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Examining the effectiveness of a GeoGebra-assisted open-ended approach on students' mathematical creative thinking ability

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Abstract

Researchers use open-ended as a learning method to help students improve their math skills. Each open investigation of mathematical knowledge produces mixed results for components of mathematical ability, each school level, and the content taught. There are more and more studies on open-ended questions nowadays. This study tested the effectiveness of the open-ended approach assisted by GeoGebra on students' mathematical creative thinking abilities. The use of meta-analysis techniques is to analyze the effect (effect size) of a preliminary study. The instruments used were coding protocol sheets and coding sheets/Comprehensive Meta-Analysis (CMA) programs to analyze data. The resulting findings are that there are differences in the research method with the most significant effect size in the quasi-experimental research method, the research year with the most significant effect size in the 2012-2022 research year, indexing journals with the most significant effect size on web indexing scientific journals; the type of publication that has the most critical influence on the kind of thesis publication. Furthermore, the GeoGebra-assisted open-ended approach to creative thinking ability has no significant effect when viewed from the research characteristics of the sample size and level of education.

Keywords: GeoGebra; meta-analysis; open-ended approach; mathematical creative thinking ability

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Introduction

The ability to think creatively can be defined as the capacity to generate multiple ideas to solve problems (Widiana et al., 2017). Formulating ideas stems from managing information and engaging in novel activities (Maharani, 2017). There are multiple indicators of students' creative thinking (Bacanli et al., 2011; Puspitasari et al., 2019). The first indicator is fluency, where students can generate many ideas. The second indicator is flexibility, where students offer different approaches to problem-solving and can tackle problems from various perspectives. Additionally, the authenticity indicator entails students being able to examine their concerns freshly. The final indicator is detailed. In this aspect, students provide comprehensive and meticulous responses, and the steps taken to solve problems are articulated clearly and accurately (Sowden et al., 2015; Sugianto et al., 2018).

Creativity is another term for the ability to think creatively, contributing to advancing mathematics (Siraman & Lee, 2011; Yoni Sunaryo, 2014). Student creativity can grow and develop when mathematics learning activities employ the appropriate learning approach (Saefudin, 2012). An open-ended approach can foster the development of mathematical creative thinking abilities among the various learning approaches (Fatah et al., 2016). The problems presented in the open-ended approach are non-routine and open-ended problems. These open-ended problems can be classified into three types: solving open-ended problems, methods for generating solutions to open-ended problems, and the outcomes produced open-ended (Shimada & Becker, 2005). In addition to selecting the appropriate learning approach, it is essential to incorporate ICT-assisted learning media. One such media that plays a vital role in developing creative thinking ability is GeoGebra (Sugandi et al., 2015). GeoGebra offers several benefits in various mathematics learning activities as a medium for demonstrating, visualizing, and constructing abstract concepts (Hohenwarter & Fuchs, 2005). Through GeoGebra, teachers can create an interactive learning environment to enable students to experiment independently and discover mathematical concepts (Siswanto & Azhar, 2018).

Over time, research has been conducted to examine the effectiveness of the open-ended approach in developing mathematical creative thinking abilities with the assistance of GeoGebra. Several studies have demonstrated a significant impact on creative thinking abilities when employing an open-ended approach assisted by GeoGebra, compared to conventional learning methods (Fatah et al., 2016; Sugandi & Bernard, 2020; Yuniarti et al., 2017). On the other hand, research indicates that the open-ended approach assisted by GeoGebra may not significantly impact mathematical creative thinking abilities (Lestari et al., 2019). Based on the findings of these studies, the results are inconsistent within the same research theme. Nevertheless, mathematics teachers seek accurate information as a foundation for decision-making when implementing the open-ended approach with GeoGebra to enhance mathematical creative thinking skills.

Researchers can contribute precise details to teachers and policymakers by analyzing and synthesizing studies from conferences, articles, theses, and dissertations (Juandi et al., 2022; Moeyaert, 2019; Oh-Young et al., 2020). Meta-analysis is a crucial method for consolidating multiple studies to enhance the validity of findings from existing studies with consistent results

and to elucidate any divergent outcomes (Kot et al., 2018; Siegel et al., 2021). A meta-analysis study was conducted to summarize population data and investigate their impact (Lee, 2019; Tamur et al., 2020). Based on the issues mentioned above, it appears necessary to conduct a meta-analysis on the effectiveness of the open-ended approach in developing mathematical creative thinking abilities with the assistance of GeoGebra. Several researchers, such as have already studied this topic. However, previous studies have primarily focused on the field of natural sciences (In'nami & Koizumi, 2009). To date, more research needs to examine the ability to think creatively through an open-ended approach using meta-analytic studies. Therefore, this study aims to analyze, evaluate, and quantify the impact of employing an open-ended approach with GeoGebra on mathematical creative thinking skills. Additionally, the study seeks to investigate various study characteristics, including substantive factors (such as level of education, research methods, and sample size) and extrinsic factors (such as year of publication, journal indexing, and publication type).

