procedural calculations and rote memorization of formulas rather than conceptual understanding and real-world application. Consequently, students struggle to connect mathematical content with everyday experiences, hindering the optimal development of 10 critical thinking and problem-solving skills [8]. In response to these challenges, various innovative instructional models have been developed, among which Problem-Based Learning (PBL) stands out. Rooted in constructivist theory, PBL emphasizes that knowledge is actively constructed through meaningful and reflective learning experiences [9]. In PBL, students are presented with authentic, ill-structured problems that encourage them to seek information, collaborate, and develop solutions based on their existing knowledge [10]. Through stages of problem identification, concept exploration, and reflection, students are expected to develop higherorder thinking skills, including critical, creative, analytical, and evaluative thinking [11], [12]. Empirical studies have demonstrated that PBL can enhance mathematical abilities. For example, Lathifah and Yolanda [13] found that PBL strengthened fifth-grade students' conceptual understanding of fractions. Mahfudhoh and Andrijati [14] reported that PBL improved students' problem-solving skills and increased their engagement in learning. Similarly, Tong et al. [15] and Hermawan and Prabawanto [16] observed that students taught using PBL demonstrated higher mathematical communication skills than those taught via direct instruction. However, several studies have reported that PBL does not have a significant effect on students' mathematical abilities [17], [18]. These inconsistencies may result from differences in research design, student characteristics, educational levels, instructional content, and intervention duration. Therefore, a quantitative synthesis approach is needed to integrate and analyze these diverse findings. One appropriate statistical technique for this purpose is meta-analysis, a statistical method that combines results from independent studies to yield more comprehensive and empirically robust conclusions [19]. Meta-analysis enables more accurate estimates of PBL's effectiveness across different types of mathematical abilities and educational levels. It also provides cumulative evidence while minimizing distortions from individual primary studies, thereby reducing inconsistencies and supporting theoretical development by identifying relationships among study characteristics [20]. Previous meta-analyses on PBL's impact on mathematics learning have been limited in scope. Juwita et al. [21] focused only on Elementary School levels, while Safiti et al. [22] examined PBL's effect specifically on mathematical understanding. Phasa [23] investigated PBL's influence on critical thinking but reported only the summary effect size without heterogeneity or funnel plot analyses. Considering the inconsistencies reported in previous empirical studies and the high degree of variability across research contexts, this study aims to fill this gap by conducting a meta-analysis of research on the effects of Problem-Based Learning (PBL) on students' mathematical abilities in Indonesia published between 2018 and 2025. Accordingly, this meta-analysis addresses the following research questions: (1) What is the pooled effect of the Problem-Based Learning (PBL) model on students' mathematical abilities in Indonesia? (2) Does the effect of PBL on students' mathematical abilities differ across educational levels (elementary, junior high, senior high, and higher education)? This study employs a meta-analytic approach to synthesize empirical evidence on the effectiveness of the Problem-Based Learning (PBL) model in mathematics education. [1] The standardized mean difference (SMD), equivalent to Cohen's d, was used as the effect size metric to ensure comparability across studies employing different measurement scales. Given the substantial variability in research contexts, a random-effects model was applied. Relevant studies were retrieved from Google Scholar, SINTA, and GARUDA databases and were limited to experimental research designs investigating [2] the effect of PBL on students' mathematical abilities. This study offers novelty by integrating recent empirical findings, analyzing heterogeneity using a random-effects model, and evaluating publication bias using funnel plots and statistical bias indicators. 2. METHOD This study employed a meta-analytic design to examine [2] the effect of Problem-Based Learning on students' mathematical abilities in Indonesia. Data collection and study selection followed the Preferred Reporting Items for Systematic Reviews and MetaAnalyses (PRISMA) guidelines [24]. At the identification stage, a total of 1,230 records were retrieved from Google Scholar, SINTA, and GARUDA databases. After removing duplicate records, 356 articles remained and were screened [1] based on titles and abstracts. During the screening stage, 303 records were excluded [2] because they were nonempirical studies, literature reviews, qualitative research, or did not explicitly examine the effect of Problem-Based Learning (PBL) on students' mathematical abilities. The full texts [1] of the remaining 53 articles were then sought and assessed for eligibility. At the eligibility stage, 23 studies were excluded due to the absence of a control group, incomplete statistical data, or outcome variables that were not relevant to mathematical ability constructs. [1] The reasons for exclusion at each stage were documented to ensure transparency and reproducibility of the study selection process. As a result of this multistage screening process, 30 studies met all inclusion criteria and were included in the final meta-analysis. A detailed summary of 11 the identification, screening, eligibility, and inclusion stages is presented in Figure 1

