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Systematic Review

Quantifying the Relationship Between Self-Efficacy and Mathematical Creativity: A Meta-Analysis

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Abstract: This study is a meta-analysis to examine the relationship between self-efficacy and mathematical creativity. This meta-analysis included 21 studies with a total sample size of 11,621 participants and 33 effect sizes across the studies. Data analysis using a random effects model using the "meta" package (version 7.0-0) in R software version 4.3.0. The results showed a positive and significant relationship between self-efficacy and mathematical creativity ($z = 3.51; 95\%\ CI\ [0.09,\ 0.32]$, $p < 0.001$). The influence of self-efficacy on mathematical creativity is included in the low category ($r_e = 0.21$). These findings had no publication bias issues with Egger's test ($t = -0.03$; $p = 0.978$) and were stable against the impact of unpublished studies ($Fail - safe\ N = 5101$; $p < 0.001$). Meta-regression revealed two variables that showed significant results: measurement method ($Q = 11.17; df = 2$; $p = 0.0038$) and study location ($Q = 372.41$, $df = 9$; $p < 0.0001$). This study provides valuable information about the relationship between self-efficacy and mathematical creativity, but more research is needed to develop effective and efficient learning strategies.

Keywords: mathematical creativity; self-efficacy; creative thinking; measurement method; meta R package; meta-analysis

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1. Introduction

Industry 4.0, marked by technological advances and global competition, demands individuals with strong talents and a high level of creativity [1]. Industry 4.0, often referred to as the Fourth Industrial Revolution, signifies a substantial shift in manufacturing and industrial methodologies, marked by the incorporation of advanced digital technologies. This revolution is characterized by the merging of the physical, digital, and biological realms, enabled by innovations like the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and cyber–physical systems [2]. To prepare an adaptive generation for this changing landscape of this industry, education must prioritize developing skills relevant to future needs [3]. In the mathematics education scope, the focus of learning extends beyond mere comprehension of computational principles and proficiency; it also embraces a culture of innovation, encouraging a holistic approach to learning. Mathematical creativity needs to be put forward to demonstrate an individual's capacity to understand original ideas, innovative solutions, and unorthodox methods [4]. This enables students to overcome dilemmas, solve complex mathematical problems, and precipitate creative problem-solving resolutions.

Creativity allows individuals to identify alternative problem-solving strategies with varied perspectives, spurring students' capacity to think adaptively [5]; make connections between different mathematical concepts; and think abstractly in generalizing mathematical concepts [6]. Individuals who are creative in mathematics can see the patterns, structures, and principles underlying complex mathematical problems, developing a more holistic understanding and applying mathematical concepts more broadly. But it should be noted that mathematical creativity is not only influenced by a single factor such as intelligence or one's innate talent [7]. In an era where innovation and creative thinking are key to success, further understanding of the relationship between mathematical creativity and those other factors is becoming increasingly important.

Previous meta-analyses have explored the relationship between self-efficacy and creativity, highlighting the influence of measurement tools on this relationship. Haase et al. (2018) found that self-assessed creativity showed a stronger correlation with self-efficacy compared to objective tests [8]. Furthermore, studies by Bicer (2020) and Suparman et al. (2020) confirmed the positive impact of self-efficacy on mathematics learning ability. Increasing students' self-efficacy can lead to improvements in their mathematical problem-solving skills and academic performance [9,10]. However, while these positive correlations exist, several studies suggest that the relationship between self-efficacy and creativity may not be universally applicable across different contexts and populations. Further research is needed to understand the nuances of how self-efficacy interacts with various factors that influence creativity in specific domains, such as mathematics. This research aims to address this gap by exploring the relationship between self-efficacy and mathematical creativity in diverse population contexts and measurement types.

Meta-analysis is a relevant statistical method used to produce stronger and more comprehensive conclusions in understanding the relationship between self-efficacy and mathematical creativity. The hallmark of meta-analysis lies in its ability to address publication bias and integrate findings from different studies that may have conflicting results [11]. By including unpublished studies, meta-analyses can offer a more comprehensive understanding of the correlation between self-efficacy and mathematical creativity. These studies can yield essential insights into insignificant or unexpected effects.

This paper aims to synthesize a meta-analysis to quantify the relationship between mathematical creativity and self-efficacy. By conducting a comprehensive analysis of the existing literature, this meta-analysis will provide a more accurate and detailed understanding of the correlation measures of self-efficacy and mathematical creativity, identify other factors that may have influence, and evaluate publication bias in related studies. In detail, this meta-analysis will prove the following assumptions:

(1) There was a positive association between self-efficacy and mathematical creativity in all studies;
(2) There was no publication bias across the studies; After reading the notes for the caption on image 2, we found that all the results or outputs are from the R Program. Therefore, we did not separate the letter Z or add (-).
(3) There are identified moderator variables that influence the relationship between self-efficacy and mathematical creativity.

In addition, this meta-analysis also explores the moderator variable's effect size that can potentially affect the publication bias and the overall effect size of the included studies. The exploration of moderator variables is crucial in meta-analyses, as these factors can significantly influence the effect size being studied. Moderator analyses may even allow us to examine relationships that have never been examined in primary research [12]. For instance, the types of assessments or measurement methods used in studies can affect the measurement of self-efficacy and its impact on mathematical creativity [13,14]. Additionally, sample size plays a vital role in the reliability and generalizability of the results; larger samples tend to yield more stable effect sizes [15]. The educational level of participants is another important moderator, as it can shape the context in which self-efficacy is developed and expressed, particularly in mathematical tasks. In this case, we posit that educational experiences shape the sources of efficacy information, such as vicarious experiences, verbal persuasion, and emotional arousal [16,17]. Furthermore, the country of origin of the studies can provide insights into cultural and educational contexts that may influence the relationship between self-efficacy and mathematical creativity [17]. These contextual factors are essential for interpreting the results of meta-analyses and understanding how self-efficacy operates across different settings.

Mapping and exploration through meta-analysis in this study are crucial and require an exploration of a more holistic understanding of the relationship between mathematical creativity and self-efficacy. This understanding will impact the development of effective and efficient learning strategies to improve mathematics education quality. This meta-analysis research will also provide a strong foundation for developing mathematics education programs oriented towards mathematical creativity and the role of self-efficacy in this process. In addition, the findings will inform the discourse on developing creative thinking skills assessment, especially in the context of mathematics learning.

