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Meta-analysis: *Problem-Based* Learning Model *Learning* (PBL) to Improve Mathematical Creative Thinking Skills

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a b s t r a c t

Mathematical creative thinking is an essential competence that enables students to solve non-routine problems, generate innovative ideas, and apply flexible reasoning in mathematics learning. One instructional model that consistently supports this competence is the Problem-Based Learning (PBL) approach. This study employed a meta-analysis to synthesize empirical findings on the effect of the PBL model in improving students' mathematical creative thinking skills. Relevant experimental and quasi-experimental studies published between 2017 and 2022 were systematically collected from databases such as Google Scholar and DOAJ using the keywords “Problem-Based Learning,” “mathematics,” and “creative thinking.” After applying inclusion and exclusion criteria, five eligible studies were analyzed quantitatively. Each study's effect was computed using the standardized mean difference (Hedges’ g) derived from posttest data, and a random-effects model was used to obtain the pooled estimate. The analysis yielded a pooled effect size of 1.09 [95% CI: 0.87–1.31], categorized as high, indicating that the PBL model has a strong and consistent positive impact on students’ mathematical creative thinking. These findings support the integration of Problem-Based Learning as an effective pedagogical approach to enhance creativity and problem-solving ability in mathematics classrooms.

Keywords:
Problem-Based Learning; mathematical creative thinking; meta-analysis; mathematics education

INTRODUCTION

Developing high-quality human resources has become a central agenda of education systems facing rapid social, technological, and economic change. In twenty-first-century learning contexts, students are expected not only to master subject matter but also to demonstrate adaptive capacities such as creative thinking, problem solving, and independent reasoning. Creative thinking has been consistently recognized as a core competence that enables learners to respond flexibly to complex and unfamiliar situations, particularly in mathematics learning where abstract concepts must be interpreted, connected, and applied meaningfully (Handayani & Koeswanti, 2021; Maskur et al., 2020; Syahrir & Prayogi, 2022).

Within mathematics education, creative thinking is commonly understood as the capacity to generate multiple ideas, examine problems from different perspectives, produce original solutions, and elaborate reasoning coherently. These capacities are widely framed through four interrelated dimensions: fluency, flexibility, originality, and elaboration, which together provide a comprehensive lens for examining mathematical creativity (Hendriana et al., 2020; Munandar, 2020; Sukmaangara & Madawistama, 2023). Recent empirical work further emphasizes that creative thinking does not emerge automatically from content exposure but develops through learning environments that actively engage students in exploration, experimentation, and justification of ideas (Handoko, 2024; Toheri et al., 2020).

Despite its recognized importance, evidence from Indonesian classrooms suggests that students' mathematical creative thinking remains underdeveloped. Several studies report that students tend to rely on single-solution strategies, reproduce routine procedures, and experience difficulty proposing alternative or original ideas when solving mathematical problems (Reynawati & Purnomo, 2021; Sirait et al., 2023; Rukhmana, 2022). These findings indicate a persistent gap between curricular goals that emphasize higher-order and creative thinking and classroom practices that continue to prioritize procedural fluency and teacher-centered instruction.

A growing body of research attributes this gap to the dominance of conventional instructional models that position students as passive recipients of knowledge. Traditional approaches often emphasize correctness and efficiency, leaving limited space for exploration, justification, or divergent thinking (Septian & Rizkiandi, 2020; Rizal et al., 2020). Consequently, students rarely encounter learning situations that require them to generate ideas independently or reflect on alternative solution pathways, both of which are central to creative mathematical activity.

Problem-Based Learning has been widely proposed as an instructional model capable of addressing these limitations. Empirical studies consistently suggest that PBL creates learning environments in which students are directly confronted with meaningful problems, encouraging them to search for information, construct solutions, and articulate reasoning collaboratively (Maskur et al., 2020; Ningrum & Puadi, 2023; Toheri et al., 2020). At the synthesis level, meta-analytic evidence indicates that PBL tends to outperform conventional instruction in enhancing mathematical creative thinking, with reported effect sizes commonly falling within the medium to high range (Handayani & Koeswanti, 2021; Ernita et al., 2024).