Figure 1. 1 PRISMA Flow Diagram

The literature search was conducted using two academic search engines, namely Google Scholar and GARUDA (Garba Rujukan Digital). To ensure comprehensive coverage of relevant studies, a combination of keywords and their synonyms was employed, including “Problem-Based Learning,” “PBL,” “problem-based,” “mathematical ability,” “mathematical literacy,” and “learning outcomes.” In Google Scholar, the following complete search string was applied: ("Problem-Based Learning" OR "PBL" OR "problem based") AND ("mathematical ability" OR "mathematical literacy" OR 2 "learning outcomes") AND mathematics. In the GARUDA database, which supports title-based Boolean searching, the following complete search string was used: ("Problem Based Learning" OR "PBL") AND ("kemampuan matematis" OR "standar proses matematis" OR "hasil belajar matematika"). The search was limited to articles published between 2018 and 2025, and all retrieved records were subsequently screened 1 based on titles and abstracts to ensure alignment with the predefined inclusion criteria. 13 The methodological quality of the included studies was assessed using a modified quality appraisal checklist adapted from established meta-analytic guidelines in educational research [25]. The assessment focused on key aspects of internal validity, including group assignment procedures, baseline equivalence, attrition, outcome measurement, 1 and completeness of statistical reporting. Each study was independently evaluated against these criteria using a dichotomous scoring system (1 = criterion met; 0 = not met). 1 Based on the total quality score, studies were classified as having low (4–5 criteria met), moderate (2–3 criteria met), or high (0–1 criterion met) risk of bias. To examine the robustness of the meta-analytic findings, a sensitivity analysis was conducted by excluding studies classified as having a high risk of bias. After excluding studies with a high risk of bias, the pooled effect size decreased slightly but remained statistically significant, suggesting that the main findings were robust despite variations in study quality. [1] The studies that met the inclusion criteria were then analyzed by calculating the effect size from each primary study. The effect size is a statistical measure used to standardize results across different research designs, allowing comparisons among studies with varying scales and instruments. Effect sizes were computed using the standardized mean difference (SMD), also known as Cohen’s d. The formula for calculating the effect size is as follows: $d = \bar{X}1 - \bar{X}2 \; Swithin$ (1) Where $\bar{X}1$ and $\bar{X}2$ are the means of the experimental and control groups, respectively, and $Swithin$ is the pooled standard deviation. To correct for small-sample bias, Cohen’s d values were adjusted using Hedges’ correction factor, resulting in Hedges’ g, which was reported as the final effect size in this meta-analysis. This adjustment is recommended for meta-analyses involving studies with relatively [1] small sample sizes. The formula for calculating the final [3] effect size is as follows: $g = d \; x \; (1 - 3 \; 4N - 9)$ (2) Effect sizes were interpreted as small ($0.20 \leq g < 0.50$), medium ($0.50 \leq g < 0.80$), or large ($g \geq 0.80$). The pooled standard deviation of the posttest scores was used to standardize mean differences between the experimental and control groups. For studies employing a pretest–posttest control group design, effect sizes were calculated based on posttest scores to ensure consistency across studies, assuming baseline equivalence between groups as reported in the primary studies. The next important step in meta-analytic studies is determining whether to [1] use a fixed-effect or a random-effects model. This decision is based on the level of heterogeneity observed in the summary effect size. The fixed-effect model is applied when heterogeneity is less than 50%, whereas the random-effects model is used when heterogeneity is 50% or higher [26]. The analysis was conducted using JASP software version 0.95.2, which provides comprehensive meta-analysis features for estimating effect sizes, assessing heterogeneity (Q, I^2, τ^2), and performing subgroup analyses based on specific moderators.