2. Literature Review

2.1. Mathematical Creativity

Mathematical creativity is a multifaceted construct that can be measured through various methodologies, including self-report, other report, and objective measurement methods. Each of these approaches offers unique insights and complements the understanding of creativity in mathematical contexts. Self-report measures often involve students or teachers reflecting on their creative processes and outputs. For instance, the Kaufman Domains of Creativity Scale (K-DOCS) is designed to capture a person's creative behavior across five domains: daily, scholarly, performance, scientific, and artistic [18]. On this scale, mathematical creativity is measured in the scientific domain. The self-report method allows for personal insight into a person's perception of their creativity but may be susceptible to bias, such as overestimating or underestimating one's abilities [19].

The method of other reports, where experts, teachers, or peers evaluate a person's creativity, can provide a more objective perspective. Research shows that creativity can be judged based on observable behaviors and problem-solving strategies, such as asking open-ended problems or coming up with multiple solutions [20]. This aligns with frameworks that emphasize the importance of collaborative environments in fostering creativity, where peer interactions can enhance individual creative capacities [21]. Furthermore, studies have shown that teacher assessments can be influenced by their understanding of creativity and their instructional strategies [22].

Objective measurement methods, such as standardized tests and performance assessments, provide quantifiable data on mathematical creativity. For instance, the development of a mathematics creativity scale has been proposed to systematically evaluate students' creative potential in mathematics [23]. These objective measures often incorporate criteria such as fluency, flexibility, and originality, allowing for a more comprehensive assessment of creativity [24]. Additionally, the use of rubrics in performance assessments can help in evaluating specific creative indicators, such as elaboration and flexibility, which are crucial for understanding students' creative processes in mathematics [25]. Combining these methodologies can lead to a more holistic understanding of mathematical creativity. For example, integrating self-report and other report methods can help triangulate data, providing a richer picture of a student's creative abilities. Moreover, aligning objective measures with qualitative assessments can enhance the validity of creativity evaluations, ensuring that different dimensions of creativity are adequately captured [26]. Therefore, each method provides valuable insights, and their integration can result in more effective educational strategies aimed at fostering creativity in mathematics.

2.2. Self-Efficacy and Mathematical Creativity

Self-efficacy or self-confidence in the context of mathematics education relates to an individual's confidence in their ability to understand, master, and overcome mathematical challenges [27]. High self-efficacy in mathematics can provide strong motivation, perseverance, and courage to face difficult mathematical problems [28,29]. Therefore, a deeper understanding of the relationship between self-efficacy and mathematical creativity can provide consideration in deciding on appropriate interventions to improve classroom learning and provide caution in assessing these two important ability components of students.

Although many studies have investigated mathematical creativity and self-efficacy separately, the relationship between these two variables requires further exploration. The existing literature reveals different findings concerning the relationship between these two concepts. Some researchers report that self-efficacy significantly impacts creative thinking skills [10], showing a high correlation value [8]. This is supported by findings revealing that students with high self-efficacy are more likely to possess high mathematical creative thinking ability and vice versa [12]. Furthermore, self-efficacy in mathematics significantly predicts students' mathematical problem-solving performance, suggesting that students who believe in their mathematical abilities are more likely to approach problems creatively [13]. Moreover, the reciprocal relationship between self-efficacy and creative performance has been documented, indicating that prior creative successes can enhance self-efficacy, which in turn fosters further creative endeavors. This cyclical dynamic suggests that as students experience success in creative mathematical tasks, their self-efficacy increases, encouraging them to tackle more complex and creative challenges in mathematics [30]. Additionally, the role of creative problem-solving learning models has been emphasized to enhance both self-efficacy and creativity in mathematics. Such models encourage students to confront real-world problems creatively, thereby reinforcing their self-efficacy as they navigate these challenges successfully [31]. This aligns with the findings of those who argue that effective teaching strategies can significantly enhance students' mathematical creative thinking abilities and self-efficacy [32]. In summary, the theoretical justification for the expected relationship between self-efficacy and mathematical creativity is grounded in the understanding that self-efficacy influences students' willingness to engage in creative tasks and that successful experiences in these tasks can further enhance their self-efficacy.

In contrast to some other researchers' opinions, self-efficacy is an inconsistent personal construct [33], so it is more precisely positioned as a predictor variable mediating the learning approach to student ability [34,35]. In this scenario, self-efficacy may not directly impact an individual's creativity but instead interacts with other variables to mold creative outcomes [30]. This suggests that in examining the relationship between self-efficacy and mathematical creativity, it is imperative to view self-efficacy as a moderator variable. By adopting this perspective, researchers can better grasp how self-efficacy influences the interplay between different variables, such as learning approaches and creative performance. Additionally, the complexity of the relationship between self-efficacy and individual creativity is underscored, indicating that self-efficacy can have varied effects depending on the individual's regulatory focus [31]. This underscores the notion that self-efficacy's influence on creativity is multifaceted and may be contingent on factors like motivation and the specific context of the creative task. Addressing these gaps necessitates a comprehensive and systematic evaluation to understand the relationship between self-efficacy and mathematical creativity and identify moderating factors that might influence it.

3. Materials and Methods

This study uses a meta-analysis approach with meta-correlation, or more specifically, the meta-analysis of the correlation coefficient r [36,37]. This approach is employed to analyze the relationship between two continuous variables across multiple studies [36]. In this study, we implemented meta-correlation to estimate the summary effect of the relationship between mathematical creativity and self-efficacy. Factors such as measurement method, sample size, study level, and location are also included as moderator variables. This approach integrates findings from various relevant studies, producing more accurate estimates of the relationships between the variables studied [38].

The selection of literature as a source of data is carried out systematically by referring to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines) [39] (see Figure 1), showing the process of identification, study selection, data extraction, analysis, and interpretation of the results occurring from February to September 2024.

