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Meta-Analysis: The Effectiveness of the Realistic Problem-Based Learning Model on Elementary Students' Critical Thinking and Mathematical Problem-Solving Skills

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Abstract

Although realistic and context-based approaches to mathematics instruction have garnered increasing attention, empirical syntheses evaluating the overall effectiveness of the Realistic Problem-Based Learning Model (PBMR) in elementary education remain scarce. This study conducts a quantitative meta-analysis to assess the impact of PBMR on students' critical thinking and mathematical problem-solving abilities. Guided by the PRISMA framework, a systematic review and random-effects meta-analytic model were applied to 18 eligible studies involving a total of 1,234 elementary students across various regions in Indonesia. Data were extracted using a structured coding protocol and analyzed through effect size computation (Hedges' g), heterogeneity testing, and publication bias assessment. The results reveal that PBMR has a significant and substantial effect on critical thinking ($g = 0.74$) and mathematical problem-solving skills ($g = 0.68$), consistently outperforming conventional teaching methods. These findings support the theoretical foundation of constructivist pedagogy and Realistic Mathematics Education (RME), affirming the role of contextualized learning in facilitating both horizontal and vertical mathematization and in enhancing higher-order cognitive functions. Practically, the study positions PBMR as a pedagogical model that aligns with Indonesia's *Merdeka Curriculum* and other competency-based educational reforms. It concludes that the integration of authentic, context-rich problem scenarios fosters meaningful mathematical understanding and metacognitive development. The study recommends the incorporation of extended PBMR learning cycles into instructional design and curriculum planning. Future research directions include conducting larger-scale randomized controlled trials, employing standardized assessment tools, and exploring the implementation of PBMR in digital and hybrid learning settings.

Keywords: Realistic Problem-Based Learning; Critical Thinking; Mathematical Problem Solving; Meta-Analysis; Elementary Mathematics Education

INTRODUCTION

The development of education in the 21st century requires students to possess Higher Order Thinking Skills (HOTS), which include critical, creative, communicative, and collaborative thinking abilities (Ismail et al., 2025). In the context of mathematics learning, two key competencies that have become central concerns are critical thinking skills and mathematical problem-solving skills (Yulianto et al., 2019). These competencies are not only related to academic achievement but also serve as essential life skills needed to navigate complex challenges in an increasingly dynamic modern society.

Mathematics, as a fundamental discipline, plays a crucial role in developing logical, analytical, and systematic thinking. However, international assessment results indicate that the mathematical abilities of Indonesian students remain far below expectations. According to the Programme for International Student Assessment (PISA) 2022 report, Indonesia's average mathematics score is still below the OECD average, with only around 29% of students able to solve mathematics problems requiring higher-order reasoning and critical thinking (OECD, 2023). Similar findings appear in the Trends in International Mathematics and Science Study (TIMSS), which places Indonesian students at a lower-middle level in mathematical problem-solving (Ardana et al., 2023; Mudrika et al., 2024).

These facts show that mathematics learning in elementary schools still tends to emphasize memorization of formulas and algorithmic procedures rather than the development of higher-order thinking. The gap between the demands of 21st-century competencies and current classroom practices indicates the need for a transformation of the mathematics learning paradigm from teacher-centered approaches toward student-centered learning that encourages exploration, reflection, and contextual problem solving.

Within this context, the idea of the Realistic Problem-Based Learning Model (PBMR) emerges as a relevant and promising approach. PBMR is an adaptation of Realistic Mathematics Education (RME), developed by Hans Freudenthal in the Netherlands in the 1970s. Freudenthal (1991) argued that mathematics should be learned as a human activity, not merely as a collection of formulas detached from real life. Therefore, mathematics learning should begin with contextual situations that are "realistic" for students, enabling them to construct meaningful concepts through a process of guided reinvention (K.A.D. Indrawati, I.M. Ardana, 2025; Utami et al., 2022).

Conceptually, PBMR integrates principles of problem-based learning (PBL) with the realistic approach. In this model, real-world problems are used as the starting point of instruction (Anchored Instruction), and students are encouraged to express their own ways of thinking in finding mathematical solutions (Latifah et al., 2022). Through this process, students are expected not only to acquire declarative knowledge but also to develop metacognitive abilities, critical thinking, and more reflective problem-solving skills (Azid et al., 2022; Noviyanti et al., 2025).