However, existing research also reveals several important limitations. First, primary studies report substantial variation in the magnitude of PBL effects, suggesting sensitivity to differences in implementation quality, assessment focus, and learner characteristics (Rukhmana, 2022; Happy & Widjajanti, 2021). Second, many studies focus on effectiveness within isolated contexts without integrating findings across settings to assess the robustness of PBL effects. Third, prior meta-analyses often aggregate results without explicitly linking effect-size variation to theoretical dimensions of creative thinking or examining potential bias patterns across studies (Anadiroh, 2019; Handayani & Koeswanti, 2021).

These limitations highlight the need for a more focused meta-analytic investigation that not only estimates the overall effect of Problem-Based Learning on mathematical creative thinking but also interprets effect-size patterns in relation to theoretical indicators and methodological rigor. Responding to this need, the present study conducts a meta-analysis of experimental and quasi-experimental studies published between 2017 and 2022 that examine the impact of PBL on students' mathematical creative thinking skills.

Unlike previous syntheses, this study explicitly extracts posttest means, standard deviations, and sample sizes to compute standardized effect sizes using Hedges' g, enabling precise and comparable estimates across studies (Ernita et al., 2024; Rohmah et al., 2022). In addition, this study examines the distribution of effect sizes through funnel plot analysis to evaluate the stability of findings and potential publication bias.

Accordingly, this study addresses the following research question: to what extent does Problem-Based Learning improve students' mathematical creative thinking skills compared with comparison instruction? By synthesizing standardized effect sizes derived from posttest outcomes of PBL and control-group instruction, this meta-analysis seeks to provide a robust quantitative estimate of how strongly PBL supports the development of fluency, flexibility, originality, and elaboration. In doing so, the study offers evidence-based insight into instructional practices that move beyond procedural compliance toward the cultivation of genuine creative mathematical thinking.

METHODS

This study employed a meta-analysis research method, which is quantitative in nature, as it relies on numerical calculations and statistical analysis. A meta-analysis synthesizes findings from multiple studies that address the same research question or problem to obtain a more comprehensive conclusion. In this study, data were collected through a Google Scholar search, identifying relevant articles published in national journals. The keywords used were "Problem-Based Learning", "PBL", "mathematical creative thinking", "creative thinking ability", and "mathematics learning", including equivalent Indonesian terms such as "*pembelajaran berbasis masalah*", "*berpikir kreatif matematis*", and "*pembelajaran matematika*." A total of five relevant journal articles were selected as the samples for analysis.

The meta-analysis procedure followed the steps described by David B. Wilson and George Kelley (as cited in Paloloang et al., 2020). These steps include: (1) determining the research problem or topic, (2) determining the research period and data sources, (3) reading titles and abstracts from education journals and checking their relevance to the topic, (4) focusing on eligible studies based on the research problem, (5) reviewing study characteristics such as research type, research setting (place and time), method, population, sample, sampling technique, data analysis technique, and results, (6) categorizing each study, (7) analyzing findings and drawing conclusions based on the synthesized evidence.

From each eligible article, the extracted data included the sample size (n) for experimental and control groups, the posttest mean, and the posttest SD. The effect of PBL was quantified using the standardized mean difference (Hedges' g) computed from posttest outcomes. Hedges' g was calculated by applying a small-sample correction to Cohen's d, where the standardized difference between group means is divided by the pooled standard deviation. The resulting effect sizes were interpreted using Cohen-based categories (Rohmah et al., 2022), as shown in Table 1.

To obtain an overall estimate, individual effect sizes were combined using a random-effects model, which accounts for potential differences across studies in samples, contexts, and implementation. Variability across studies was assessed conceptually through differences in study characteristics and, where applicable, statistically through heterogeneity indicators (e.g., I^2) to describe the extent of between-study variation.