3. RESULTS AND DISCUSSION

3.1. Results

[2] In this study, the outcome variables from each primary

research study were categorized based on their theoretical similarities. Several studies employed different terms such as conceptual understanding, problem-solving, mathematical communication, and mathematical connection. Nevertheless, all these variables share a common orientation, representing students' learning achievements after receiving instructional interventions.

https://doi.org/10.58421/misro.v4i4.880 1381 Therefore, all outcomes were classified under a single overarching construct, namely mathematics ability. The studies included in this meta-analysis were conducted across various educational levels, ranging from Elementary School and junior high schools to senior high schools and universities. The following table presents 1 the studies included in the analysis, along with their respective effect sizes. Table 1. Effect size of each study No Researcher/Year Educational Level Measured ability g SE Category 1 Putri, et al (2024) Elementary School Procedural 1,50 0,31 Large Effect 2 Wahyuni, (2024) Elementary School Problem Solving 1,25 0,27 Large Effect 3 Rubianti, et al (2019) Elementary School Conceptual Understanding -0,14 0,26 Small Effect 4 Rahman, et al (2024) Elementary School Conceptual Understanding 1,25 0,25 Large Effect 5 Indriani, et al. (2023) Elementary School Conceptual Understanding 1,25 0,70 Large Effect 6 Mahfudoh & Andrijati (2024) Elementary School Problem Solving 1,38 0,27 Large Effect 7 Farmah & Nindiasari (2025) Elementary School Procedural 1,68 0,32 Large Effect 8 Abidin (2020) Elementary School Procedural 0,47 0,29 Small Effect 9 Hermawan & Prabawanto (2023) Elementary School Procedural 1,81 0,34 Large Effect 10 Farhan, 2 et al (2021) Elementary School Procedural 1,85 0,37 Large Effect 11 Durasa, et al. (2024) Junior School Problem Solving 0,61 0,21 Medium Effect 12 Erlinda (2022) Junior School Procedural -0,06 0,25 Small Effect 13 Aini, etal. (2021) Junior School Conceptual Understanding 0,62 0,27 Medium Effect 14 Yudistira (2020) Junior School Conceptual Understanding 0,74 0,28 Medium Effect 15 Yustianingrum, et al. (2022) Junior School Problem Solving 1,22 0,24 Large Effect 16 Sinaga & Manik (2019) Junior School Procedural 0,14 0,23 Small Effect 17 Suryana (2025) Junior School Conceptual

Understanding 1,61 0,31 Large Effect 18 Monica (2018) Junior School Conceptual Understanding 0,36 0,25 Small Effect 19 Butar-Butar, et al (2022) High School Conceptual Understanding 2,12 0,29 Large Effect 20 Ramadhani (2018) High School Problem Solving 0,92 0,26 Large Effect

https://doi.org/10.58421/misro.v4i4.880 1382 No Researcher/Year Educational Level Measured ability g SE Category 21 Yulianti & Gunawan (2019) High School Conceptual Understanding 0,80 0,27 Large Effect 22 Raisah, et al. (2024) High School Procedural 2,47 0,40 Large Effect 23 Farid, et al (2020) High School Conceptual Understanding 0,86 0,27 Large Effect 24 Umayrah (2023) High School Conceptual Understanding 0,60 0,38 Medium Effect 25 Rohmawati, et al (2019) High School Problem Solving 2,27 0,40 Large Effect 26 Umam, 2 et al (2021) High School Procedural 1,79 0,47 Large Effect 27 Susilo (2020) University Conceptual Understanding 0,20 0,27 Small Effect 28 Laksanawati & Rofiroh (2020) University Problem Solving 1,75 0,35 Large Effect 29 Oktaviana & Haryadi (2020) University Problem Solving 1,36 0,31 Large Effect 30 Kusuma & Nurmawanti (2023) University Problem Solving 2,28 0,35 Large Effect 3 Based on the data presented in Table 1, the studies were conducted across several educational levels: Elementary School (10 studies), 16 junior high school (8 studies), senior high school (8 studies), and higher education (4 studies). In total, the analyzed studies involved 905 students in the experimental groups and 901 students in the control groups. According to the classification 3 of effect sizes, 20 studies (66.7%) demonstrated a significant effect, four studies (13.3%) showed a medium effect, and six studies (20%) indicated a small effect. These findings suggest that implementing the Problem-Based Learning (PBL) model generally exerts a strong influence on improving mathematics ability. This evidence reinforces the view 2 that PBL is effective across different educational levels in enhancing students’ mathematical abilities, including conceptual, procedural, and problem-solving skills. The data from these studies were further analyzed 1 to calculate the summary effect size using the Standardized Mean Difference (SMD) method, as each primary study employed different measurement instruments and scales. The interpretation followed Cohen’s [27] classification, where values of 0.00–0.20 indicate a small effect, >0.20–0.50 indicate 3 a medium effect, >0.50–0.80 indicate a large effect, and values above 0.80 indicate a very large effect. Model Summary Table 2. Meta-Analytic Tests Test p Heterogenity Qe=165.56 < .001 Pooled effect z=8.58 < .001

