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A Meta-analysis of the Utilization of Problem-Posing Approach in Enhancing Students' Academic Achievement: Direction for Mathematics Learning

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Abstract. This meta-analysis examined the effect of using the problem-posing approach on students' academic achievement in Mathematics. Results from 16 studies showed that problem posing has a large positive effect on students' academic achievement ($g = 0.73$) following a random-effects model. Subgroup analysis revealed that the positive effect is moderated by grade level and subject matter. Notably, the problem-posing approach has the largest effect at the tertiary level, is relatively large at the senior and junior secondary levels, and is smallest at the primary level. In addition, the problem-posing approach produces the largest effect when it is implemented in calculus and algebra, and the least effect in Geometry. Neither the study's sampling design (i.e., randomized, convenience, or purposive) nor the country in which the study is implemented moderates the effect of problem posing on academic achievement. Consequently, this study recommends using a problem-posing approach in mathematics classrooms.

Keywords: problem posing; academic achievement; meta-analysis; mathematics learning

1. Introduction

Improving academic achievement in mathematics has been a long-standing research agenda. Beyond serving as an essential indicator of student learning (Cabuquin & Abocejo, 2023), mathematics achievement influences students' future employment opportunities (Eidlin-Levy et al., 2023). For these reasons, teaching innovations have been proposed and tested across countries to address student learning difficulties and foster student achievement and learning outcomes (Castillo et al., 2024). Alongside this, there is a continuing effort to develop practical frameworks that explain how different teaching approaches impact students' mathematics achievement (Semeraro et al., 2020).

One teaching approach aimed at increasing knowledge and achievement in mathematics is problem posing (Li et al., 2020; Baumanns & Rott, 2022). Anchored on the belief that the solver must discover real-life problems, problem posing posits that learning occurs when students are guided to create and solve mathematical problems (Schoenfeld, 2013; Papadopoulos et al., 2021). This approach shifts the traditional classroom dynamic from merely solving problems to actively generating them. Such a shift fosters a more interactive learning environment and promotes deeper cognitive involvement (Sadak et al., 2022). Hence, the utilization of problem posing in mathematics education has been advocated across studies (Cai & Hwang, 2020).

Problem posing has been shown to improve problem-solving abilities, stimulate creativity, and enhance critical thinking (Rosli et al., 2014). The same cognitive abilities are essential in developing practical mathematical thinking skills (English, 2020; Calabrese et al., 2022). When students formulate their problems, they are encouraged to explore mathematics' underlying concepts and structures more profoundly (Singer et al., 2013). Additionally, studies show that students participating in problem-posing exercises are often more motivated and interested in learning mathematics (Divrik et al., 2021). These deepen students' understanding of the subject, leading to improved academic performance and a more positive attitude (Kutlu & Kültür, 2021).

Despite its known advantages in enhancing academic achievement, implementing problem posing in the classroom can result to a different extent (Polat & Özkaya, 2023). Several studies on the utilization of problem posing report a significant effect on students' academic achievement (e.g., Akay & Boz, 2010; Cankoy, 2014; Sari & Surya, 2017), while some other studies report a non-significant effect on students' mathematics achievement (e.g., Christidamayani & Kristanto, 2020; Muzayyanah & Wutsqa, 2023). To understand the variation of the effect of problem posing, a comprehensive summary of its actual effect on students' academic achievement is needed. This better addresses students' needs by recognizing the practical advantages of problem posing in classroom settings (Patac & Herrera, 2019).

Studies have been conducted to summarize the effect of problem-posing on students' academic achievement. For instance, Calabrese et al. (2022) examined the effect of problem posing on students' problem-solving skills. Another study by Rosli et al. (2014) found that problem posing has a positive effect on students' academic achievement. However, this study summarizes studies up to 2011. Nevertheless, Higgins et al. (2003) suggest updating the meta-analysis every two years to maintain relevance.