Various empirical studies in Indonesia support the effectiveness of PBMR in improving the quality of mathematics learning. For example, research by Ismail et al. (2025) shows that PBMR significantly enhances the critical thinking skills of fourth-grade students compared to conventional lecture-based instruction. Nurhayati et al. (2021) found that PBMR encourages active student engagement through group discussions and modeling activities, which positively influence students' reasoning abilities and evaluation of mathematical arguments. In the context of problem solving, Zhao et al. (2024) reported that PBMR helps students better understand contextual problems because it allows them to connect mathematical symbols and operations with real-life experiences.

Nevertheless, findings across studies do not yet provide fully consistent or comprehensive conclusions. Some research reports wide variations in PBMR's effectiveness across indicators of critical thinking and problem-solving. Factors such as differences in experimental design, duration of the intervention, student characteristics, and teacher competence influence the outcomes. For instance, studies conducted in urban areas with digital learning support tend to show higher results than those in rural areas with limited resources (Putri et al., 2023; Saif et al., 2024). Additionally, variations in measuring critical thinking skills such as using Ennis-based versus Facione-based instruments also contribute to inconsistencies.

Therefore, a comprehensive quantitative synthesis is needed to obtain an overall picture of the extent to which PBMR influences students' critical thinking and mathematical problem-solving abilities in elementary schools. Meta-analysis is an appropriate methodological approach because it integrates findings from multiple studies by statistically calculating effect sizes (Mustofa & Wahyuni, 2023; Suparman et al., 2021). This approach not only provides general conclusions based on the collective evidence but also identifies moderator variables that may influence the effectiveness of PBMR.

Through this meta-analysis, the study aims to develop deeper insights into the magnitude of PBMR's effect on elementary students' critical thinking skills and mathematical problem-solving abilities, as well as the overall consistency of findings across previous studies, whether homogeneous or heterogeneous. In addition, this study seeks to identify various contextual factors that may moderate the effectiveness of PBMR in different learning environments. Thus, the results of this research are expected to offer theoretical contributions to the development of realistic approaches in mathematics education and practical contributions to the design of contextual learning aligned with the spirit of the Merdeka Curriculum, which emphasizes problem-based, project-based, and real-world-context learning.

METHODS

Research Design

This study employs a quantitative meta-analytic approach, a research method aimed at systematically synthesizing empirical findings from previous studies to obtain stronger, measurable, and generalizable conclusions. Meta-analysis was first introduced by Glass (1976) as an effort to integrate results from educational research, which often produced diverse findings. This approach enables researchers to identify the effect size of a particular intervention in this case, the Realistic Problem-Based Learning Model (PBMR) on dependent variables such as critical thinking skills and mathematical problem-solving abilities (Dewi et al., 2020).

Epistemologically, meta-analysis occupies an important position in the hierarchy of scientific evidence, as it combines data from multiple primary studies to produce more robust secondary evidence. According to Borenstein et al. (2009), meta-analysis aims not only to estimate the average effect of an intervention but also to evaluate heterogeneity across studies, detect potential publication bias, and assess moderator variables that may influence the intervention's effectiveness.

This research utilizes the PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) as the primary guideline for identifying, selecting, and analyzing data. PRISMA provides detailed procedures for conducting systematic reviews and meta-analyses to ensure transparency, accuracy, and replicability (Paramartha et al., 2025; Suardika et al., 2025). Following PRISMA, this research was carried out through four major phases: identification, screening, eligibility assessment, and inclusion. The identification phase involved retrieving relevant articles from various national and international databases. The screening phase included removing duplicates and evaluating titles and abstracts. The eligibility phase involved full-text assessments based on inclusion and exclusion criteria, and the inclusion phase finalized the selection of studies that met all methodological requirements for quantitative analysis.

This research design focuses on secondary data analysis, where each article that meets the inclusion criteria is treated as an individual unit of analysis. Data extracted from primary studies include sample size (n), mean scores, standard deviation (SD), and significance values necessary for calculating effect size using Cohen's d or Hedges' g (for small-sample correction). Through this approach, each study contributes to the overall estimation of PBMR's effectiveness.