https://doi.org/10.58421/misro.v4i4.880   1383 Table 3. Meta-Analytic Estimates Estimate 95% CI Lower Uper Pooled effect 1.132 0.873 1.390 I2 83.263 73.163 90.808 Based on the analysis results in the Model Summary table, the pooled effect size was 1.132, with a 95% confidence interval of 0.873-1.390. This value falls into the very high effect category according to Cohen's classification, indicating that overall, the implementation of Problem-Based Learning (PBL) has a strong influence on improving mathematics learning outcomes. Furthermore, the heterogeneity test showed a $Q_e(29)$ value of 165.56 ($p < 0.001$), indicating significant heterogeneity among the analyzed studies. In other words, there are significant differences in the effect sizes across studies. Furthermore, the I^2 (Heterogeneity) value of 83.26% indicates a high level of heterogeneity (above 75%); therefore, 18 a random-effects model was used in this analysis. This indicates that 1 the variation in effects is not solely due to sampling error but is also influenced by differences in the research context, educational level, and mathematical ability variables measured across studies. The next step was to provide a clearer visualization of the distribution of effects from each study, the consistency of the research results, and the possibility of publication bias by conducting forest plot and funnel plot analyses. Forest plot analysis is used to illustrate the size and direction of each study's effect and the combined estimate (summary effect), while funnel plots are used to detect imbalances in the distribution of studies that could indicate publication bias in the research.   Figure 2. Forrest Plot

https://doi.org/10.58421/misro.v4i4.880 1384 The figure shows that most studies reported a positive effect size and were on the right side of the zero line, indicating a positive effect. The summary effect size (pooled effect) was 1.132 [95% CI = 0.873 – 1.390], with $p < 0.001$, indicating a significant overall effect [2] and in the very high category. Furthermore, the I^2 value of 83.26% indicates high heterogeneity across studies, suggesting that [1] a random-effects model is appropriate. The next step was to analyze the possibility of publication bias. In meta-analytical research, publication bias is a weakness that researchers must avoid. Publication bias [1] occurs when studies are excluded from the analysis because their results are deemed insignificant or inconsistent with expectations, leading to inaccurate conclusions. [3] To detect publication bias, a funnel plot is used as a visual analysis tool. Publication bias is indicated if the study effect size is not symmetrically distributed around the vertical line in the funnel plot. If the plot does not show perfect symmetry, further testing is performed using Rosenthal's Fail-Safe N (FSN) approach. [3] The funnel plot results are considered robust to publication bias if the FSN/(5K+10) value is greater than 1, where K is the number of studies analyzed. Figure 3. Funnel Plot Figure 3 shows that the distribution of points on the funnel plot is asymmetrical around the centerline. This indicates that the analyzed studies are not evenly distributed and there is a tendency for publication bias. To confirm this, Rosenthal's Fail-Safe N (FSN) statistical test was performed. [1] Based on the calculation, the FSN value was 1486. Furthermore, using the formula (1486/(5×30)) + 10 yielded a value of 9.29, which is greater than 1. Table 4. Publication Bias Assesment Test Name value p Fail-N Safe 1486.000 < .001 Kendals Tau 0.483 < .001 Egger's Regression 3.617 < .001 These results indicate that publication bias did not significantly affect the metaanalysis, so no additional or deleted studies were needed to eliminate this bias. The table