2. Research Objectives

This study seeks to summarize empirical studies on enhancing students' academic achievement through the use of the problem-posing approach. Specifically, it sought to answer the following questions: (1) How strong is the effect of the use of a problem-posing approach in enhancing students' academic achievement? and (2) Do some moderating factors, such as sampling method, educational level, country, and subject matter, vary the strength of the effect of intervention in enhancing students' academic achievement?

3. Methodology

This research examined existing studies on using the problem-posing approach to enhance students' achievement under a meta-analysis design. It aimed to systematically investigate the magnitude of the effect of the problem-posing approach on students' mathematical achievement based on the studies conducted on the topic (Cooper, 2017).

3.1. Search Strategy

This review study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram (Moher et al., 2009) to organize the extracted studies from a scholarly electronic database. Google Scholar was used as the primary database for searching relevant studies. This choice was based on evidence suggesting that Google Scholar offers a broad range of coverage of scholarly literature and can therefore be used as a source of relevant literature (Gehanno et al., 2013; De Winter et al., 2014).

Although major bibliographic databases such as Scopus and Web of Science are widely used in systematic reviews, evidence shows that Google Scholar could still provide broad coverage of peer-reviewed journal articles, theses, dissertations, and conference proceedings, making it a suitable tool for identifying empirical studies in educational research (Haddaway et al., 2015; Halevi et al., 2017). Previous methodological reviews have demonstrated that Google Scholar captures a comparable set of relevant studies to databases like Web of Science and Scopus, primarily when used with caution (De Winter et al., 2014; Halevi et al., 2017).

To maintain transparency and reliability, this study employed multiple relevant search strings, applied clearly defined inclusion criteria, and systematically screened all retrieved records using the PRISMA protocol. Additionally, following the recommendations of Haddaway et al. (2015), the researchers screened all viewable search results up to 1,000 records to enhance transparency and coverage. Therefore, while reliance on Google Scholar places some limits on replicability and coverage, the search strategy was designed to maximize comprehensiveness within resource constraints.

To identify relevant studies, the researchers implemented the following *search strategy*. First, the researchers used the search strings: “problem posing” AND “achievement” AND “mathematics”; “problem posing” AND “performance” AND “mathematics”; “problem posing” AND “success” AND “mathematics”; and “problem posing” AND “learning” AND “mathematics.” Second, search results were filtered using Google Scholar’s custom date range from 2009 to 2024. Third, the researchers manually screened titles and abstracts to ensure relevance to problem posing and achievement in mathematics education. Fourth, once a study passes the title and abstract screening, the journal in which the study is published is reviewed to confirm its peer-reviewed publication status. Finally, the researchers implemented the same steps up to 1,000 viewable Google Scholar records. Only studies meeting the inclusion criteria below were retained for full-text review.

3.2. Inclusion Criteria

This study employed a set of inclusion criteria to select the final sample of studies for the meta-analysis. These criteria were: (a) the study must use problem posing as an intervention; (b) the study must employ a quasi-experimental or experimental design; (c) the study must focus on determining the effect of problem posing on the achievement of students in Mathematics; and (d) the study must report sufficient statistical data for calculation of effect sizes.