Methods

In this study, the meta-analysis method was employed, involving the review of numerous articles published in national and international journals. Researchers analyzed primary studies that examined the impact of the open-ended approach on mathematical creative thinking skills with the assistance of GeoGebra. The stages of meta-analysis, as proposed by Borenstein et al., (2009), include establishing inclusion criteria for the studies under analysis, collecting empirical data, coding variables, and employing statistical techniques.

Inclusion criteria

To determine the eligibility of the studies, all articles obtained from the initial search were examined and evaluated based on the following inclusion criteria: (1) studies conducted between 2012 and 2022; (2) primary studies focusing on students at the elementary, junior high, or high school education levels; (3) articles published in international, national, or indexed SINTA journals or proceedings involving Indonesian authors; (4) inclusion of at least one experimental group using the open-ended approach and one comparison group using a conventional model as a control group; (5) availability of statistical data, including mean, standard deviation, sample size, t-value, and p-value.

Data collection

Relevant research articles were obtained through searches in SINTA (Science and Technology Index), Google Scholar, and IOP Publishing databases. The keywords used in "*pendekatan open-ended*", "*Kemampuan Berpikir Kreatif Matematis*", or"open-ended approach" are creative thinking ability. This stage yielded 115 articles published between 2012 and 2022. After applying the inclusion criteria, only 16 articles were eligible for analysis.

Two coders who specialize in meta-analytic research assessed the quality of the studies. The two coders coded and evaluated the studies using Microsoft Excel software, which were

then grouped on a consensus sheet. The coders will calculate the agreement using Cohen's kappa coefficient from De Raadt et al., (2019) with the assistance of SPSS. After going through the stage of assessing study quality, a total of 22 relevant studies were obtained. Table 1 presents the number of characteristics obtained from these 22 studies. The characteristics of studies numbered 1 to 3 are referred to as substantive, while characteristics of studies numbered 4 and 5 are considered extrinsic.

Table 1. Inclusion criteria

Study Characteristics	Groups	Number
Education level	Junior High School	12
	Senior High School	1
	University	3
Research method	Experiment	5
	Quasi Experiment	11
Sample size	≤ 30	8
	≥ 30	8
Year of publication	2012-2017	0
	2017-2022	16
Journal Indexing	Google Scholar	7
	IOP Publishing	1
	SINTA	6
	Web of Science	2
Publication Type	Journal	14
	Thesis	1
	Proceeding	1

Statistical analysis

The unit of analysis in meta-analysis is the effect size (Glass, 2015). In this study, the effect size serves as an index to measure the impact of the Open-ended approach on creative thinking, assisted by GeoGebra. The statistical procedures in research, as explained by Borenstein et al., (2009), consist of the following steps: (1) calculating the effect size, (2) conducting homogeneity tests and selecting estimation models, (3) examining publication bias, and (4) calculating the p-value for hypothesis testing. Once the estimation model is determined, random-effects analysis is performed to identify factors contributing to variations in effect size, such as the relationship between moderator variables (Haidich, 2010). The Comprehensive Meta-Analysis Program (CMA) is software used to assist in the data analysis process. The Hedge's g equation is employed by researchers to account for variations in sample sizes across studies, allowing for the determination of the effect size index. According to S. Sullivan & Feinn (2012), effect sizes are interpreted using Cohen's criteria: effect sizes below 0.2 are considered small, effect sizes between 0.2 and 0.5 are medium, effect sizes between 0.8 and 1.3 are significant, and effect sizes above 1.3 are substantial.

The heterogeneity test is conducted by validating the Q statistic and the p-value. If the p-value is less than 0.05, the null hypothesis, indicating homogeneity of effect sizes across studies, is rejected, and a random-effects model is chosen. The null hypothesis is accepted if the p-value

is more significant than 0.05 and a fixed-effect model is employed. The random-effects model is used when analyzing the study's variation level, considering the specified variables.