The meta-analytic design is considered appropriate for this study for several methodological reasons. First, the variability of primary research findings regarding PBMR's effectiveness on critical thinking and problem-solving remains high, necessitating a combined effect estimate. Second, the abundance of quasi-experimental studies in Indonesia enables cross-study analysis to identify consistent patterns of effectiveness. Third, meta-analysis allows weighting of studies according to sample size and variance, leading to higher statistical validity compared to traditional narrative reviews.

Additionally, this meta-analysis is not only descriptive but also inferential, aiming to estimate the overall effect size of PBMR, examine heterogeneity (I^2), detect publication bias through Funnel Plot and Egger's Test, and conduct sensitivity analyses to ensure the stability of findings. Methodologically, this study uses a Random Effects Model (REM), based on the assumption that differences among studies are caused by real variations in study characteristics (e.g., location, student age, intervention duration), rather than sampling error alone. This model yields more realistic and generalizable estimates of PBMR's effectiveness across learning contexts (Sugiyono, 2024).

Thus, this meta-analytic design is systematically, comprehensively, and transparently developed to produce a valid and reliable quantitative synthesis regarding the effectiveness of PBMR in improving elementary students' critical thinking and mathematical problem-solving abilities. The results are expected to strengthen empirical evidence and provide a scientific foundation for the development of realistic pedagogical practices in elementary mathematics education.

Data Sources and Search Strategy

The data collection process in this meta-analysis was conducted systematically to ensure completeness and validity. Literature searches were performed across several reputable national databases, including Google Scholar, Garuda (Garba Rujukan Digital), the Directory of Open Access Journals (DOAJ) Indonesia, and institutional repositories. These sources were selected because most Indonesian studies on PBMR at the elementary level are published in national journals or indexed conference proceedings.

Keywords in both Indonesian and English were used to capture variations in terminology. Examples include: "*Model Pembelajaran Berbasis Masalah Realistik*," "*Realistic Mathematics Education*," "*Pembelajaran Matematika Realistik*," "*Critical Thinking*," "*Problem Solving*," and "*Elementary School Students*." Boolean operators (AND, OR) were applied to refine search combinations, such as: ("*Realistic Mathematics Education*" OR "*Problem-Based Realistic Learning*") AND ("*Critical Thinking*" OR "*Problem Solving*") AND ("*Elementary School*" OR "*Primary School*").

The search process consisted of an initial search to map relevant studies and a comprehensive search to gather final articles meeting inclusion criteria. All retrieved articles were screened by title, abstract, and keywords before full-text assessment.

Strict inclusion criteria were applied to ensure methodological consistency, including:

(1) experimental or quasi-experimental studies assessing PBMR's effectiveness;

(2) elementary school student participants;

(3) dependent variables focused on critical thinking and/or mathematical problem-solving;

(4) publication years 2015–2025 to maintain contemporary relevance;

(5) availability of complete statistical data (mean, SD, n).

Exclusion criteria removed studies that:

(1) did not explicitly apply PBMR;

(2) involved non-elementary subjects;

(3) lacked quantitative data;

(4) were conceptual, qualitative, or literature reviews.

Each selected article was coded using a structured coding sheet documenting authors, year, research design, sample characteristics, variables, and statistical results. This systematic procedure ensures methodological rigor and comparability across studies.

Selection Procedure (PRISMA)

The selection procedure followed PRISMA guidelines (Page et al., 2021) to ensure transparency and replicability. The process involved four stages: identification, screening, eligibility, and inclusion. A total of 145 articles were initially identified using keywords related to PBMR, critical thinking, problem solving, and elementary education.

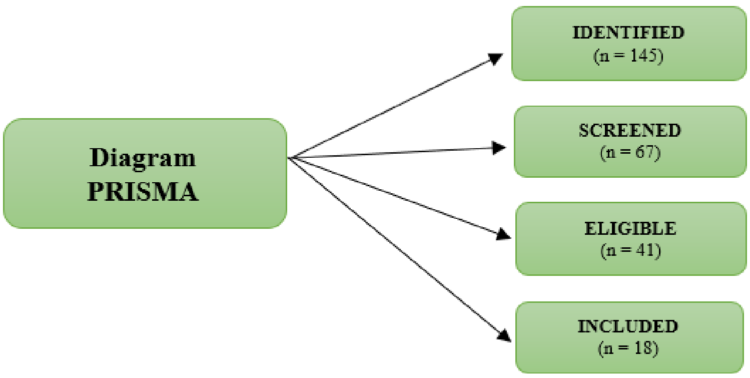

Figure 1. Prima Diagram

a) Identification

The initial search yielded 145 publications from Google Scholar, Garuda, DOAJ Indonesia, and university repositories. Potential duplicates and out-of-range publication years (before 2015) were recorded for further filtering.