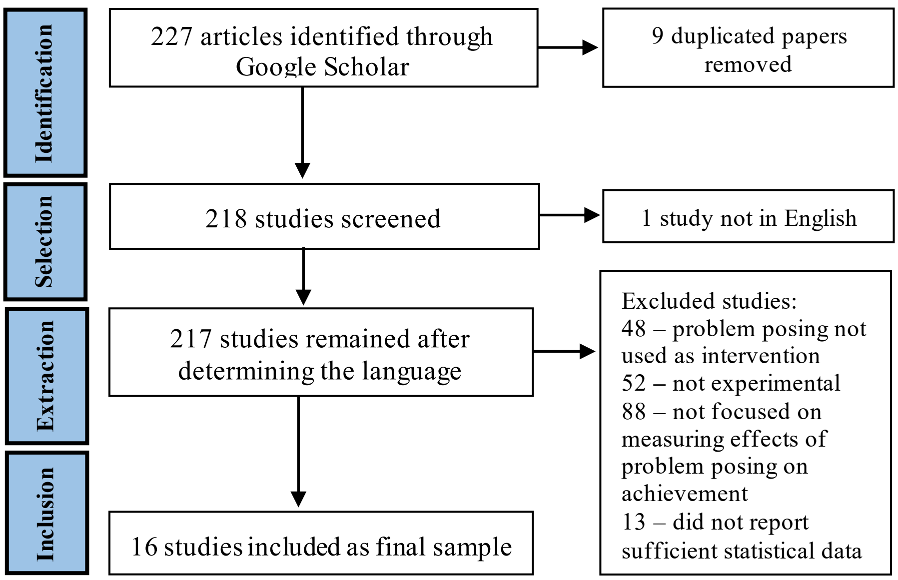

Figure 1. Flow diagram for the study sample selection process (PRISMA)

Figure 1 presents the flow diagram of the study selection process. After implementing the *search strategy* described above, 227 studies were initially identified. Duplicated records (n=9) and non-English publications (n=1) were removed, resulting in 217 studies eligible for further screening. Among these, 48 did not use problem posing as an instructional intervention in mathematics, 52 were non-experimental studies, 88 did not focus on measuring the effects of problem posing on students' achievement, and 13 had insufficient statistical data reported for calculating the effect sizes. After applying the inclusion criteria, 16 studies were considered as the final sample for this meta-analysis.

3.3. Data Extraction

After identifying 16 relevant studies that were included in the final sample of this study, the researcher reviewed the information from each study and extracted the necessary statistical reports for this meta-analysis. The coding sheet considered the following information: study details (e.g., author names, year of publication, and type of publication) and intervention information including research design (e.g., pretest-posttest-control). Statistical data, including mean, standard deviation, and sample size, for both the pretest and posttest, as well as for both the experimental and control groups, were identified from each study. The figures extracted were agreed by the two researchers. Information concerning moderating factors, such as grade level, sampling method, country, and subject matter, was coded for each study. Table 1 presents the general information of the studies included in this meta-analysis. It is essential to note that various studies on problem posing originate from different countries; however, only 16 were examined to meet the criteria set for this study.

Table 1. General information of the studies included in the meta-analysis

Study	Sampling	Educational Level	Country	Topic
Chang et al. (2012)	Purposive	Primary	China	Arithmetic
Chen et al. (2015)	Purposive	Primary	China	General Math
Christidamayani and Kristanto (2020)	Random	Junior Secondary	Indonesia	Geometry
Guvercin and Verbovskiy (2014)	Purposive	Junior Secondary	Kazakhstan	General Math
Guvercin et al. (2014)	Purposive	Junior Secondary	Kazakhstan	Geometry
Kadir (2023)	Random	Senior Secondary	Indonesia	Calculus
Laconde and Lomibao (2018)	Random	Junior Secondary	Philippines	General Math
Mahendra et al. (2017)	Random	Junior Secondary	Indonesia	Geometry
Muzayyanah and Wutsqa (2023)	Random	Junior Secondary	Indonesia	General Math
Ozdemir and Sahal (2018)	Random	Primary	Turkey	Arithmetic
Polat and Özkaya (2023)	Purposive	Primary	Turkey	Arithmetic
Suarlin et al. (2021)	Convenient	Senior Secondary	Indonesia	General Math
Tan et al. (2018)	Random	Junior Secondary	Philippines	Algebra
Tan (2018)	Random	Junior Secondary	Philippines	Algebra
Karasel et al. (2009)	Purposive	Primary	Cyprus	Arithmetic
Akay and Boz (2009)	Random	Tertiary	Turkey	Calculus

3.4. Data Analysis

The Hedge's g was employed to determine the effect sizes of the included studies in terms of Standardized Mean Difference (SMD). This statistical test enhances the reliability of calculating effect sizes, as it is particularly suitable for studies with relatively small sample sizes (Lipsey & Wilson, 2009; Helsa et al., 2023). The interpretation of the magnitude of the calculated effect sizes was based on the standard given by Cohen (2009) as cited in Durlak (2009). Specifically, effect sizes around 0.20 are considered "small," those around 0.50 are "medium," and those around 0.80 are "large."