To avoid misrepresentation of findings, a publication bias check is performed. Meta-analyses tend to include more published studies than unpublished ones, leading to concerns about overestimated effect sizes (Borenstein et al., 2009; Tamur et al., 2020). To address this concern, funnel plots are examined to assess the potential bias, and Rosenthal's FSN statistic (Tamur & Juandi, 2020) is used to evaluate the impact of bias. If the distribution of effect sizes in the funnel plots shows symmetry around the vertical line, it indicates robustness against bias (Borenstein et al., 2009). However, Rosenthal's failsafe N statistic (FSN) is employed if the effect sizes are not symmetrically distributed. If FSN/((5k+10)> 1), where k represents the number of studies in the meta-analysis, it indicates the research is resistant to publication bias (Mullen et al., 2001).

Results

The meta-analysis study focuses on synthesizing relevant studies that examine the impact of the open-ended approach on mathematical creative thinking abilities with the assistance of GeoGebra. Electronic databases were searched using a combination of keywords, including "open-ended," "mathematical creative thinking," and " GeoGebra." Based on predetermined inclusion criteria, only 16 preliminary study articles met the criteria. Subsequently, coding and data extraction were conducted on these primary studies to gather the necessary information for the researchers. The data extraction process is crucial in statistics as it involves processing the effect size, which allows for describing the influence of the open-ended approach intervention on mathematical creative thinking ability.

The data extraction took place after the completion of the coding process, and it involved the researcher and two other raters to ensure coding reliability. Cohen's kappa statistic was used to assess the coding consistency, also known as interrater reliability (IRR). The results of interpreting agreement categories between the raters will be presented in Table 2.

Table 2. IRR test results with Cohen's Kappa

Data Items	Cohn's kappa (κ)	Category
Code	1	Very high
Citation	1	Very high
Mean Open-ended Approach	0.621	Height
Standard Open-ended Approach	0.727	Height
Sample Size of Open-ended Approach	1	Very high
Comparative Means	0.545	Medium
Standard Deviation of Comparison	0.909	Very high
Effect Size of Comparison	1	Very high
t-value	1	Very high
p-value	0.264	Low
Research Year	1	Very high
Level of Education	1	Very high
Sample Size	0.925	Very high
Publications Indexer	0.699	Height

Data Items	Cohn's kappa (κ)	Category
Publication Type	1	Very high
Research Methods	1	Very high

Table 2 shows ten items or the agreement level of the two coders with very high categories, three items in high categories, and 3 with low categories. From these results, the IRR test with Cohen's Kappa shows that all items in the coding are reliable. That way, the coding process is declared feasible for the next stage.

The next stage involved conducting a publication bias test on twenty-two studies. Figure 1 is a funnel plot depicting the effect sizes of the eleven studies.

