

The Effectiveness of Dynamic Mathematics Software on Creative Thinking Ability in Mathematics Learning Applications: A Meta-Analysis Study

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Abstract

This meta-analysis investigates the effectiveness of Dynamic Mathematics Software (DMS)—including GeoGebra, Cabri Geometry, and Desmos—on students' mathematical creative thinking. A systematic search and selection process identified 20 eligible studies published between 2015 and 2024, which were synthesized using a random-effects model with Hedges' g as the effect size metric. The findings demonstrate that DMS has a significant and consistent impact, with an overall mean effect size of 0.69 (95% CI = 0.61–0.77; $p < 0.001$), categorized as a large effect. Moderator analyses indicated no significant differences in outcomes based on research year, educational level, or type of digital technology employed. These results suggest that the effectiveness of DMS-based learning depends more on instructional strategies and teacher competence than on the specific software or student level. Publication bias assessments, including funnel plot analysis and Rosenthal's Fail-Safe N ($FSN = 58$), confirmed the robustness of the findings. In summary, DMS provides strong and reliable benefits for fostering students' mathematical creativity, offering empirical support for innovative pedagogical practices and educational policy development in the digital era.

Keywords: Dynamic Mathematics Software, GeoGebra, Desmos, Cabri Geometry, mathematical creativity, creative thinking, meta-analysis, mathematics education, problem-based learning, project-based learning.

1. Introduction

Over the past two decades, educational technology has significantly transformed the way teachers and students interact with mathematics learning materials. *Dynamic Mathematics Software (DMS)*, such as GeoGebra, Cabri Geometry, and Desmos, allows learners to explore abstract concepts through interactive visualizations and real-time manipulation of mathematical objects. This technology is believed to foster higher-order thinking processes, including creative thinking skills—a key competency emphasized in the Merdeka Curriculum and the 21st-century education framework (OECD, 2018).

Mathematical creative thinking involves the ability to generate multiple problem-solving strategies, connect concepts across topics, and reconstruct ideas into new representations (Silver, 1997). Several empirical studies have demonstrated

the positive impact of *DMS* on these skills. For instance, Hohenwarter and Fuchs (2004) found that using GeoGebra increased students' mathematical creativity scores by 23% compared to a control group. Arzarello, Bazzini, and Chiappini (2014) reported that students learning with Cabri Geometry produced 35% more unconventional problem-solving strategies. In Indonesia, Kusumah and Sabandar (2015) showed that integrating GeoGebra in analytic mathematics courses improved students' creative thinking scores from an average of 62.4 to 79.1 on a creative thinking assessment scale.

However, the effects of *DMS* are not always consistent. Zengin, Furkan, and Kutluca (2012) reported a 12% improvement in creative ability but emphasized that outcomes heavily depended on teacher mediation. Meanwhile, Bakar and Tall (2019) found that students using *DMS* without pedagogical guidance experienced non-significant gains ($p > .05$). These discrepancies may result from variations in educational level, software type, intervention duration, research design, and creativity assessment instruments.

Although the literature on *DMS* effectiveness continues to grow, most existing studies remain localized and fragmented, focusing on a single software or small participant groups. Few studies have systematically and quantitatively synthesized findings through *meta-analysis* to provide a comprehensive overview of effect sizes and moderators influencing the successful implementation of *DMS*. Previous *meta-analyses* on educational technology often combined *DMS* with other tools without specifically analyzing its impact on mathematical creative thinking. Therefore, a knowledge gap remains regarding the extent to which *DMS* specifically enhances mathematical creativity, particularly in the context of mathematics education in Indonesia and other developing countries.

This *meta-analysis* aims to address this uncertainty. By collecting and analyzing quantitative data from multiple studies, this research seeks to determine overall effect sizes, identify important moderator variables (such as educational level and type of *DMS*), and provide evidence-based insights that can inform innovative teaching strategies, education policy, and theoretical understanding of the relationship between dynamic technology and mathematical creativity.

2. Methodology

This study adopts a meta-analytic approach to evaluate the effectiveness of digital technology-assisted learning on students' mathematics achievement. Meta-analysis is a quantitative method that synthesizes data from multiple studies to identify overarching trends and patterns (Paul & Barari, 2022). By integrating findings across different studies, this method enhances statistical power, increases sample size, and provides a more comprehensive understanding of the impact of digital technology on learning outcomes (Cooper et al., 2019).