This study also utilized the I^2 index to examine the heterogeneity of the 16 studies included as a sample (Huedo-Medina et al., 2006). A value of $I^2 > 0.75$ decides whether to use a random-effects model over a fixed-effects model (Higgins et al., 2003; Lim et al., 2019). Particularly, this study used a random-effects model to estimate the combined effect sizes. Moreover, Cochran's Q test was used to analyze the homogeneity of the moderating variables. Meanwhile, all analyses appropriate for the satisfaction of this study's aim were performed in R software using the packages "meta" and "metafor" (Viechtbauer, 2010; Balduzzi et al., 2019; R Core Team, 2024).

3.5. Test of Publication Bias

Publication bias was investigated with a funnel plot, fail-safe number, and Egger's linear regression test. As shown in the funnel plot presented in Figure 2, the distribution of effect sizes is symmetrical with respect to the funnel. This means that each study included in this meta-analysis is free from publication bias (Sterne & Egger, 2001; Lin & Chu, 2018). Egger's regression test was conducted to quantify this symmetry, which showed that $p = 0.6821 > 0.05$ (with $t = 0.42$). This supports the symmetry of data in the funnel plot and provides strong evidence that the studies involved had no significant bias (Rothstein et al., 2005; Schwarzer et al., 2019). In addition, Rosenthal's fail-safe N procedure suggests that 1259 studies with non-significant results are required to make the combined effect size of this meta-analysis non-significant. Again, this provides strong evidence that there is no publication bias (Ferguson & Brannick, 2012), thereby establishing the reliability of this meta-analysis (Varlik, 2023).

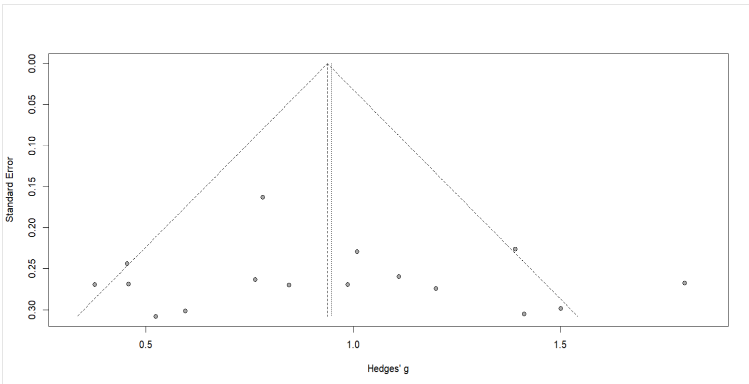

Figure 2. Funnel plot of the effect sizes of problem-posing approach on academic achievement

4. Results

This review study included 16 independent studies in the meta-analysis. Based on the analysis's results, heterogeneity was observed, with a calculated value of $I^2 = 87\% > 75\%$ with $p = 0.01$, as presented in Figure 3. This value shows a high level of heterogeneity between effect sizes (Juandi et al., 2021). Therefore, a random-effects model guided the calculation of combined effect sizes, standard errors, and confidence intervals of the studies involved.