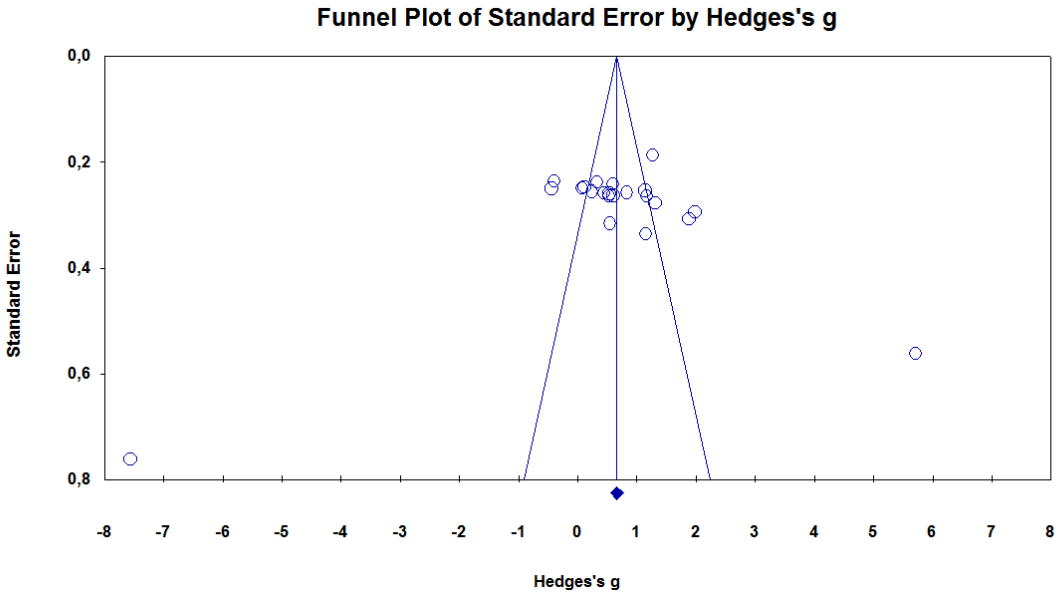

Figure 1. Effect size funnel plot

Figure 1 illustrates that the distribution of effect sizes spreads symmetrically on the left and right of the funnel diagram. However, when studied further, several effect sizes with positions deviate from the distribution of other effect sizes. As a result, the distribution of effect sizes could be more symmetrical. Therefore, it is necessary to carry out a publication bias test to maintain the results of the interpretation and analysis of funnel plots through the Trim and Fill test in Table 3.

Table 3. Trim and fill test results

	Studies Trimmed	Random Effect			Q Value
		Point Estimate	Lower Estimate	Upper Estimate	
Observed values		0.62976	0.18528	1.07425	315.28265
Adjusted values	0	0.62976	0.18528	1.07425	315.28265

Following are the results of the Trim and Fill test with the help of CMA 3.0 software. When conducting the test, the observed values (Observed values) and the results made by virtual effects (Adjusted values) obtain the same results. It is also seen that the number of

studies excluded is zero. Thus, this study did not identify publication bias, and no studies were excluded.

The next step involves determining the effect size model based on the heterogeneity test. The following are two possible effect size models in Table 4.

Table 4. Recapitulation of effect sizes by model

Model	Number	Effect Sizes	Heterogeneity			Test of null (2-Tail)	
			Q	Df	P	Z	P
Fixed effect	16	0.66	315.283	21	0.000	11.614	0.000
Random effect	16	0.62				2.777	0.005

Based on Table 4, a value of 315.283 is obtained. The value obtained is greater than the critical Q value, 32.6706, with 21 degrees of freedom in the χ table and $p < 0.05$; the effect size distribution has a homogeneous structure. The random effect model with an effect size of 0.62 is the estimation model used in sixteen various studies. Z value in Table 4 is 2.777 and $p < 0.05$; it can be concluded that there are significant differences in the implementation of the GeoGebra-assisted open-ended approach to creative thinking abilities compared to conventional approaches.

The next stage involves analyzing the characteristics of the study in each group. Two components are analyzed: substantive and extrinsic. Table 5 is an analysis of the study characteristics based on the substantive component.

Table 5. Analysis of substantive study characteristics

Study Characteristics	Group	N	Effect Size		Test of Null (2-Tail)		Heterogeneity		
			ES	SE	Z	P	Qb	Df(Q)	P
Education level	Junior High School	16	0.52	0.15	7.543	0.000	12.737	2	0.002
	Senior High School	3	0.88	0.06	-5.628	0.000			
	University	3	0.997	0.13	7.675	0.000			
Sample size	≤ 30	9	0.545	0.098	5.593	0.000	2.164	1	0.000
	≥ 30	13	0.722	0.070	10.277	0.000			
Research method	Experiment	6	0.424	0.109	3.876	0.000	7.047	1	0.008
	Quasi Experiment	16	0.765	0.068	11.265	0.000			

The first can be seen in Table 5 is that the effect size obtained at the junior high school level is 0.52 (moderate), high school is 0.88 (large), and university is 0.99 (large). The homogeneity value between group (Q_b) based on educational level is 12.737. Then, the critical Q with 2 degrees of freedom is 5.991. This means that there are differences in the study effect sizes. Differences in educational level moderated the variation in study effect sizes. Thus, there are differences in the effectiveness of the open-ended approach in the educational level

category. Second, the effect size obtained in the table above is based on the sample size group; the homogeneity value between groups (Q_b) is 2.164. Because the value obtained is smaller than the value of 3.8415 with a significance level of 0.05, there is no difference between the effectiveness of the open-ended approach according to sample size.

The next stage involves analyzing the characteristics of the study on the extrinsic component. Table 6 presents the analysis of the study characteristics of the extrinsic component.