https://doi.org/10.58421/misro.v4i4.880 1385 below shows the results of the publication bias tests, which included the Fail-Safe N, Kendall's Tau, and Egger's Regression Test. The p-values < .001 in all three tests indicate results [20] consistent with the conclusion that publication bias does not substantially affect the meta-analysis. 3.2. Discussion [2] The findings of this meta-analysis demonstrate that PBL has a strong and consistent positive effect on students' mathematical abilities across educational levels. This 20 aligns with the theoretical foundation of PBL, which emphasizes active inquiry, collaborative problem-solving, and reflective thinking [28], [29]. The positive impact of PBL on conceptual understanding, procedural fluency, and mathematical reasoning underscores the model's effectiveness in fostering deeper learning. The high heterogeneity ($I^2 = 83.26\%$) suggests that contextual 3 factors such as instructional duration, teacher experience, mathematical topic, and student characteristics may moderate PBL's effectiveness. Nevertheless, the consistently positive direction of effect sizes indicates that PBL is adaptable and beneficial across diverse learning environments. These findings extend previous meta-analyses that focused only on specific grade levels or mathematical competencies. By including studies from elementary to university levels and by comprehensively analyzing publication bias, this research provides stronger empirical evidence on the effectiveness of PBL in the Indonesian education context. 2 The findings of this meta-analysis are consistent with previous empirical studies demonstrating the effectiveness of Problem-Based Learning in enhancing students' mathematical abilities. For example, Anugraheni et al. [30] reported that students who learned through PBL demonstrated significantly higher mathematical problem-solving abilities than those taught using conventional instruction. Regugio [31] found that PBL effectively improved elementary students' problem-solving skills by encouraging active engagement and collaborative reasoning. In addition, studies by Ramadhan [32] and Handayani et al. [33] revealed that PBL not only enhances students' mathematical ability but also strengthens their self-confidence and interest in learning. 6 These findings suggest that PBL facilitates meaningful learning experiences by situating mathematical concepts within real-life problem contexts, which aligns with the consistently large effect size observed in the present meta-analysis. 4. CONCLUSION This meta-analysis demonstrates that Problem-Based Learning is an effective instructional model for enhancing students' mathematical abilities 8 across various educational levels in Indonesia. Overall, the findings 6 indicate that PBL consistently supports the development of conceptual understanding, procedural fluency, and problemsolving skills, regardless of differences in educational context. From a practical perspective, these results suggest that mathematics teachers and curriculum designers should consider integrating PBL into classroom instruction to promote active learning and higher-order thinking skills. Theoretically, this study strengthens constructivist perspectives on learning by providing empirical evidence that problem-centered instruction leads to meaningful mathematical learning outcomes. Despite its contributions, this study has several limitations. First, the high level 1 of heterogeneity among the included studies reflects variability in instructional implementation, sample characteristics, mathematical content, and research design. Second, although several primary studies considered affective factors such as self-efficacy, learning interest, and learning styles, 2 the number of such studies remains limited. Moreover, this meta-analysis did not conduct detailed subgroup or moderator analyses related to instructional duration, topic complexity, or affective variables due to data constraints. Future research is therefore encouraged to examine further 10 the role of affective factors in PBL-based mathematics instruction, such as self-regulated learning, mathematical disposition, cognitive style, or mathematics anxiety, which may act as important moderators of learning outcomes. In addition, future studies may explore 2 the effectiveness of modified PBL approaches by integrating complementary instructional frameworks such as Concrete–Pictorial–Abstract (CPA), Realistic Mathematics Education (RME), or technology-enhanced PBL supported by digital tools like GeoGebra or GamesBased Learning. For the general public and educational stakeholders, this research provides evidence-based support for adopting student-centered and integrative instructional models that foster meaningful, transferable, and sustainable mathematical learning. 11 ACKNOWLEDGEMENTS I would like to express my thesis advisors, Mrs. Iva and Mr. Yunus, for their unwavering support, constructive criticism, and mentorship, which greatly contributed to the refinement and completion of this article and I am also deeply

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