4.1. Effect of the Use of Problem-Posing Approach in Enhancing Students' Academic Achievement

Figure 3 presents the forest plot of the effects of problem posing on students' academic achievement in Mathematics. The plot reveals that the combined effect size of problem-posing intervention on students' achievement in Mathematics is estimated at $SMD = 0.73$

($p < 0.01$). At $\alpha = 0.05$, this indicates that problem posing has a substantial positive effect on students' achievement. Moreover, the results show that the impact of problem posing on achievement is statistically significant, with a "large" magnitude.

Among the studies, the largest coefficient in effect size is observed at approximately 1.80 and 1.50. These are considered to have a very large magnitude of effect on academic achievement. Akay and Boz (2009) asserted that this intensity of effect was due to students having high opportunities for active involvement. Moreover, Laconde and Lomibao et al. (2018) corroborated this finding by qualifying that the effect of problem posing on academic achievement is attributed to students' active involvement and participation inside the classroom. Such a result is congruent with the claim that students' level of engagement in the classroom is a determining factor of academic achievement (Maamin et al., 2021).

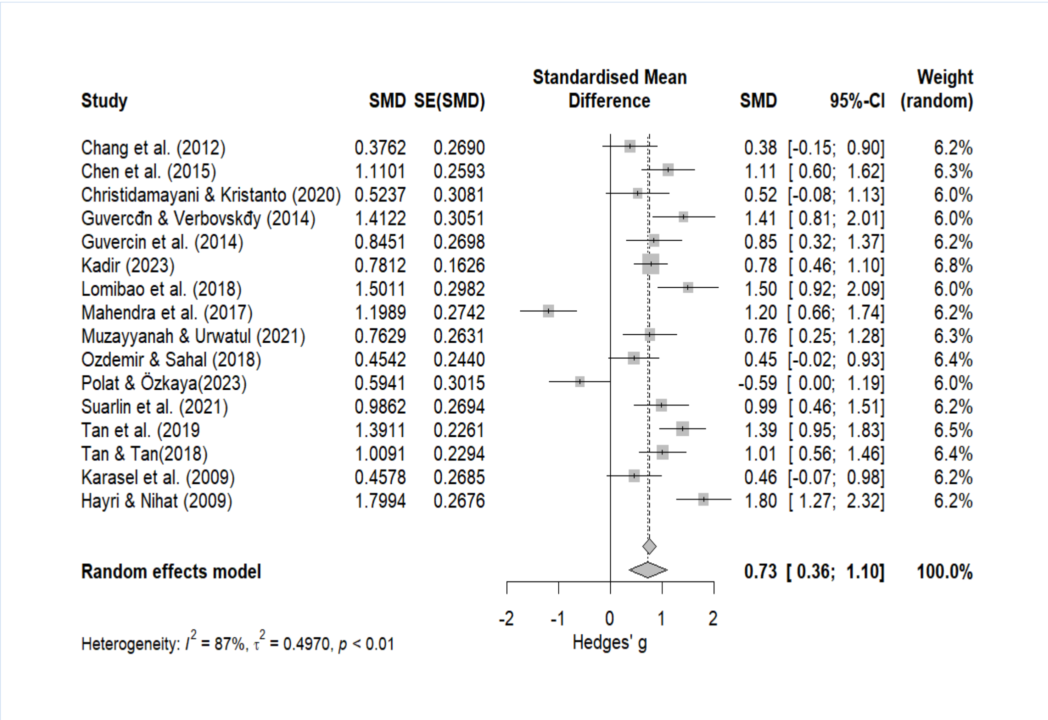

Figure 3. Forest plot of effects of problem posing on students' academic achievement

The forest plot also reveals that Chang et al. (2012) reported the smallest effect size at approximately 0.38. Although this is a small effect size, the study noted that the problem-posing system, implemented through a game-based approach, stimulated students' performance by increasing their problem-solving ability. In this study, the nature of game-based strategy was demonstrated to be suitable for integrating problem posing.

The forest plot shows that all studies conducted utilizing the problem-posing approach to enhance students' academic achievement in Mathematics report a positive effect size. This implies that students taught using the problem-posing approach exhibit a higher gain in mathematics achievement than those taught in traditional math classrooms.