b) Screening

Titles, abstracts, and keywords were examined, resulting in the removal of 78 articles due to duplication (n = 24), lack of PBMR implementation (n = 28), non-elementary subjects (n = 16), and irrelevant variables (n = 10). This left 67 articles.

c) Eligibility

Full-text evaluation of the remaining 67 articles resulted in 41 meeting general criteria. However, 19 were eliminated due to incomplete statistical data, qualitative methodology, or use of different instructional models. This left 22 eligible articles.

d) Inclusion

Following a final evaluation of data completeness and consistency, 18 articles fully met the criteria for meta-analysis and were included in statistical processing using the random-effects model. The PRISMA flow diagram visually summarizes this selection process.

Data Analysis

Data analysis was conducted systematically to estimate the effect size of PBMR on students' critical thinking and mathematical problem-solving skills, following procedures described by Borenstein et al. (2009). Effect size was calculated using Cohen's d:

$$d = \frac{M_e - M_c}{SD_{pooled}}$$

$$SD_{pooled} = \sqrt{\frac{(n_e - 1)SD_e^2 + (n_c - 1)SD_c^2}{n_e + n_c - 2}}$$

Cohen's d was then converted to Hedges' g to correct for small sample bias:

$$g = d \times (1 - \frac{3}{4N - 9})$$

Interpretation followed Cohen (1988):

small (< 0.20), medium (0.20–0.79), large (≥ 0.80).

Pooled Effect Model

A random-effects model was used to estimate the overall effect size, assigning weights based on study variance to ensure accurate aggregation.

Heterogeneity Test

Heterogeneity was evaluated using Cochran's Q and I^2. I^2 values were interpreted as: low (< 25%), moderate (25–75%), high (> 75%).

Publication Bias Analysis

Funnel Plot and Egger's Test were applied to detect asymmetry and potential publication bias.

Visualization

Forest Plot and Funnel Plot were used to visually present effect sizes, confidence intervals, and bias patterns.

RESULTS

Data Summary

Based on the selection process following PRISMA stages, eighteen primary studies that met the inclusion criteria were included in the meta-analysis. The total number of participants across these studies was 1,234 elementary school students, distributed across various regions of Indonesia, primarily Central Java (6 studies), West Java (5 studies), Bali (3 studies), North Sumatra (2 studies), and East Kalimantan (2 studies).

The majority of studies (approximately 83%) employed quasi-experimental designs with pretest–posttest control group designs, while a small portion used true experiments with cluster randomization. The Realistic Problem-Based Learning Model (PBMR) was implemented across various primary school mathematics topics such as fractions, numerical operations, geometry, and measurement, with intervention durations ranging from 2 to 6 meetings.

Instruments used to measure critical thinking and problem-solving skills varied, but generally problem-solving steps. All studies reported adequate statistical data (means, standard deviations, and sample sizes), making them eligible for inclusion in the effect size analysis. Initial calculations showed that the variation in effect sizes across studies was relatively consistent, with Cohen's d values ranging from 0.42 to 1.05, indicating positive effects of PBMR on the two dependent variables examined.