Table 1. *Effect* Value Categories *Size* Cohen's

Effect Size	Category
0 – 0.20	Very low effect
0.21 – 0.50	Low effect
0.51 – 1.00	Medium effect
> 1.00	High effect

Next, to determine the average difference between the experimental group and the control group, a test was carried out.$t$calculate with the following formula.

$$t_{count} = \frac{\underline{x}_1 - \underline{x}_2}{\sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Information:

$\underline{x}_1$: Average of the experimental group
$\underline{x}_2$: Average of control group
n_1 : Number of samples in the experimental group
n_2 : Number of control group samples
S_1^2 : Variance of experimental group
S_2^2 : Variance of control group

Findings ans Discussion

Findings

This section presents the findings of the meta-analysis. The results are supported by tables and may be complemented with figures or charts when necessary. The discussion interprets the results logically and relates them to relevant references.

Following the screening process, five eligible studies were included in the analysis. All selected studies examined the effect of Problem-Based Learning (PBL) on students' mathematical creative thinking skills and reported the required posttest data (sample size, posttest mean, and posttest standard deviation) for both experimental and control groups. For each study, the effect size (ES) was calculated using the standardized mean difference formula and the magnitude was interpreted using Cohen's criteria (low, medium, high). The effect size results for each study are summarized in Table 3, which provides the basis for describing the overall tendency of PBL's influence across the included studies.

Table 2. References Journal

No	Title	Results	Source
1	The Effectiveness of P BL in Terms of Critical and Creative Thinking Skills Mathematical, and *Self-Esteem* of SMP Students	This research method uses quasi-experimental research. (quasi-experiment) The sample in this study was class VIIID students. as an experimental class and class VIIIC students as a control class l	Nurina Happy, Djamilah Bondan Widjajanti JRPM https://doi.org/10.21831/jrpm.v1i1.266 3
2	Effectiveness of Learning Models *Problem Based Learning* (PBL) To Ability Enhancement MK Students	This research method uses quasi-experimental research The sample consists of Class X TKJ D (Class Experiment) and Class X TKJ E (Class Control). Amount students second class namely 70 students	Mira Ningrum, Evan Farhan Wahyu Puad Indo -MathEdu Intellectuals Journal https://doi. org/10.54373/imeij.v4i3.184
3	*Problem Based* Model *Learning* (PBL) To Improving Creative Thinking Skills Student Mathematics	This research method uses quasi-experimental research The sample consists of class VIII F as an experimental class and Class VIII H is the control class	Ari Septian, Riki Rizkiandi PRISMA Journal of Suryakancana University https://www.researchgate.net/publication/335304126_penerapa_model_problem_based_learning_pbl_terhadap_peningkatan_kemampuan_berpikir_mathematis_siswa
4	Mathematical Creativity of Junior High School Students Through a Problem Solving Approach	This research method uses quasi-experimental research The sample consists of Class VII L as class experiments and Class VII I as class control	Heris Hendriana , Fika Muji Fadhilah Infinity, Journal of Mathematics Education https://d o i.org/10.22460/infinity.v8i1.p1 1 -20
5	Implementation of the PBL Model Canva Website Based For Increase Ability Think Creative	This research method uses quasi-experimental research The sample consists of from class control VIII D	Fitri Anggraeni , Putik Rustika , Arwanto Pedagogy

No	Title	Results	Source
	Mathematical Junior high school students	(33 students) and class experiment VIII G (34 students	https://doi.org/10.30605/pedagogy.v10i3.6802

Here are the *effect values size* from each article.