4.2. Analysis of Effect Sizes Concerning Moderator Variables

The test for heterogeneity revealed a significant difference in effect sizes, suggesting the need to explore potential moderating variables that could contribute to heterogeneity. Table 2 presents the analysis of the effect of the problem posing on academic achievement based on the moderator variables.

Table 2. Effect of problem posing on students' achievement for moderator variables

Moderator Variables	k	g	95% CI	Q_b (between group)
Sampling				
Purposive	6	0.6040	[0.0524; 1.1555]	0.97 ($p = 0.6169$)
Random	9	0.7825	[0.2200; 1.3450]	
Convenient	1	0.9862	[0.4582; 1.5142]	
Grade Level				
Primary	5	0.3732	[−0.1484; 0.8949]	15.57 ($p = 0.0014$)
Junior Secondary	8	0.7816	[0.1781; 1.3851]	
Senior Secondary	2	0.8359	[0.5631; 1.1088]	
Tertiary	1	1.7994	[1.2749; 2.3239]	
Country				
China	2	0.7466	[0.0275; 1.4658]	10.84 ($p = 0.0547$)
Indonesia	5	0.3766	[−0.4011; 1.1543]	
Kazakhstan	2	1.1108	[0.5561; 1.6654]	
Philippines	3	1.2729	[0.9768; 1.5691]	
Turkey	3	0.5580	[−0.7936; 1.9096]	
Cyprus	1	0.4578	[−0.0685; 0.9841]	
Subject Matter				
Arithmetic	4	0.1915	[−0.2884; 0.6713]	15.40 ($p = 0.0039$)
General Math	5	1.1276	[0.8685; 1.3868]	
Geometry	3	0.0546	[−1.1938; 1.3031]	
Calculus	2	1.2681	[0.2712; 2.2650]	
Algebra	2	1.2021	[0.8277; 1.5764]	

Note: $\boldsymbol{k}$ is number of studies; $\boldsymbol{g}$ is the effect size given in Hedges g; and $\boldsymbol{Q_b}$ is the Cochran's value

The results show that the sampling method employed in studies and the grade level from which studies are conducted do not exhibit significant heterogeneity regarding the effect of problem posing on academic achievement. In terms of sampling design, $Q_b = 97$ ($p = 0.6169$) means the effect of problem posing is homogeneous regardless of how participants are sampled in the studies. In addition, $Q_b = 10.84$ ($p = 0.0547$) means the country from which the study was conducted is not a factor in the heterogeneity of effect sizes. These figures indicate that, regardless of the sampling methodology and geographical location of the study, the effect of the problem-posing approach on students' achievement will not be significantly different.

On the other hand, $Q_b = 15.57$ ($p = 0.0014$) and $Q_b = 15.40$ ($p = 0.0039$) mean that grade level and subject matter are factors of heterogeneity of the effect of problem posing on students' academic achievement. These two factors serve as moderators that influence the significance of the difference in the distribution of effect sizes.

In terms of grade level, studies conducted at the tertiary level record the largest effect size ($g = 1.7994$), followed by studies in senior secondary ($g = 0.8359$) and junior secondary ($g = 0.7816$), and studies at the primary level record the smallest effect size ($g = 0.3732$). From this trend, we can infer that when problem posing is conducted at a higher grade level, the magnitude of the effect on academic achievement eventually increases.

Also, when subject matter is considered, studies under calculus ($g = 1.2681$) and algebra ($g = 1.2021$) record the largest effect size. However, it is important to emphasize that only one study has been conducted on calculus. It is also worth noting that studies conducted in Geometry report the smallest effect size ($g = 0.0546$). This can be attributed to the fact that students learning arithmetic are at a stage where they are still beginning to appreciate mathematics (Darlena et al., 2022). This figure suggests that subject matter is a factor to consider when implementing a problem-posing approach in mathematics.