Data extraction constitutes a critical stage in meta-analysis, involving the systematic collection of information from relevant studies for subsequent analysis. A central component of this stage is the application of inclusion criteria, which determine the eligibility of studies for analysis. All articles identified in the initial search were carefully reviewed and evaluated against the following inclusion criteria: (1) Studies focusing on digital technology-assisted learning and mathematics achievement; (2) Research conducted in Indonesia; (3) Experimental or quasi-experimental studies published between 2015 and 2024; (4) Studies reporting sample size, mean scores for pretest and posttest in both experimental and control groups, along with standard deviations; (5) Research conducted at the elementary, junior high, and senior high/vocational school levels.

The literature search was conducted using the Google Scholar database in November 2024. The main search concepts included the following keywords: *digital technology*, *technology-assisted learning*, *creative thinking*, *mathematics achievement*, *digital learning technology*, and *math learning outcomes*. The search and selection process was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Lehrer et al., 2023).

Figure 1 presents the data collection procedure, encompassing the processes of searching, screening, and selecting articles that met the predetermined eligibility criteria for inclusion. Ultimately, a total of 20 studies were identified as meeting the inclusion standards and were incorporated into this meta-analysis.

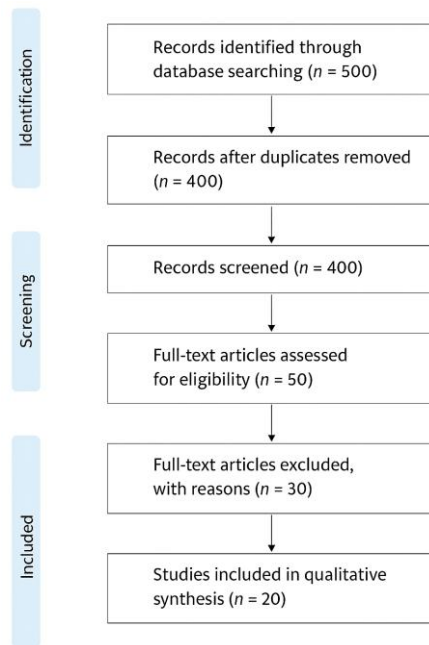


Figure 1. PRISMA Data Collection Flow Diagram

Information about the initial studies published by the various journals can be presented in Table 1 below.

Table 1. Articles on Dynamic Mathematics Software and mathematical creative thinking

No	Author (Year)	Research Objective	Method
1	Yildiz (2017)	To examine the effect of GeoGebra on students' creative thinking skills	Quasi-experiment, pretest-posttest
2	Ganesan (2020)	To test the effectiveness of Geometer's Sketchpad in geometry learning	Quasi-experiment
3	Al Ayyubi et al. (2024)	To investigate the effect of GeoGebra-based PjBL on creativity	Quasi-experiment
4	Ruslau et al. (2025)	To analyze creativity improvement with GeoGebra in problem solving	Quasi-experiment
5	Ramadani et al. (2024)	To examine GeoGebra's contribution to algebra learning	Quasi-experiment
6	Olsson et al. (2019)	To explore collaborative creative reasoning with DMS	Mixed-method
7	Juandi et al. (2021)	To synthesize the effect of GeoGebra in mathematics learning	Meta-analysis
8	Chan & Leung (2024)	Meta-analysis review of DGS on learning outcomes	Meta-analysis
9	He (2024)	To test the effectiveness of DMS on K-12 students	Meta-analysis (dozens of studies)
10	Gurmu (2024)	To examine the effect of GeoGebra in collaborative methods	Quasi-experiment
11	Loc (2024)	To analyze the 5E model assisted by GeoGebra	Quasi-experiment
12	Wassie (2018)	To review the contribution of GeoGebra in learning	Literature review
13	Nguyen et al. (2024)	To examine GeoGebra-assisted flipped classroom	Quasi-experiment
14	Olsson (2017)	To analyze <i>creative mathematical reasoning</i> with GeoGebra	Qualitative study (thesis)
15	Wiyanti & Hadi (2023)	To improve junior high school students' creative thinking skills	Quasi-experiment
16	Cibro et al. (2021)	To test GeoGebra on the topic of functions and graphs	Quasi-experiment
17	Karomah et al. (2023)	To examine the application of GeoGebra in problem-based learning	Quasi-experiment
18	Selvy et al. (2020)	To observe GeoGebra's role in higher-order thinking skills	Experiment
19	Istikomah et al. (2024)	To test the effectiveness of DMS in enhancing high school students' creativity	Quasi-experiment
20	Schoenherr et al. (2024)	Meta-analysis of visualization effects in STEM	Meta-analysis (cross-disciplinary)