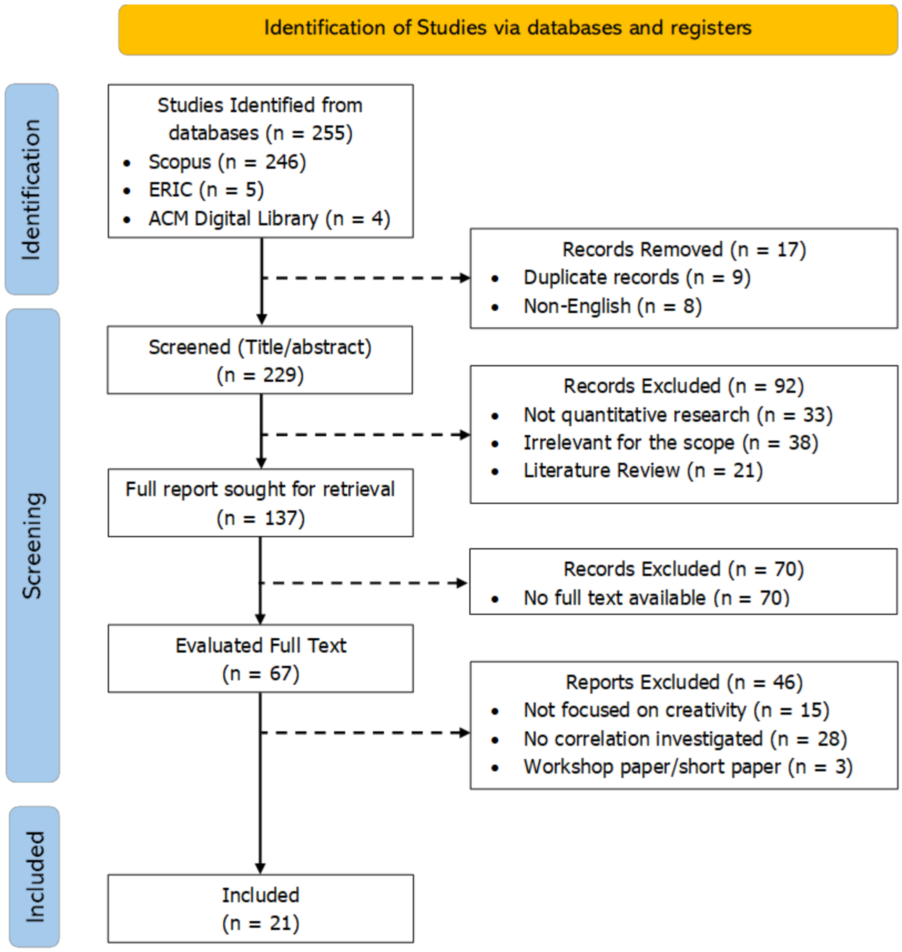

Figure 1. Screening process (adapted from PRISMA guidelines).

The search strategy was developed using text words associated with the literature on mathematical creativity and self-efficacy. The search was conducted by applying the keywords "Mathematical Creativity" AND "Self-efficacy" in three databases (Scopus, ERIC, and ACM Library), including studies in English. Furthermore, the initial filtering method is applied through multiple data source filtering (deduplicated) between databases. Initial filtering uses the SR-Accelerator's Deduplicator automated tool [40].

At the screening stage, the included studies must conform to predetermined inclusion and exclusion criteria. Overall, this meta-analytic study is based on three search criteria, namely to (1) investigate the relationship between at least one variable of mathematical creativity and self-efficacy, (2) use operationalization or clear indicators (containing the size and characteristics of samples, research locations, and measurement methods), and (3) report correlation coefficients or other statistics convertible to effect size r (e.g., effect size *d*, beta path coefficient, *t* count, *F* count, and *p*-value) and the number of participants.

At the title and abstract screening stage, researchers use the help of SR-Accelerator's Screenatron automatic tool [40] to ensure that the study is relevant to quantitative research focused on the correlation between mathematical creativity and self-efficacy. The subsequent source evaluation stage requires full-text access and focuses on research reports emphasizing creativity as part of academic performance.

Quality evaluation of observational studies [41] is applied in the screening process to avoid the risk of bias in quantitative studies, including sample selection, data collection, variable measurement, and statistical analysis. At this stage, the six researchers reviewed the study based on inclusion criteria using the help of SR-Accelerator's Deduplicator tool [40] to resolve differences through consensus or by referring to the fourth author.

After screening, relevant data are extracted from selected studies, including sample size, correlation coefficient, t count, F count, or significance value to quantify the relationship between mathematical creativity and self-efficacy. In addition, the moderator variables applied in this study were obtained through the process of extracting measurement method, sample size, grade level, and location. The test types are concluded by examining the instruments used to measure mathematical creativity in the included studies (Table 1). This measurement method consists of self-report, other report, and objective measurement methods [19]. The sample size variable consists of two categories, namely large samples ($N \leq 100$) and small samples ($N > 100$) [42]. Grade level indicates the education level of the subject or person whose mathematical creativity is measured.

Table 1. Examples of methods, types, and aspects to measure mathematical creativity.

Method	Example	Type	Aspect
Self-report	Teach with portals questionnaire [43]	Verbal and Figural	Place
	SenSel creativity sensitization and self-questionnaire [44]	Verbal and Figural	Process
	Modified attitude toward mathematics scale [45]	Verbal	Person
	The creative teaching rating scale [46]	Verbal	Process
	Kaufman domains of creativity scale (KDOCS) [18]	Verbal and Figural	Process
	Innovative behaviors [47]	Verbal	Place
Other report	Product creativity measurement by expert raters [48]	Verbal	Product
	The mathematical problem-posing cognitive style [49]	Verbal	Person
	Creative teaching evaluation instrument [50]	Verbal	Process
	The mathematical creative thinking ability-based learning barrier [51]	Verbal and Figural	Place
	Individual interviews and mathematics-related affect surveys [52]	Verbal	Place
	Kirton adaption innovation (KAI) [53]	Verbal	Person
Objective measurement	The mathematical creativity test (MCT) [54]	Verbal	Process
	The creative problem-posing test [55]	Verbal and Figural	Process
	Open-ended essay test [56]	Verbal	Process
	Mathematical creative problem-solving ability test [57]	Verbal	Process
	MCT-based ethnomathematics test (MCTBE) [58]	Verbal and Figural	Process
	The Geometrical Objects Achievement Test (GOAT) [59]	Verbal and Figural	Process

After the entire data are extracted, statistical analysis is performed to combine data from selected studies [37]. Research data that only report F values or t values are converted into r values (correlation coefficients) using the following equation:

$$F = t^2 \quad (1)$$

$$t = \sqrt{F} \quad (2)$$

$$r = \frac{t}{t^2 + N - 2} \quad (3)$$

with N representing the total sample size. Furthermore, statistical analyses of all data were conducted using R software version 4.3.0, with statistical significance determined at a p-value threshold of < 0.05. The "meta" package (version 7.0-0) was specifically employed to execute the meta-analysis [12]. The results from the meta-correlation analyses were visually represented through a forest plot.