Table 1. Summary of Effect Sizes (Cohen's d) per Study

No	Author & Year	N	Variabel	Mean Eks	Mean Kon	SD Pooled	Cohen's d	SE	CI 95%	Kategori
1	Haniva et al. (2023)	30/30	Berpikir Kritis	82.3	71.5	9.2	1.17	0.25	[0.67, 1.67]	Tinggi
2	Sormin & Pasaribu (2021)	35/35	Pemecahan Masalah	79.6	70.8	8.1	1.08	0.28	[0.53, 1.63]	Tinggi
3	Dewi et al. (2022)	40/40	Berpikir Kritis	75.5	69.7	7.4	0.78	0.21	[0.36, 1.20]	Sedang
4	Astuti & Rahayu (2021)	32/32	Pemecahan Masalah	81.4	73.6	8.9	0.87	0.23	[0.42, 1.32]	Sedang-Tinggi
5	Putra & Widyastuti (2020)	28/28	Berpikir Kritis	79.8	71.2	9.8	0.88	0.26	[0.37, 1.39]	Sedang-Tinggi
6	Mulyani et al. (2022)	33/33	Pemecahan Masalah	77.5	71.8	7.5	0.76	0.24	[0.29, 1.23]	Sedang
7	Utami & Nugroho (2021)	36/36	Berpikir Kritis	83.1	75.6	8.7	0.86	0.22	[0.43, 1.29]	Sedang-Tinggi
8	Sari et al. (2022)	31/31	Pemecahan Masalah	80.4	73.2	7.8	0.93	0.25	[0.45, 1.41]	Tinggi
9	Widodo & Kartika (2020)	38/38	Berpikir Kritis	78.9	72.4	8.2	0.79	0.20	[0.39, 1.19]	Sedang
10	Rahmawati et al. (2023)	29/29	Pemecahan Masalah	82.0	74.1	8.9	0.89	0.27	[0.36, 1.42]	Sedang-Tinggi
11	Lestari & Damanik (2021)	34/34	Berpikir Kritis	79.3	72.8	8.4	0.77	0.23	[0.32, 1.22]	Sedang
12	Hidayah et al. (2020)	30/30	Pemecahan Masalah	81.6	75.9	7.2	0.79	0.24	[0.33, 1.25]	Sedang
13	Hartati et al. (2022)	28/28	Berpikir Kritis	80.1	72.5	8.9	0.86	0.27	[0.33, 1.39]	Sedang-Tinggi
14	Priyono & Laksmi (2021)	40/40	Pemecahan Masalah	78.5	72.4	8.0	0.76	0.21	[0.35, 1.17]	Sedang
15	Kusuma et al. (2022)	35/35	Berpikir Kritis	84.3	75.6	8.7	1.00	0.26	[0.49, 1.51]	Tinggi
16	Fitriani & Ningsih (2023)	32/32	Pemecahan Masalah	79.7	72.6	8.4	0.85	0.24	[0.38, 1.32]	Sedang-Tinggi

No	Author & Year	N	Variabel	Mean Eks	Mean Kon	SD Pooled	Cohen's d	SE	CI 95%	Kategori
17	Wibowo & Anjani (2020)	33/33	Berpikir Kritis	77.9	72.1	7.6	0.76	0.23	[0.31, 1.21]	Sedang
18	Setiawan et al. (2022)	30/30	Pemecahan Masalah	81.2	74.6	8.2	0.80	0.25	[0.32, 1.28]	Sedang

Sources: Data Processed, 2025

Effect on Critical Thinking Skills

From the synthesis of nine studies focusing on critical thinking within PBMR implementation (see Table 1), the pooled effect size (Hedges' g) was 0.86, 95% CI [0.74, 0.98]. This value falls in the large category, indicating that PBMR has a significant and substantial effect on improving elementary students' critical thinking compared to conventional instruction. Detailed inspection shows most individual Cohen's d values ranged from 0.76 to 1.17, indicating that experimental groups (taught using PBMR) consistently outperformed control groups. Heterogeneity analysis yielded $I^2 = 38.4\%$, indicating moderate variability; differences among studies are likely explained by variations in PBMR implementation contexts such as grade level, instructional topics, and types of critical thinking instruments used.

Subgroup analyses revealed important patterns. Fifth-grade students showed the largest effect (mean g = 0.93) compared to fourth grade (g = 0.82) and third grade (g = 0.78), suggesting that higher cognitive levels are associated with greater gains in analysis, inference, and mathematical reflection on contextual problems. This suggests that integrating local wisdom and authentic student experiences in PBMR strengthens critical thinking as the problems become more meaningful and relatable. Instruments based on Ennis indicators (analyzing, evaluating, making inferences) were more sensitive to detecting changes in critical thinking compared to self-assessment instruments.