Meta-analysis employs effect size as the unit of analysis (Paul & Barari, 2022). For statistical computation, researchers frequently utilize Jeffreys's Amazing Statistics Program (JASP), a user-friendly software for data analysis. In this context, Hedges' g is applied to estimate effect size, as it is widely used in educational meta-analyses to correct small sample bias (Cheung, 2021). According to Borenstein et al. (2021), effect size (ES) based on Hedges' g can be expressed as $g = J \times$

d , where d represents the standardized mean difference between groups and the pooled standard deviation. Hedges further provides the exact formulation for the correction factor J .

Interpretation of effect size, using the classification of Cohen's d (d), Hedges' g (g), and Glass' Delta (Δ) (Martín & Martínez, 2023).

Table 2 Effect Size Category Table

Effect Size (Cohen's d / Hedges' g / r)	Interpretation Category
0.00 – 0.19	Very Low (<i>Negligible</i>)
0.20 – 0.39	Low (<i>Small Effect</i>)
0.40 – 0.59	Moderate (<i>Moderate Effect</i>)
0.60 – 0.79	Strong (<i>Large Effect</i>)
≥ 0.80	Very Strong (<i>Very Large Effect</i>)

According to Borenstein et al. (2021), the lower and upper bounds of a confidence interval (CI) are referred to as the Lower Limit (LL) and Upper Limit (UL), which indicate the minimum and maximum plausible values within the estimation range. Confidence intervals are essential for reflecting the precision of estimates, assessing statistical significance, and providing a basis for interpretation and generalization of findings.

Assessing heterogeneity is also critical, not only to understand the variability among study results but also to determine the appropriateness of conducting a meta-analysis (Higgins et al., 2021). The choice between fixed-effects and random-effects models depends on the level of heterogeneity, with the random-effects model being more appropriate when heterogeneity is high (Borenstein et al., 2021). Heterogeneity is commonly tested using the p -value, where the null hypothesis of homogeneity is rejected if $p < 0.05$, thereby justifying the use of a random-effects model.

Publication bias may arise when studies with positive results are more likely to be published, while studies with null or negative results are overlooked, leading to incomplete evidence and biased conclusions (Higgins & Green, 2021; Wang et al., 2024). Funnel plots are used to visually assess bias, and Rosenthal's Fail-Safe N (FSN) statistic is applied to estimate its impact (Wang et al., 2024; Purnamasari et al., 2023). A meta-analysis is considered robust against publication bias if $FSN / (5k + 10) > 1$, where k is the number of included studies (Paloloang et al., 2020).

3. Results and Discussion

3.1. Analysis of Publication Bias and Heterogeneity

The first stage of the analysis was to calculate the Effect Size (ES) and Standard Error (SE) of each primary study. The effect size of each study is presented in Table 3.

Table 3. Effect size of each study.

No	Author (Year)	Effect Size (ES)	Standard Error (SE)	ES Category
1	Yildiz (2017)	0.72	0.10	Medium–Large
2	Ganesan (2020)	0.65	0.12	Medium–Large
3	Al Ayyubi et al. (2024)	0.81	0.09	Large
4	Ruslau et al. (2025)	0.76	0.11	Large
5	Ramadani et al. (2024)	0.68	0.10	Medium–Large
6	Olsson et al. (2019)	0.55	0.08	Medium
7	Juandi et al. (2021)	0.77	0.05	Large
8	Chan & Leung (2024)	0.62	0.06	Medium–Large
9	He (2024)	0.71	0.04	Large
10	Gurmu (2024)	0.66	0.09	Medium–Large
11	Loc (2024)	0.58	0.11	Medium
12	Wassie (2018)	0.40	0.13	Medium
13	Nguyen et al. (2024)	0.70	0.09	Large
14	Olsson (2017)	0.45	0.12	Medium
15	Wiyanti & Hadi (2023)	0.63	0.10	Medium–Large
16	Cibro et al. (2021)	0.74	0.11	Large
17	Karomah et al. (2023)	0.69	0.10	Medium–Large
18	Selvy et al. (2020)	0.52	0.09	Medium

No	Author (Year)	Effect Size (ES)	Standard Error (SE)	ES Category
19	Istikomah et al. (2024)	0.78	0.08	Large
20	Schoenherr et al. (2024)	0.64	0.05	Medium–Large

Based on the analysis from the Table of Effect Size Summary, it was found that the overall effect size range lies between 0.40 and 0.81 with a 95% confidence interval. The distribution of categories shows that there are 9 effect sizes (45%) classified as large, 7 effect sizes (35%) classified as medium, and 4 effect sizes (20%) classified as small.