The first stage estimates the overall effect size and heterogeneity of studies. Data analysis is performed using the random effect model and includes coefficient correlations of all studies. The random effect model is used to analyze studies that have diverse sample and measurement characteristics that allow for variability in population effect size among the analyzed studies [37]. Furthermore, we utilized Fisher's r-to-z transformation on the "meta" package to standardize the effect sizes associated z (ZCOR) with each correlation coefficient r [60,61]. This transformation allows for the correlation coefficients to be represented in a normal distribution, thereby enhancing the accuracy of estimating the overall effect size [62]. Subsequently, we computed the overall correlation between the variables of interest in our meta-analysis based on these standardized effect sizes.

The measure of the effect of self-efficacy on mathematical creativity can be observed through the estimated value of the summary effect (ZCOR Total) or random effect (r_e). Three categories of influence sizes can be inferred based on this test, namely low ($r_e = 0.1$), medium ($r_e = 0.3$), and high ($r_e = 0.5$) [62].

Heterogeneity was primarily assessed using the I-squared (I^2), H statistic, τ (tau), and τ^2 (tau-squared) statistics [12]. The I^2 statistic quantifies the proportion of total variability in effect sizes attributable to heterogeneity rather than random chance [12]. We categorized I^2 values of 25%, 50%, and 75% to be indicative of low, moderate, and high heterogeneity, respectively [36]. The H statistic evaluates the impact of individual studies on the overall meta-analytic results [12,36]. The τ statistic assesses the variance in effect sizes between studies, serving as a measure of heterogeneity. A higher τ value signifies increased heterogeneity among the studies [36]. The τ^2 statistic estimates the variance of true effects across studies, adjusting for sampling error [36]. The results from the meta-correlation analyses were visually represented through a forest plot.

The publication bias can be observed through the view of the plot funnel. The asymmetrical plot funnel indicates the absence of publication bias in the analyzed studies. To identify more accurately if the funnel plot is symmetrical, we used the indicators generated from Egger's test, as well as Rosenthal's method. The $p > 0.05$ from Egger's test shows that the plot funnel is symmetrical. Meanwhile, Rosenthal's method was used to prove that there were no problems with publication bias based on Fail-safe N (FSN) with significance targets of 0.05 and $p < 0.001$. If K is the total of studies included, and $FSN > 5K + 10$, then there is no problem with the publication bias in this meta-analysis study [63].

The second stage estimates the summary effect by including moderator variables, including measurement method, sample size, grade level, and research location. The purpose of this step is to see to what extent these factors influence the summary effect size of the relationship between mathematical creativity and self-efficacy. The last stage is to interpret the statistical analysis results and compare them with similar research to produce comprehensive deductions about the relationship between mathematical creativity and self-efficacy.

4. Results

4.1. Study Selection Results

The selection of studies was conducted in Scopus, ERIC, and ACM Digital Library databases until 12 September 2024. We extracted a combined sample size of $N = 11{,}621$, with 33 observations in 21 studies, to be analyzed for this meta-analysis. In addition, we also included other important factors, including measurement method, sample size, grade level, and location (Table 2). The sources found have a varied distribution of data. Studies on the relationship between mathematical creativity and self-efficacy have had mixed results. In general, these studies showed a positive correlation between mathematical creativity and self-efficacy and only one study showed a negative value.

Table 2. Results of selection and data extraction.

Study	N	Gender (%)			r	MM	SS	GL	Location
		M	F	NR					
Antequera-Barosso et al. (2024) [43]	100	-	-	100	0.04	SR	Sml	PS	Spain
Baumanns and Rott (2024a) [64]	187	74.87	22.46	2.67	−0.14	OM	Lrg	PS	Germany
Baumanns and Rott (2024b) [64]	187	74.87	22.46	2.67	−0.14	OM	Lrg	PS	Germany
Baumanns and Rott [64]	187	74.87	22.46	2.67	−0.16	OM	Lrg	PS	Germany
Baumanns and Rott (2024d) [64]	187	74.87	22.46	2.67	−0.14	OM	Lrg	PS	Germany
Bicer et al. (2020) [65]	205	-	-	100	0.78	OM	Lrg	ES	USA
Demirtas and Karaduman (2021) [44]	509	-	-	100	0.48	SR	Lrg	PS	Turkey
Deng et al. (2020a) [66]	266	60	40	-	0.03	SR	Lrg	PS	Spain
Deng et al. (2020b) [66]	266	60	40	-	0.07	SR	Lrg	PS	Spain
Han et al. (2023) [67]	359	10.58	89.42	-	0.40	SR	Lrg	PS	China
Hayati et al. (2023a) [50]	242	33.8	66.2	-	0.54	OR	Lrg	PS	Malaysia
Hayati et al. (2023b) [50]	242	33.8	66.2	-	0.44	OR	Lrg	PS	Malaysia
Hayati et al. (2023c) [50]	242	33.8	66.2	-	0.41	OR	Lrg	PS	Malaysia
Hayati et al. (2023d) [50]	242	33.8	66.2	-	0.54	OR	Lrg	PS	Malaysia
Jamaluddin et al. (2022) [68]	128	-	-	100	0.13	OM	Lrg	JS	Indonesia
Lee et al. (2020) [52]	212	-	-	100	0.02	OR	Lrg	PS	South Korea
Liu et al. (2022) [69]	1019	-	-	100	0.75	OR	Lrg	PS	China
Maskur et al. (2020) [56]	42	-	-	100	0.08	OM	Sml	HS	Indonesia
Meier et al. (2024a) [70]	167	60.48	38.32	1.2	−0.19	OM	Lrg	PS	Germany
Meier et al. (2024b) [70]	167	60.48	38.32	1.2	0.09	OM	Lrg	PS	Germany
Munahefi et al. (2022) [71]	36	-	-	100	0.08	OM	Sml	HS	Indonesia
Niemi et al. (2023) [72]	490	-	-	100	0.07	OM	Lrg	JS	Finland
Rahyuningsih et al. (2022) [29]	96	43.75	56.25	-	0.77	OR	Sml	JS	Indonesia
Ramdani et al. (2021) [73]	108	32.41	67.59	-	0.38	OM	Lrg	PS	Indonesia
Suherman (2024) [74]	896	46.3	53.7		−0.10	OM	Lrg	JS	Indonesia
Suherman and Vidákovich (2024a) [58]	896	46.3	53.7	-	0.07	OM	Lrg	JS	Indonesia
Suherman and Vidákovich (2024b) [58]	896	46.3	53.7	-	0.08	OM	Lrg	JS	Indonesia
Suherman and Vidákovich (2024c) [58]	896	46.3	53.7	-	0.06	OM	Lrg	JS	Indonesia
Suherman and Vidákovich (2024d) [58]	896	46.3	53.7	-	0.02	OM	Lrg	JS	Indonesia
Suherman and Vidákovich (2024e) [58]	896	46.3	53.7	-	0.05	OM	Lrg	JS	Indonesia
Supandi et al. (2021) [51]	154	-	-	100	0.24	OR	Lrg	PS	Indonesia
Tezer and Cumhur (2017) [59]	60	-	-	100	−0.03	OM	Sml	JS	Cyprus
van Broekhoven et al. (2020) [75]	145	89	56	-	0.03	OR	Lrg	PS	Germany