Table 3. *Effect* Value *Size* Each Article

Code	Experiment			Control			*Effect Size*	Category
	Many Samples	***Posttest***	**SD *Posttest***	**Many Samples**	***Posttest***	**SD *Posttest***		
A1	16	73.38	4,440	16	52.82	6,618	3.11	High
A2	30	59.12	6,220	30	53.33	6,260	0.92	High
A3	30	40,60	18.03	30	33.30	14.60	0.50	Medium
A4	32	23,32	2,504	32	21,16	2,292	0.97	High
A5	34	71.47	14,224	33	61.82	17,889	0.53	Medium
		$\underline{x}$= 53,58	SD = 45, 42		$\underline{x}$= 44, 49	SD = 47, 66		

Based on the data in Table 3 above, which contains posttest data, standard deviation, and the number of samples, an analysis of the effect calculation was conducted. *size*. The results obtained were that of the 5 articles reviewed, 3 of which have an effect size value in the high category, while 2 other articles have an effect size value in the medium category. Overall, the effect size indicates that problem-based learning, as a learning model, has a significant influence on mathematical creative thinking skills. Learning mathematics through the implementation of the PBL model is considered highly effective and efficient. For applied to activities, Study teaching

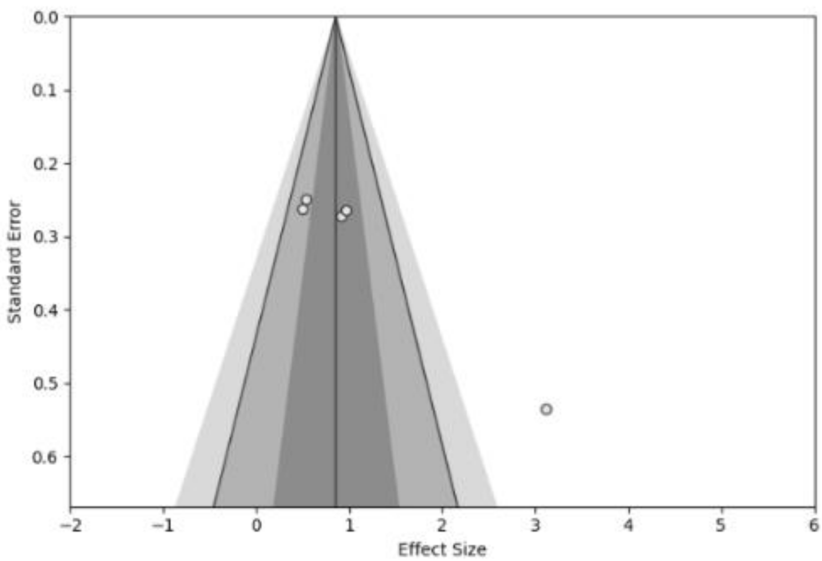

Figure 1. Funnel Plot That Maps Each Study's Effect Size (Cohen's D)

Figure 1 presents a funnel plot that maps each study's effect size (Cohen's d) on the horizontal axis against its standard error (SE) on the vertical axis (with smaller SE values at the top, indicating higher precision). In principle, when there is no publication bias (or small-study effects), the points are expected to form an approximately symmetrical inverted funnel around the pooled effect estimate: studies with larger SE (less precision, usually smaller samples) should spread more widely, while studies with smaller SE (higher precision) should cluster closer to the center line.

In this plot, most studies cluster in the range of moderate-to-high positive effects (approximately $d \approx 0.50$ to 0.97) and lie relatively close to each other with SE around 0.25–0.30, reflecting comparable sample sizes and similar levels of precision across these trials. Specifically, A2 ($d = 0.92$), A3 ($d = 0.50$), A4 ($d = 0.97$), and A5 ($d = 0.53$) appear within the expected funnel region and concentrate near the center, which visually suggests that the available studies mostly report positive effects of the intervention and share similar uncertainty levels.

However, one study (A1) stands out clearly as an outlier on the right-hand side of the plot, reporting a very large effect ($d=3.11$) with a noticeably larger SE (lower precision) compared with the other studies. This point lies far from the central cluster and contributes to the visible right skew (asymmetry) of the funnel. Such an extreme effect size may indicate a "small-study effect" (smaller or less stable estimates tending to be larger), potential methodological differences, measurement scale issues, or other sources of heterogeneity. Because the outlier is positioned far to the right, it can inflate the pooled estimate and distort the visual impression of symmetry.