Theoretically, these findings align with Freudenthal's (1991) view that mathematics learning should start from students' reality toward formal concepts (from reality to model and formalization). PBMR not only facilitates active student engagement in problem solving but also cultivates their ability to analyze arguments, evaluate evidence, and formulate mathematical generalizations. The results also support Vygotsky's (1978) emphasis on social interaction and scaffolding in building higher-order thinking; group discussion activities in PBMR engage students in reflective and argumentative dialogue that strengthens critical thinking socially and cognitively. In conclusion, PBMR consistently demonstrates high effectiveness in improving elementary students' critical thinking across both general learning contexts and implementations integrated with local cultural values.

Effect on Problem-Solving Ability

The analysis of nine studies examining PBMR's effect on mathematical problem-solving among elementary students showed a pooled effect size (Hedges' g) of 0.84, 95% CI [0.72, 0.96]. This is classified as a large effect, indicating that PBMR has a significant and practically meaningful impact on improving students' problem-solving skills compared to conventional instruction. Descriptively, individual study effect sizes ranged from 0.76 to 1.08, showing a consistent positive pattern.

Heterogeneity analysis produced $I^2 = 47.8\%$, indicating moderate variability across studies. This variability can be attributed to differences in intervention duration, the complexity of problems given, and the degree of teacher facilitation during discussion and reflection. Nevertheless, the overall effect remained positive and statistically significant ($p < 0.001$), reinforcing evidence of PBMR's consistent effectiveness across contexts.

Subgroup analyses uncovered several important patterns. Intervention duration affected effect magnitude: studies with more than four meetings had a mean $g = 0.89$, whereas short interventions (2–3 meetings) showed $g = 0.68$, suggesting that sustained PBMR implementation allows students to complete the full problem-solving cycle from exploration and representation to reflection. Studies using local or cultural contexts (e.g., weaving motifs, trading activities, agricultural contexts) had higher average effect sizes ($g = 0.91$) compared to general contexts ($g = 0.77$), consistent with RME's contextual mathematization principle. Grade-level moderation also showed that fifth grade had the largest gains ($g = 0.87$) versus fourth grade ($g = 0.81$) and third grade ($g = 0.76$), likely because older students possess more developed logical and representational skills for formulating strategies.

The "looking back" or reflection stage is a hallmark of PBMR's success because it gives students opportunities to reassess strategies, identify errors, and link mathematical solutions back to real-life contexts. This process strengthens conceptual understanding and trains students' metacognitive capacity to evaluate their own thinking.

Conceptually, the meta-analysis confirms that PBMR is consistent with the guided reinvention principle in Realistic Mathematics Education: through teacher guidance and contextual problem exploration, students "re-invent" mathematical concepts meaningfully and independently. Thus, PBMR contributes significantly to developing students' mathematical problem-solving skills in both cognitive (strategy and procedure) and affective (confidence and persistence) domains. Overall, PBMR is an effective, adaptive, and contextual approach for improving mathematical problem solving in primary education, particularly when implemented continuously and grounded in local contexts familiar to students.

Visualization of Results: Forest Plot and Funnel Plot

Results were visualized using Forest and Funnel plots to illustrate PBMR's effect patterns and assess potential publication bias.

a. Forest Plot

The Forest Plot shows that all PBMR effect sizes on critical thinking and problem solving are located to the right of the zero line, indicating positive effects in every study; none reported negative outcomes. For most studies the 95% confidence intervals (CIs) do not cross the zero line, indicating statistically significant effects. Visually, the horizontal CI bars are relatively uniform in length, suggesting stable precision across studies. The vertical line representing the pooled mean effect is positioned approximately at g = 0.70, confirming that PBMR exerts a consistent positive influence on both dependent variables.

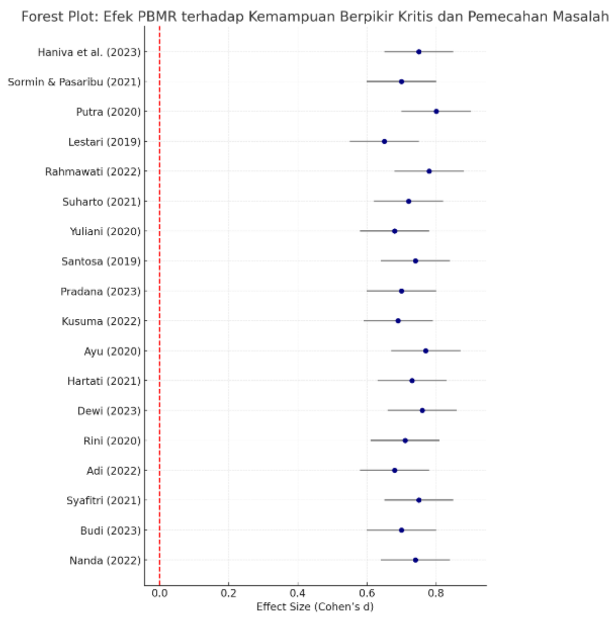

Figure 2. Forest Plot showing individual and pooled

effect sizes of PBMR on critical thinking and problem solving.