5. Discussion, Conclusion, and Limitation

This meta-analysis of 16 studies showed that the problem-posing approach effectively enhances students' academic achievement in mathematics. The substantial positive effect of problem posing is consistent with the view that problem posing aids mathematical learning outcomes through fostering deeper cognitive engagement and problem-solving skills (Rosli et al., 2014). The result confirms that students' active involvement in problem-posing tasks, such as formulating questions, generating new problems, and exploring alternative solutions, enhances their mathematical reasoning and performance in the subject (Sari & Surya, 2017). Moreover, the problem-posing approach encourages students to be engaged in the learning process, thereby promoting autonomy (Liljedahl & Cai, 2021). These results underscore the importance of designing instructional strategies that capitalize on problem posing to enhance student engagement and deepen conceptual understanding. The results of this study lend credence to the effectiveness of the problem-posing approach in mathematics instruction (Cai & Jiang, 2017).

Despite the seemingly consistent, significant positive impact of problem posing on students' achievement in the classroom, several factors should be considered For instance, the context of integration, such as the readiness of students to engage in the problem-posing activities, may hinder effective participation in the classroom. Additionally, students' inherent difficulty with the content area and subject matter may also complicate the issue (Mahendra et al., 2017; Namkung & Fuchs, 2019). With this, Polat and Özkaya (2023) make a point to integrate the problem-posing strategy in teaching fraction operations, as they claim it is a complex topic in sixth-grade mathematics. These factors may influence students' perception of the subject and can affect the integration of problem posing.

The results further demonstrate the moderating effect of grade level and subject matter on the impact of problem posing on students' mathematical achievement. This suggests that the approach is efficient for higher-grade students, corroborating the argument that older learners possess greater cognitive flexibility and autonomy in mathematical problem-solving (Yao et al., 2021). This trend may be attributed to the increasing complexity of mathematical content at higher educational levels, where students benefit more from self-generated problems that facilitate deeper learning and understanding. Conversely, the declining effect on lower grade levels may reflect the fact that younger students are developing their cognitive structures. This case should require additional scaffolding to maximize the benefits of problem-posing interventions.

Moreover, the subject matter in which problem posing is implemented plays a critical role in determining its effectiveness. The findings indicate that problem posing has the most substantial impact in calculus and the least effect in arithmetic. The advanced cognitive demands of calculus can explain this, where students must construct and manipulate abstract mathematical concepts, making problem posing an effective means of reinforcing conceptual understanding (Karasel et al., 2009). In contrast, the relatively smaller effect in geometry may be due to the foundational nature of the subject, where students are still in the early stages of mathematical reasoning and may rely more on direct instruction rather than exploratory learning (Silmi Juman et al., 2022). These results suggest that mathematics educators should carefully consider the subject domain when integrating problem posing into instruction, ensuring that activities are developmentally appropriate and aligned with students' cognitive readiness.

In conclusion, this meta-analysis provides robust empirical support for the efficacy of the problem-posing approach in enhancing students' academic achievement in mathematics. This demonstrates that the integration of problem posing is a transformative strategy that significantly enhances mathematical learning. This study contributes to the growing literature by providing evidence in appraising problem posing as a classroom pedagogy. It offers theoretical insights into the impact of student-centered techniques, such as problem generation and reformulation, as tools for achieving mathematical learning gains. It affirms the value of problem posing as a powerful instructional approach, offering meaningful directions for improving mathematics education.

A limitation of this review is the exclusive use of Google Scholar as the search platform. Although its broad coverage increases the likelihood of capturing diverse studies, it does not offer the same level of indexing transparency or advanced filtering capabilities found in Scopus or Web of Science. This may have affected the ability to identify every eligible study on the problem-posing approach. Future meta-analyses may incorporate multiple bibliographic databases to enhance search sensitivity and reliability further.

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