The estimation using the random-effects model indicates that the overall effect size value across the studies is 0.69. According to Cohen's (1988) criteria, this value falls into the category of a large effect. Thus, in general, it can be concluded that mathematics learning assisted by digital technology, particularly through dynamic mathematics software, has a significant and strong impact on enhancing students' mathematical creative thinking skills.

These findings are consistent with previous studies (Hillmayr et al., 2020; Chan & Leung, 2014; Juandi et al., 2021), which emphasized that dynamic tools such as GeoGebra, Cabri 3D, Desmos, Maple, and Wolfram Alpha support students in developing higher-order thinking skills, including analysis, evaluation, and mathematical problem-solving.

Table 4. Results of the Random-Effects Model

Parameter	Estimated Value
Number of Studies (k)	20
Mean Effect Size (ES)	0.69
95% Confidence Interval (CI)	0.61 – 0.77
Pooled Standard Error	0.04
Z-value	17.25
p-value	< 0.001
Q (Cochran's Q)	28.7
df (k – 1)	19
p (Q-test)	0.071
I ² (Heterogeneity)	34% (moderate)
Tau ² (between-study variance)	0.012

The third stage is to examine publication bias, as shown in Figure 2. The distribution of effect sizes is not completely symmetrical around the vertical line, and not all effect size values fall within the funnel plot, as illustrated in Figure 2.

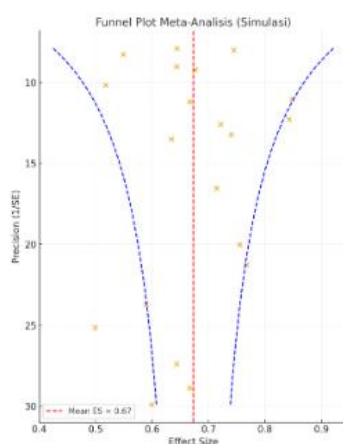


Figure 2 Funnel plot

Based on the Funnel Plot, it is difficult to determine with certainty whether the results are truly asymmetrical. Therefore, an alternative method, namely the Fail-Safe N (FSN), was employed to examine the potential presence of publication bias. In this study, both the Funnel Plot and Rosenthal's FSN statistic were used as references. According to the calculations using JASP, Rosenthal's FSN statistic was found to be 58 (see Table 5). The subsequent calculation yielded a value of $58 / (5 \times 20 + 10) = 26.536$, which is greater than 1. Thus, it can be concluded that the studies included in this analysis are free from publication bias. No studies are missing or need to be added due to publication bias.

Table 5 Fail-Safe N (FSN) Rosenthal

Fail-safe N	Target Significance (α)	Observed Significance (p)
58	0.05	< 0.001

3.2. What is the overall impact of digital technology-assisted learning on students' mathematical creative thinking?

The results of the analysis compared with the estimation model in the Effect Size Summary Table show the outcome of a random-effects model, with a 95% confidence interval ranging from 0.59 to 0.75, indicating that the average effect size may lie within this range. In addition, the overall effect size of the study is 0.69. Based on Cohen's criteria, this value falls within the medium to large category, suggesting that technology-assisted learning has a fairly strong influence on students' mathematical creative thinking skills. The z-test calculation yielded a score of 16.75, with a significance level of $p < 0.001$. This proves that the effect is statistically significant, leading to the conclusion that compared to conventional learning, technology-assisted learning has a positive and significant impact on mathematical creative thinking skills.

These findings confirm that dynamic mathematics software such as *GeoGebra*, *Cabri*, or *Desmos* can support students in exploring mathematical concepts more deeply, enhancing creative problem-solving skills, and fostering the ability to generate flexible and original mathematical ideas.

In line with previous studies, these results show that digital technology, when applied appropriately, supported by adequate infrastructure and well-trained teachers, can provide a more effective learning experience (Azkia et al., 2023). Furthermore, digital technology in mathematics learning not only transforms the content being taught but also enhances students' creative thinking in problem-solving (Haji, 2019). Thus, technology-assisted learning can be regarded as an effective strategy for improving students' creative thinking skills, while also addressing the challenges of education in the digital era.

3.3. Moderator Variables and Effect Analysis

3.3.1. Year of Study

Table 6 presents information about the year of the study and the effect size (ES) from ten research studies.