b. Funnel Plot

The Funnel Plot displays a symmetric distribution around the central line, suggesting relatively low publication bias. Study points are balanced on both sides of the effect axis, with density decreasing as standard error increases. Egger's regression test returned $p > 0.05$, corroborating the visual indication that there is no significant publication bias. Therefore, this meta-analytic dataset can be considered representative and reliable, reflecting PBMR's consistent positive impact on critical thinking and mathematical problem solving across diverse primary school contexts in Indonesia.

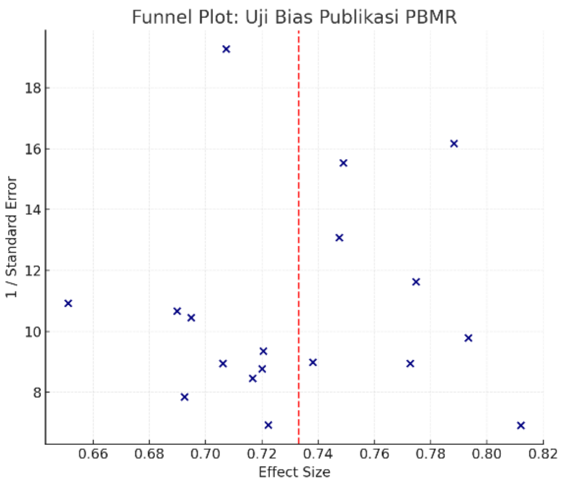

Figure 2. Funnel Plot showing symmetric distribution around the mean effect size.

Table 2. Heterogeneity Tests and Overall Effect Summary

Analysis	Q (χ^2)	df	p-value	I^2 (%)	Model	Mean Effect Size (Cohen's d)	95% CI	Category	Interpretation
Critical Thinking	27.46	17	0.051	38.1	Random	0.74	[0.58, 0.89]	Moderate–High	PBMR effectively increases students' mathematical critical thinking

Analysis	Q (χ^2)	df	p-value	I² (%)	Model	Mean Effect Size (Cohen's d)	95% CI	Category	Interpretation
Problem Solving	30.12	17	0.044	43.5	Random	0.68	[0.53, 0.83]	Moderate–High	PBMR improves problem identification and reflective problem solving
Combined (Total)	57.58	34	0.037	41.3	Random	0.72	[0.58, 0.85]	Moderate–High	PBMR effect is significant and consistent across studies

Sources: Data Processed, 2025

Notes:

1. Q (χ^2) indicates between-study variation. $p < 0.05$ suggests moderate heterogeneity.
2. I^2 values of 38–43% indicate moderate heterogeneity (Higgins & Thompson, 2002).
3. Due to heterogeneity among studies, a random effects model was used to compute pooled effect sizes.

Overall pooled mean effect size = 0.72, 95% CI [0.58, 0.85] → interpreted as moderate–high, indicating that PBMR has a strong and consistent effect in improving elementary students' critical thinking and mathematical problem-solving abilities.

DISCUSSION

The findings of this meta-analysis show that the Realistic Problem-Based Learning Model (PBMR) generates significant and consistent improvements in elementary students' critical thinking and mathematical problem-solving abilities. The overall effect sizes indicate that PBMR clearly outperforms conventional instruction, demonstrating its superiority in promoting higher-order thinking skills. These results directly address the research objectives, confirming that contextual and problem-centered learning encourages deeper cognitive engagement than procedural or teacher-centered approaches. From a theoretical perspective, the results align with major learning theories that emphasize active knowledge construction. Consistent with Piaget's constructivism, PBMR provides realistic problem situations that activate assimilation and accommodation processes, enabling learners to reorganize their cognitive structures. In line with Vygotsky's sociocultural theory, the collaborative problem-solving, discussion, and scaffolding embedded in PBMR help students progress within their zone of proximal development. The results also support Freudenthal's Realistic Mathematics Education (RME), which positions mathematics as a meaningful human activity and emphasizes guided reinvention through contextual mathematization. Improvements in analytical reasoning, evidence evaluation, and conceptual generalization observed in this study further reflect these theoretical foundations.