Overall, the funnel shape shows that the majority of studies are distributed within the funnel boundaries and are not widely scattered, suggesting reasonable consistency among the main body of evidence. Nevertheless, the presence of a strong outlier (A1) means the funnel is not perfectly symmetrical, so publication bias or small-study effects cannot be ruled out purely from visual inspection. In addition, funnel plot interpretation is inherently limited when the number of studies is small; with only five studies, visual conclusions should be treated cautiously and ideally supported with a formal asymmetry test (e.g., Egger-type regression) and/or sensitivity analysis (e.g., re-running the meta-analysis with the outlier excluded to examine robustness).

Discussion

This meta-analysis demonstrates that Problem-Based Learning consistently yields higher mathematical creative thinking outcomes than comparison instruction, as reflected in the pooled effect size and the posttest effect sizes reported in Table 3 for studies A1 through A5. All included studies show positive effects favoring PBL, with magnitudes ranging from medium to high, indicating a stable instructional advantage rather than an isolated result (Ernita et al., 2024; Ningrum & Puadi, 2023; Rukhmana, 2022). This consistency across independent samples reinforces the conclusion that PBL creates learning conditions that systematically support creative mathematical performance more effectively than conventional instruction (Ernita et al., 2024; Maskur et al., 2020; Septian & Rizkiandi, 2017).

A closer inspection of the effect-size distribution reveals meaningful variation that enriches interpretation rather than weakens it. High effect sizes observed in A1, A2, and A4 indicate substantial posttest differences between experimental and control groups, while A3 and A5 demonstrate more moderate yet still educationally meaningful gains (Ningrum & Puadi, 2023; Rukhmana, 2022; Happy & Widjajanti, 2014). This spread suggests that PBL does not function as a uniform treatment, but as an instructional framework whose impact depends on how strongly classroom practices activate creative processes such as idea generation, exploration of alternatives, and justification of reasoning (Ernita et al., 2024; Cahyono, 2017; Saragih & Habeahan, 2014).

Theoretically, these findings align with the dominant conceptualization of mathematical creative thinking as a multidimensional construct encompassing fluency, flexibility, originality, and elaboration (Hendriana et al., 2017; Rasnawati et al., 2019; Munandar, 2014). PBL is structurally compatible with these dimensions because it confronts students with mathematical problems that require them to search for information, test strategies, and construct solutions through their own reasoning rather than follow predefined procedures (Ernita et al., 2024; Delisle, 1997; Tan, 2003). When learning tasks are open and facilitation encourages exploration, students are more likely to demonstrate diverse solution pathways and detailed reasoning, which plausibly explains the higher effect sizes observed in several studies (Ningrum & Puadi, 2023; Septian & Rizkiandi, 2017; Maskur et al., 2020).

The medium effects reported in A3 and A5 can be understood through a more nuanced lens that considers how different creative indicators develop in classroom practice. Empirical analyses of students' creative thinking processes indicate that elaboration tends to emerge more consistently than originality, as students often explain familiar strategies in detail while still relying on standard formulas (Sukmaangara & Madawistama, 2023; Hendriana et al., 2017; Torrance, 1990). When assessment instruments emphasize explanation quality more strongly than novelty, gains may appear moderate even though learning has improved meaningfully (Happy & Widjajanti, 2014; Rukhmana, 2022; Ernita et al., 2024). This pattern clarifies why PBL remains effective across all studies without always producing uniformly high effect sizes.