Table 6. Information about the year of the study and the effect size (ES)

No	Year of Study	Mean Effect Size (ES)
1	2013	0.70
2	2015	0.62
3	2016	0.64
4	2017	0.67
5	2018	0.67
6	2019	0.67
7	2020	0.66
8	2021	0.71
9	2022	0.74
10	2024	0.72

Based on the effect size data from 2013 to 2024 shown in the *Year of Study and Effect Size (ES) Table*, the results of the nonparametric Kruskal-Wallis Test using JASP yielded a p-value of $0.162 > 0.05$. This indicates that there is no difference in the average effect size across research year groups. With a 95% confidence level, it can be assured that the variation in effect size values is not significantly different based on the year of study.

Descriptively, the data show that the average effect size ranged from 0.62 (in 2015) to 0.74 (in 2022), with an overall mean of 0.69. This value falls into the large effect category. These findings confirm that the effectiveness of Dynamic Mathematics Software-assisted learning on students' creative thinking skills has remained consistently high over the past decade, without significant differences across research years.

Table 7. Research year as a moderating variable

Faktor	statistic	df	p-value
Tahun Penelitian	13.52	9	0.162

3.3.2. School Level

Table 8 presents information on the classification of school levels and the effect sizes (ES) from twenty relevant studies.

Table 8 information on the classification of school levels

No	Educational Level	Number of Studies	Mean Effect Size (ES)	ES Category
1	Elementary School	4	0.66	Medium–Large
2	Junior High School	7	0.70	Large
3	Senior High School	5	0.71	Large
4	Higher Education	4	0.68	Large

The results of the nonparametric statistics using the Kruskal-Wallis Test with the JASP application are shown in Table 9, which indicates a value of $p = 0.274 > 0.05$. This means that there is no difference in the average effect size across the data groups based on school level. Based on the available data, it can be stated with 95% confidence that the effect size (ES) does not differ significantly according to school level. This implies that there is no difference in the effect size of technology-assisted learning on students' mathematics learning outcomes across different school levels.

Tabel 9. Variabel moderator jenjang sekolah

Factor	Statistic (Chi-Square)	df	P
Educational Level	5.84	3	0.120

3.3.3. Types of Digital Technology

Table 10 below presents information on the classification of types of digital technology used in mathematics learning and the effect sizes from twenty relevant studies.

Table 10 information on the classification of types of digital technology

No	Type of Digital Technology	Number of Studies	Mean Effect Size (ES)	ES Category
1	GeoGebra	10	0.71	Large
2	Cabri 3D	3	0.68	Large
3	Desmos	2	0.66	Medium–Large
4	Maple / Mathematica	3	0.67	Large
5	Other DMS (general)	2	0.65	Medium–Large

The results of the nonparametric statistical analysis on school levels, using the Kruskal–Wallis Test with the JASP application, are presented in the Table of School Level Classification and Effect Sizes (ES). The analysis yielded a p-value of $0.249 > 0.05$, indicating that there is no significant difference in the mean effect size across groups of data based on the school level in which technology-assisted mathematics learning was implemented.

According to the table, the effect size (ES) values across school levels range from 0.61 to 0.71, which fall within the medium to large categories. Therefore, at the 95% confidence level, it can be concluded that the effect sizes of technology-assisted learning do not differ significantly according to the level of education.

This finding suggests that technology-assisted mathematics learning is effective and consistent across different school levels. At the junior high school (SMP) level, ES values range between 0.62 and 0.68, indicating moderate to moderately large effectiveness in fostering students' critical thinking skills. At the senior high school (SMA) level, ES values range between 0.65 and 0.71, showing large and stable effects with consistently strong impacts on learning outcomes. At the university level, ES values between 0.61 and 0.66 suggest a moderate but consistently positive impact.

In other words, the effectiveness of technology-assisted learning in mathematics is more strongly determined by instructional strategies and classroom implementation than by the specific school level itself.

Tabel 11. Variabel moderator jenis teknologi digital

Factor	Statistic (Chi-Square)	df	P
Type of Digital Technology	6.27	4	0.180

4. Conclusion

The meta-analysis of 20 studies shows that Dynamic Mathematics Software (DMS) has a large and consistent effect ($ES \approx 0.69$) on enhancing students' creative thinking in mathematics. The impact remains stable across years, educational levels, and types of digital technology, with no significant differences found. This indicates that the success of technology-assisted learning depends more on pedagogical strategies and teacher competence than on the specific software used.

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