Overall, from the data in Table 2, the included studies used self-report methods (15.15%), other reports (27.27%), and objective measurement (57.58%) to measure mathematical creativity. The tests were applied to two categories of sample sizes, namely larger samples (84.85%) and small samples (15.15%). Measurement subjects with post-high school levels were most involved in these studies (61.61%). Other grade levels are filled by junior high school (30.3%), elementary school (6.06%), and senior high school (3.03%). The distribution by location is represented by Indonesia (36.37%), Germany (21.21%), Malaysia (12.12%), Spain (9.09%), China (6.06%), South Korea (3.03%), Turkey (3.03%), Finland (3.03%), and Cyprus (3.03%).

4.2. The Overall Effect Size of Each Primary Study

4.2.1. The Overall Effect Size

The overall effect size estimation used a random effect model. Some important statistics were found from the results of this analysis. First, the model used is relevant in explaining variability in the data analyzed. A test of residual heterogeneity showed that the 33 effect sizes of the studies analyzed were heterogeneous ($Q = 1325.47$; $df = 32$; $p < 0.001$). These results prove that the random effect model is more suitable for use in estimating the effect size in this meta-analysis study. Second, the analysis results showed that there was a significant positive relationship between self-efficacy and mathematical creativity

($z = 3.51; 95\%\ CI[0.09, 0.32],\ p < 0.001$). The effect size of each study is visualized through the forest plot in Figure 2.

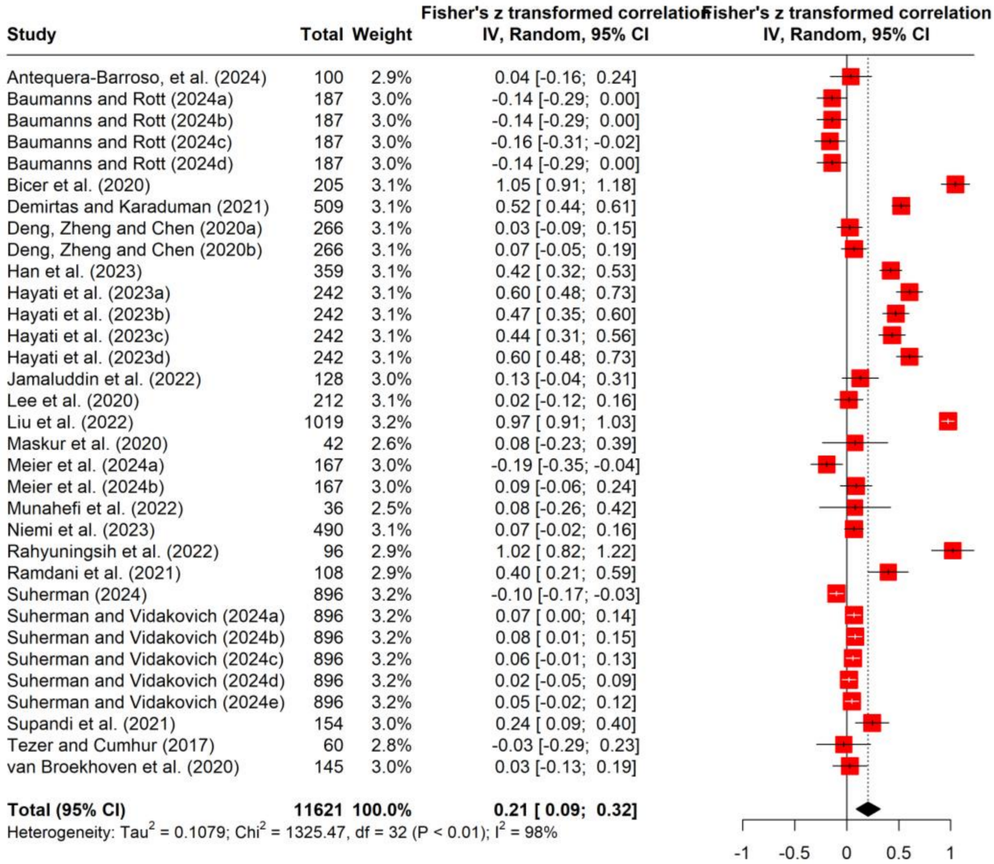

Figure 2. Forest plot of overall effect size [29,43,44,50–52,56,58,59,64–75].