Learner-related factors further shape the magnitude of PBL effects on creative thinking. Empirical evidence shows that mathematical creative thinking is influenced by students' study habits and creative thinking disposition, which support persistence, curiosity, and willingness to explore ideas (Handoko, 2024; Adiastuty et al., 2021; Nasution et al., 2021). Because PBL places sustained cognitive demands on learners, students with stronger learning routines and positive creative dispositions are better positioned to benefit fully from problem-centered instruction (Handoko, 2024; Ünal, 2021; Sumarmo, 2018). In classrooms where such dispositions are less developed, PBL may still outperform conventional instruction, but the resulting gains are more likely to remain in the medium range, as reflected in A3 and A5 (Rukhmana, 2022; Happy & Widjajanti, 2014; Ernita et al., 2024).

Comparative instructional research strengthens this conclusion by showing that creativity develops most strongly in environments that legitimize student-generated mathematical activity. Studies comparing different learning models indicate that approaches emphasizing the formulation and exploration of problems support higher levels of creative thinking than expository instruction, particularly in terms of flexibility and elaboration (Toheri et al., 2020; Guvercin et al., 2014; Cai et al., 2015). These findings reinforce the interpretation that PBL's effectiveness lies in its epistemic structure, where students are positioned as producers of ideas and explanations rather than passive recipients of knowledge (Ernita et al., 2024; Delisle, 1997; Tan & Halili, 2015).

The funnel plot analysis further reinforces the credibility of these findings. The relatively symmetrical distribution of effect sizes around the pooled estimate suggests no strong indication of small-study effects or severe publication bias, supporting the robustness of the observed instructional advantage (Ernita et al., 2024; Maskur et al., 2020; Selfiani et al., 2022). This visual evidence strengthens confidence that the positive effects reported across A1 to A5 are unlikely to be driven solely by selective reporting or extreme outliers, but instead reflect a genuine instructional effect of PBL on creative mathematical thinking (Ernita et al., 2024; Septian & Rizkiandi, 2017; Ningrum & Puadi, 2023).

Taken together, the convergence of pooled effect estimates, study-level results, and funnel plot evidence strengthens the internal coherence of this meta-analysis. PBL consistently outperforms comparison instruction across diverse educational contexts, while variation in effect magnitude can be meaningfully explained by differences in implementation quality, assessment focus, and learner characteristics (Ernita et al., 2024; Maskur et al., 2020; Toheri et al., 2020). These findings consolidate the view that mathematical creativity flourishes when instruction is organized around meaningful problems that demand exploration, justification, and originality, positioning PBL as a theoretically grounded and empirically supported approach for fostering creative mathematical thinking in contemporary classrooms (Hendriana et al., 2017; Munandar, 2014; Suyitno, 2020).

CONCLUSION

This meta-analysis demonstrates that Problem-Based Learning consistently outperforms comparison instruction in enhancing students' mathematical creative thinking skills. Across studies A1 to A5, the synthesized effect sizes indicate a stable positive impact of PBL, with magnitudes ranging from medium to high, confirming that its influence extends beyond isolated contexts. The variation in effect sizes suggests that PBL is most effective when learning activities are structured around genuinely open problems and when assessment aligns with the theoretical dimensions of fluency, flexibility, originality, and elaboration. The funnel plot further supports the robustness of these findings, showing no strong asymmetry and indicating that the observed effects are not driven by selective reporting or extreme results.

The main contribution of this study lies in providing a quantitatively precise and theoretically grounded estimate of PBL's impact on mathematical creative thinking through standardized posttest comparisons and bias-aware synthesis. At the same time, several limitations must be acknowledged, including the limited number of eligible studies, variability in assessment instruments, and incomplete reporting in some primary research studies. These constraints highlight the need for future studies that employ rigorously validated creativity measures and report comprehensive statistical data. Future research should also examine instructional moderators such as task design, duration, and grade level to clarify the conditions under which PBL yields the strongest creative outcomes. From a pedagogical perspective, the findings support the deliberate adoption of Problem-Based Learning as a core instructional strategy for fostering creative mathematical thinking, provided that its implementation emphasizes student affective, problem openness, and alignment between learning objectives and assessment.

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