Table 6. Characteristics of studies on extrinsic components

Study Characteristics	Group	N	Effect Size		Test of Null (2-Tail)		Heterogeneity		
			ES	SE	Z	P	Qb	Df(Q)	P
Year of publication	2012-2017	5	1.282	0.13	9.859	0.000	27.57	1	0.000
	2018-2022	17	0.520	0.064	8.078	0.000			
Journal Indexing	Google Scholar	10	0.509	0.090	5.629	0.000	29.05	3	0.000
	IOP Publishing	1	0.248	0.259	0.957	0.338			
	SINTA	9	0.639	0.090	7.132	0.000			
	Web of Science	2	1.445	0.161	8.971	0.000			
Publication Type	Journal	17	0.593	0.065	9.181	0.000	17.453	2	0.000
	Tesis	4	1.211	0.148	8.193	0.000			
	Proceeding	1	0.248	0.259	0.957	0.338			

Table 6 first presents two aspects of the year of publication: 2012-2017 and 2018-2022, regarding implementing the open-ended approach in the learning process. Based on the table, $Q_b = 27{,}575 > Q_{tabel} = 3{,}8415$. Therefore, there are significant differences in implementing the open-ended approach to creative thinking skills. Second, the study characteristics of journal indexers obtained a value of Q_b = 29.05. This value is higher than Q_b , which 7.8147, indicating significant differences in the implementation of the open-ended approach to creative thinking skills when considering the journal indexer. Third, the table above shows that the statistical value of homogeneity between groups (Q_b) is 7.047. The acquisition value is more significant than Q_{table}, namely 3.8415 and p> 0.05, so the characteristics of the study in terms of research methods illustrate that there are significant differences in the effectiveness of the open-ended approach to creative thinking skills. Lastly the table above provides study characteristics based on the publication type, including journals, theses, and proceedings. The value of $Q_b = 17{,}453$, while $Q_{tabel} = 5{,}9915$. This indicates that $Q_b > Q_{tabel}$, revealing significant differences in implementing the open-ended approach to creative thinking ability.

Discussion

Studies show that using an open-ended approach improves students' mathematical creative thinking abilities. One of the requirements for appropriate content to help students' mathematical creative thinking talents is to connect theory to real-world situations (Sabrina et

al., 2018). Students may think creatively and examine difficulties while adopting an open-ended learning method to identify solutions. This study's findings are consistent with previous research (Yulianti et al., 2020). They claimed that using an open-ended learning method improved students ' creative thinking abilities. Students will acquire more hands-on experience and opportunities to enhance their creative thinking abilities by using this method to study mathematics. Furthermore, incorporating statistical material into mathematics instruction enhances students' creative thinking skills and cultivates their analytical abilities (Fatah et al., 2016). Educators can foster a deeper understanding of mathematical concepts and their practical applications by presenting real-world data and encouraging students to explore patterns and draw conclusions. Additionally, an open approach to teaching statistics in mathematics empowers students to think creatively and independently, equipping them with problem-solving skills that extend beyond the classroom and into their future careers.

The open-ended approach can train students to reason and think creatively, where the teacher provides opportunities for students to learn actively. Students answer using their thinking to solve problems by developing analytical skills and managing existing information (Effect et al., 2016; Magelo et al., 2019; Wanelly & Fauzan, 2020). According to the analysis, the number of students in experimental groups using Open-Ended did not influence their opinions of the classes compared to students in control groups who received conventional instruction (Cahyani et al., 2019). That is, the impact of an Open-Ended method on students' perspectives remains constant regardless of sample size (Memon et al., 2020). This is supported by the results of research examining Open-Ended sample size, and it is underlined that Open-Ended may be used in groups when the sample size of the group is big or with individual studies when the sample size of the group is small.

There is a need for further research, such as moderator variable analysis, when a random effect size model is selected. Because it would indicate that individual studies are lower than meta-analysis studies (Jackson & Turner, 2017; Juandi et al., 2021). This is not in line with Maximus Tamur & Juandi (2020) that a sample size of less than 30 is more effective with a constructivist-based learning model. This finding contradicts the research conducted by Gürdogan-Bayir & Bozkurt (2018), which suggests that the year of publication has no significant effect on the conducted studies. Siddiq and Scherer (2019) and Suparman et al. (2021) also suggested differences in effect sizes based on the characteristics of publication indexers.

Conclusion

In this study, 16 studies demonstrated that implementing an open-ended approach significantly influenced students' mathematical creative thinking abilities, falling into the high-effect category. There are variations in the effect size of implementing the GeoGebra-assisted open-ended approach on creative thinking abilities when considering the research method, with the quasi-experimental research method showing the highest effect size; the research year, with the highest effect size observed in the 2012-2022 period; the journal indexer, with the web of science journal indexer showing the highest effect size; the type of publication, with the thesis

publication type exhibiting the highest effect size. Furthermore, the GeoGebra-assisted open-ended approach had no significant effect when considering the study characteristics of sample size and level of education.

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