Based on the forest plot in Figure 2, it can be observed that the analyzed Fisher r-to-z-transformed correlation coefficients varied from −0.19 to 1.05, with most of the values reported to be positive (78.78%). The measure of influence of self-efficacy on mathematical creativity is included in the low category ($r_e = 0.21$).

4.2.2. Heterogeneity

The test of heterogeneity results using the random effect model indicated significant heterogeneity among the studies included in the meta-analysis (Q (32) = 1325.47; $p < 0.01$, $\tau^2 = 0.1079$, $I^2 = 98\%$). This high heterogeneity indicates that there is potential to investigate the moderator variables that influence the relationship between self-efficacy and mathematical creativity.

4.3. Publication Bias

Using the random effect model, some important statistical data were obtained to evaluate publication bias. In this meta-analysis, publication bias was identified through the funnel plot (Figure 3). The funnel plot was verified through Egger's test and Rosenthal's method.

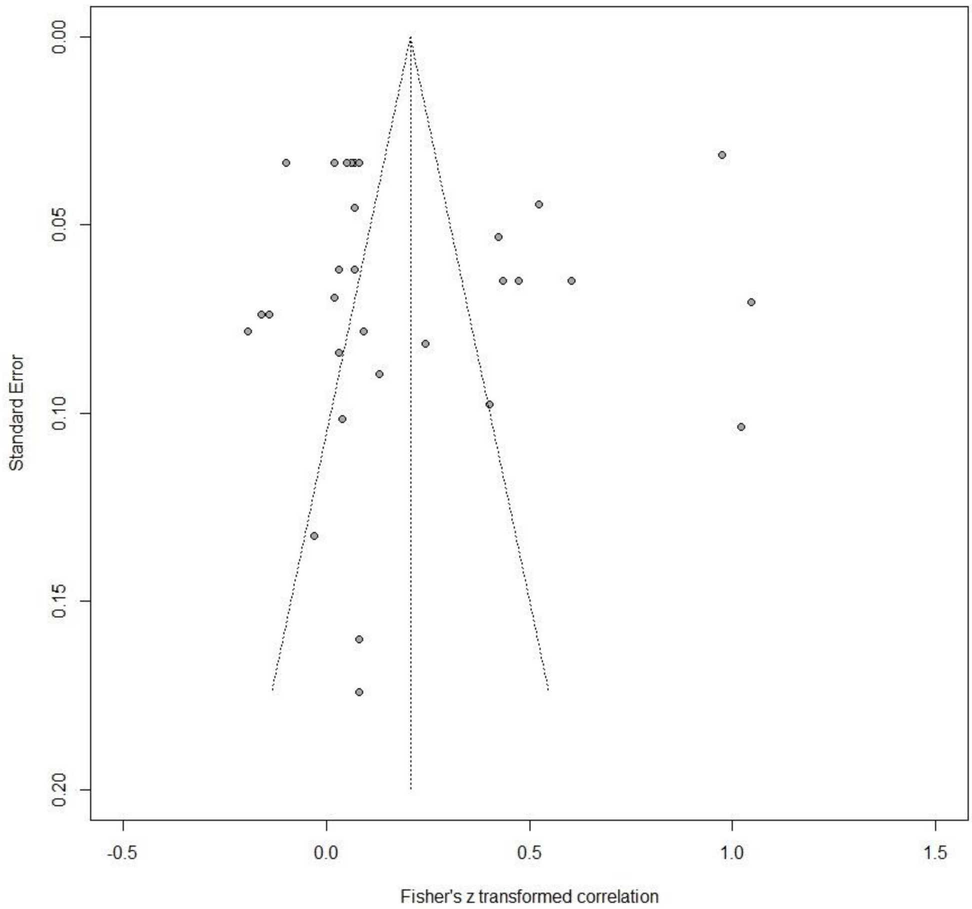

Figure 3. Funnel Plot.

The Egger's test results showed that the estimated bias was not significant (t = 0.03; p = 0.978), so the funnel plot can be said to be symmetrical. Moreover, the Fail-safe N obtained was 5101, with a significant target of 0.05 and $p < 0.001$. By substituting combined effect sizes (K = 33) into the formula $5K + 10$, a value of 175 was obtained. Because the $FSN > 175$, it was concluded that there was no publication bias problem in the meta-analysis study. In this case, the total studies with zero effects were required to change the meta-analysis's conclusions to be insignificant. The Fail-safe N value also predicted that there were about 5101 unpublished studies and concluded that there was no significant relationship between self-efficacy and mathematical creativity.

4.4. Effect Size of Moderator Variables

In the results of the analysis, we can observe the relationship between self-efficacy and mathematical skills by considering the moderator variables using a random effect model. The distribution of measures of influence of each observed moderator variable confirms in more detail the findings of these overall effect sizes (Figure 4).

Figure 4 shows the effect size distribution of moderator variables estimated using a random effect model in the R Program, including the measurement method, sample size, grade level, and research location. The subgroup difference test revealed two variables that showed significant results: the measurement method variable ($Q = 11.17; df = 2;\ p = 0.0038$) and the study location ($Q = 372.41,\ df = 9;\ p < 0.0001$). Regarding the measurement method variables, we found that the use of other report measurement methods showed a stronger relationship ($ZCOR = 0.49; 95\%\ CI\ [0.27; 0.71]$) compared to the self-report measurement method ($ZCOR = 0.23; 95\%\ CI\ [0.04; 0.41]$) and measurement objective ($ZCOR = 0.07; 95\%\ CI\ [-0.06; 0.19]$). This indicates that measuring mathematical creativity using raters or peers (other reports) is more effective in predicting the relationship between self-efficacy and mathematical creativity compared to objective measurement methods (such as competency tests and other standardized tests) and subjective assessments of the individual themself (self-report). In the context of the study sites, the analysis results showed that study sites in certain countries such as the USA ($ZCOR = 1.05,\ 95\%\ CI\ [0.91;\ 1.18]$) and Turkey ($ZCOR = 0.52,\ 95\%\ CI\ [0.44;\ 0.61]$) are stronger associations compared to other countries. The difference in effect size values based on the location of this study shows that studies conducted in countries such as the USA and Turkey have more moderate values in predicting the relationship between self-efficacy and mathematical creativity than studies conducted in other countries.