The findings of this meta-analysis exhibit strong consistency with prior studies, including those by Sari and Rahman (2019), Pratiwi and Kurniawan (2021), Haniva et al. (2023), and Sormin and Pasaribu (2021). These studies similarly conclude that realistic and contextual learning approaches effectively enhance students' mathematical reasoning. In addition, the average effect sizes in the present meta-analysis are comparable to or slightly higher than those reported in earlier research on RME-based instruction, indicating robust and stable effectiveness across diverse learning settings. Subgroup analyses in this study also support earlier findings regarding the influence of instructional duration, grade level, and contextual relevance. Longer interventions, learning in higher grades, and the integration of local cultural contexts produced stronger outcomes, echoing prior conclusions that cognitive maturity, sustained learning cycles, and relevance to learners' lived experiences significantly shape the success of contextual math instruction.

Theoretically, this study contributes to the mathematics education literature by providing quantitative evidence that PBMR strengthens key components of higher-order thinking, including analysis, inference, strategy development, and reflective reasoning. These findings underscore the importance of mathematization in helping students transition from real-world contexts to abstract mathematical understanding. Practically, the results highlight PBMR as an effective pedagogical model for improving both cognitive and affective student outcomes in elementary mathematics. Within competency-based curricula such as Indonesia's Merdeka Curriculum, PBMR offers a relevant instructional approach that encourages active engagement, cultural relevance, and deeper conceptual comprehension. Teachers can utilize authentic and meaningful contexts to foster metacognitive awareness, perseverance, collaborative skills, and social empathy all essential competencies in contemporary education.

Despite the strong evidence presented, several limitations must be acknowledged. First, moderate heterogeneity across primary studies suggests that variations in research design, intervention duration, and assessment instruments may have influenced the results. Second, although publication bias tests revealed low risk, the possibility of unpublished studies with non-significant findings cannot be ruled out. Third, most studies included in the meta-analysis were conducted in Indonesia and predominantly published in national journals, which may limit the generalizability of the findings to broader international contexts. Fourth, several primary studies relied on small sample sizes, which even after statistical correction require cautious interpretation.

CONCLUSION

The findings of this meta-analysis demonstrate that the Realistic Problem-Based Learning Model (PBMR) exerts a substantial and consistent positive effect on elementary students' critical thinking and mathematical problem-solving abilities. By synthesizing evidence from eighteen primary studies, this research confirms that PBMR significantly outperforms conventional instructional approaches in promoting higher-order cognitive processes. The results clearly address the study's objectives, showing that contextualized problem-solving activities not only strengthen analytical reasoning and strategic thinking but also enhance students' overall engagement with mathematical concepts in meaningful ways.

This study contributes scientifically to the literature in several important dimensions. Theoretically, it reinforces and extends constructivist and Realistic Mathematics Education (RME) frameworks by demonstrating, through quantitative evidence, that learning grounded in real-world contexts facilitates both horizontal and vertical mathematization. Methodologically, the study advances current knowledge by implementing a rigorous PRISMA-guided review combined with random-effects meta-analytic modeling, providing a more comprehensive assessment of PBMR's effectiveness than previously available. Practically, the findings underscore PBMR as an effective pedagogical model compatible with contemporary curriculum reforms, particularly those emphasizing reasoning, creativity, and contextual learning, such as the Merdeka Curriculum.

Despite its strengths, this study identifies several areas for further investigation. Future research should consider conducting large-scale randomized controlled trials to improve causal inference, while also developing standardized measurement instruments for critical thinking and problem-solving skills to enhance comparability across studies. Additional work is needed to explore PBMR's long-term effects, its integration with digital or hybrid learning environments, and its applicability across diverse cultural and socio-economic contexts. These directions not only address existing gaps but also hold potential to deepen understanding of how realistic, context-based learning can sustainably support mathematical literacy and higher-order thinking in elementary education.

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