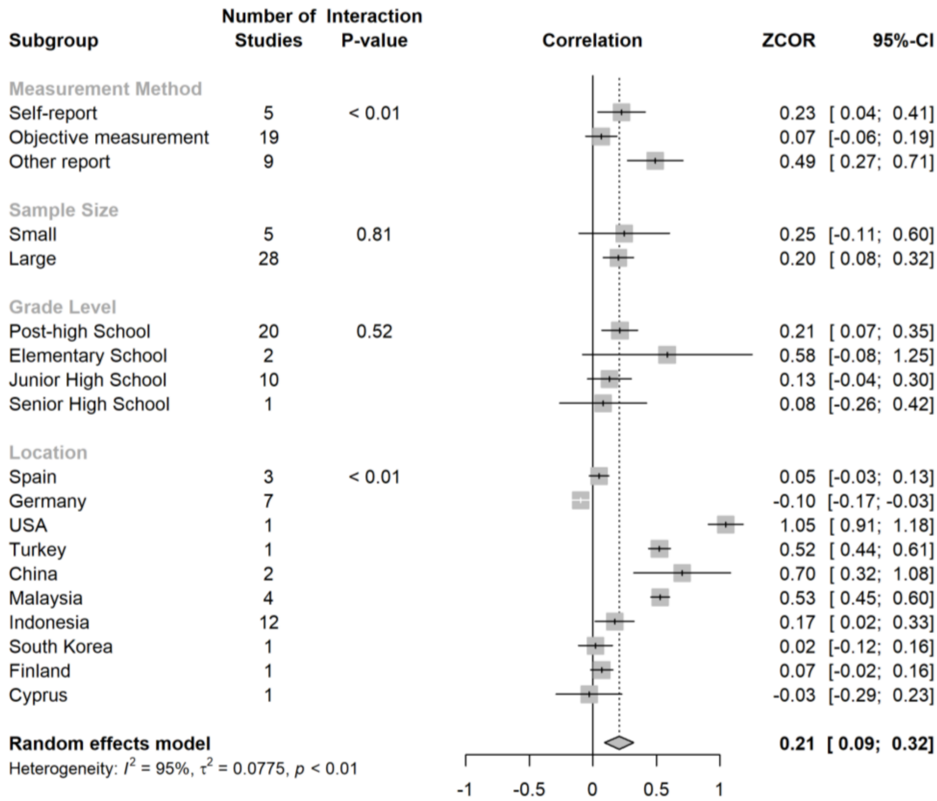

Figure 4. Forest plot of effect size on moderator variable.

Despite attempts to reduce heterogeneity through this meta-regression, residual heterogeneity remains substantial ($Q\ (32) = 1325.47; p < 0.01,\ \tau^2 = 0.0775,\ I^2 = 95\%$). This means that there is a large variation in the strength of the relationship between self-efficacy and mathematical creativity across the studies analyzed. This variation suggests that factors not considered in this meta-regression analysis may play a role in moderating the relationship between self-efficacy and mathematical creativity. Future research is needed to identify factors that may explain the variation in the relationship between self-efficacy and mathematical creativity.

5. Discussion

The combined effect estimation in this meta-analysis used a random effect model using R software version 4.3.0 to explore the relationship between self-efficacy and mathematical creativity. This model represents the random effects model in the meta-analysis. The selection of this model is an attempt to obtain a more accurate estimate under conditions of significant heterogeneity ($Q\ (32) = 1325.47;\ p < 0.01,\ \tau^2 = 0.1079,\ I^2 = 98\%$). The test results showed that the estimated overall effect size indicated a significant positive relationship between self-efficacy and mathematical creativity ($z = 3.51; 95\%\ CI[0.09, 0.32]$, $p < 0.001$). The measure of influence of self-efficacy on mathematical creativity is included in the low category ($r_e = 0.21$).

These findings align with the perspective that self-efficacy is an independent contributing factor to students' mathematical solving abilities [76]. Mathematical self-efficacy is a strong predictor of mathematical creativity and problem-solving performance among students [13]. The results of their research show that along with increasing self-efficacy, so does the ability to engage in creative problem-solving, so confidence is needed in fostering students' creativity. In addition, other findings also support the idea that teachers' self-efficacy can influence their creative teaching practices, which in turn has an impact on students' creativity [50]. This confirmed that self-efficacy affects individual students and extends to educators, creating an environment conducive to creative thinking. Creative self-efficacy has been shown to predict the relationship between teaching responsiveness and creativity, suggesting that a supportive educational environment increases students' self-efficacy and subsequently impacts their creative outcomes [1]. In addition, emotional intelligence and self-efficacy are interconnected, with self-efficacy serving as a mediator that improves creative performance among gifted children [77].

Although self-efficacy has a significant relationship with mathematical creativity, this component is not the main factor affecting a person's creative ability. It is justified by the social cognitive theory that self-efficacy is not related to the skills a person possesses, but rather to an assessment of what a person can achieve with those skills [78]. Self-efficacy is a personal construct that can influence and be influenced by behavior and social or environmental variables [79]. In some cases of mathematics learning, self-efficacy would be more appropriate to be used as a predictor variable to mediate the learning approach to student ability [34,69,80]. In this case, it is also important to understand that although general self-efficacy in mathematics is an important factor in predicting various academic outcomes, it may not always serve as the best predictor of mathematical creativity. This difference arises from the difference between general self-efficacy and special self-efficacy, especially in the context of mathematical tasks. General creativity and mathematical ability contribute to mathematical creativity, but the relationship is clearer when specific mathematical skills are considered [26]. In addition, the role of cognitive and affective factors in mathematical creativity cannot be ignored, emphasizing the importance of cognitive components (such as fluency and flexibility) and affective components (such as self-efficacy and attitude) in fostering mathematical creativity [29]. Therefore, these important findings can be used as a basis for consideration for educators and researchers in the factor of self-efficacy in learning. In practical terms, these findings mainstreamed the presentation of self-efficacy in regression studies as a predictor variable. The accuracy of self-efficacy in mediating mathematical creativity as a dependent variable depends on the purpose of measurement and the context in which creativity performance is measured.

Overall, the findings on the relationship between self-efficacy and mathematical creativity in this study have accurately reflected the literature analyzed. The Egger test confirms the absence of significant evidence to support publication bias ($t = -0.03$; $p = 0.978$). The massive Fail-safe N value ($FSN = 5101$; $p < 0.001$) indicates that even if numerous unpublished studies existed, they would not significantly alter the overall conclusions drawn from this meta-analysis [13,50]. This stability in findings reinforces the assertion that self-efficacy is a vital component in the development of mathematical creativity, providing a solid foundation for future research and educational practices aimed at enhancing both self-efficacy and creativity in mathematics education.

In addition to the above findings, this meta-analysis also evaluates factors that can potentially influence the size effect of the relationship between self-efficacy and mathematical creativity, including measurement method, sample size, grade level, and country where the study was implemented. The subgroup difference test revealed two variables that showed significant results: measurement method variable ($Q = 11.17$; $df = 2$; $p = 0.0038$) and study location ($Q = 372.41$, $df = 9$; $p < 0.0001$). These findings show that the relationship between self-efficacy and mathematical creativity is influenced by several factors, namely the mathematical creativity measurement method and study location. This result is confirmed by previous research that shows that measuring the mathematical creativity method has a significant influence on the strength of relationships with other variables [9]. This is consistent with the findings that highlight that the use of assessment procedures, such as changing the number of tasks or raters, can affect the quality of creativity assessment [81]. The number of raters (e.g., two or three) is sufficient to obtain a reliable score for making relative decisions [82]. In addition, the findings regarding the influence of study location on the relationship between self-efficacy and mathematical creativity are in line with research that emphasizes the role of culture and social context in influencing self-efficacy and creativity [83]. Moreover, the culture and values embraced in a country can affect students' perception of self-efficacy and creative behavior [84–86]. However, it should be noted that although the measurement method and study location showed a significant influence on the interaction between self-efficacy and mathematical creativity, the significant residual heterogeneity of this meta-regression $\left(Q\ (32) = 1325.47; p < 0.01,\ \tau^2 = 0.0775,\ I^2 = 95\%\right)$ indicates the need for further research to identify other factors that may explain the variation in the relationship between self-efficacy and mathematical creativity. Further research may consider factors such as individual characteristics, sociocultural context, and the learning design used in the analyzed study. By understanding the factors that cause heterogeneity, we can develop more effective educational interventions to improve self-efficacy and mathematical creativity in students.

Although this meta-analysis provides a deeper understanding of the relationship between self-efficacy and mathematical creativity, some limitations need to be considered. This analysis only focuses on the moderating factors identified in the studies analyzed, so there may be other factors not considered in this analysis that may influence the relationship between self-efficacy and mathematical creativity. In addition, this analysis is based on the data available in the studies analyzed, so the quality and diversity of the data used in this analysis may affect the results and conclusions obtained. Moreover, this analysis only shows the relationship between self-efficacy and mathematical creativity; it cannot prove causality. Further research is needed to test the causality of the relationship between self-efficacy and mathematical creativity; for example, by using experimental or longitudinal studies.

These limitations indicate that the results of this meta-regression analysis need to be interpreted with caution. The results of this analysis cannot be considered absolute evidence and further research is still needed to confirm these findings and examine other factors that may influence the relationship between self-efficacy and mathematical creativity. The significant heterogeneity in this study suggests the need for further research to identify factors that may explain variation in the relationship between self-efficacy and mathematical creativity. Future research should explore additional factors that might moderate the relationship between self-efficacy and mathematical creativity, such as gender, cultural background, socioeconomic status, and different teaching methodologies. Nevertheless, this analysis provides valuable information for further research and can help in the development of more effective educational programs to improve students' self-efficacy and mathematical creativity.

Additionally, intervention studies designed to enhance self-efficacy and assess their impact on mathematical creativity should be conducted. Experimental designs with control groups can provide stronger evidence of causality. Educational policymakers should consider these findings when developing curricula, emphasizing a balanced focus on both cognitive skills and affective factors like self-efficacy. Professional development programs for teachers could include training on fostering self-efficacy, potentially promoting greater creativity and innovation in mathematics.

6. Conclusions

There was a significant positive association between self-efficacy and mathematical creativity. The measure of influence of self-efficacy on mathematical creativity is included in the low category. These findings mainstreamed the presentation of self-efficacy in regression studies as a predictor variable. Statistically, the findings of this meta-analysis are very stable and unlikely to be significantly affected by the potential for unpublished studies. The measurement method and study location factors show a significant influence on the relationship between self-efficacy and mathematical creativity. The results of this meta-analysis contribute to current theoretical frameworks in education and psychology by providing empirical evidence for the relationship between self-efficacy and mathematical creativity. The findings suggest that self-efficacy, as a key affective factor, plays a significant role in shaping students' creative mathematical abilities. This aligns with social cognitive theory, which emphasizes the role of self-beliefs in influencing behavior and performance. The study also suggests the need for further exploration of the complex interplay between self-efficacy and other factors, such as learning approaches and specific contexts, to fully understand this relationship. The findings of this meta-analysis have significant implications for educators and policymakers. The positive correlation between self-efficacy and mathematical creativity suggests that fostering self-efficacy in students can be an effective strategy for promoting mathematical creativity. This can be achieved through various interventions, such as implementing self-efficacy-enhancing strategies in classrooms, developing teacher training programs that focus on promoting self-efficacy and integrating cognitive and affective development goals in curriculum design. This meta-analysis highlights the need for further research to explore the relationship between self-efficacy and mathematical creativity in greater depth. Future research should investigate the mediating and moderating effects of various factors, examine the role of self-efficacy in different mathematical domains, and develop and test interventions designed to enhance self-efficacy and mathematical creativity in students. This study provides a foundation for future research and practice in fostering mathematical creativity and self-efficacy in students. By understanding the relationship between these two constructs, educators and policymakers can develop effective strategies to enhance students' mathematical abilities and prepare them for success in the 21st century.

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