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Open-Ended Approach for Critical Thinking Skills in Mathematics Education: A Meta-Analysis

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Abstract
There has been numerous research on developing students' critical thinking skills through an open-ended approach in mathematics education show conflicting results. Some research results implied a strong effect; others range from moderate to modest effect. This research aims to summarize and predict the implementation of an open-ended approach to critical thinking skills in mathematics education over the last five years. This research utilized a meta-analysis using the PICOS (Population, Interventions, Comparator, Outcomes, and Study Design) approach. The sample used in this research is studies published in the form of articles and proceedings as well as theses and dissertations. The databases are sourced from Google Scholar, Crossref, and Semantic Science using the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) method, which includes 14 primary studies found during 2018-2023 in Indonesia. The results are the implementations of an open-ended approach to improve critical thinking skills in mathematics education, shows an average of 1.44, which is included in the high category. Factors that influence the heterogeneity of effect sizes are study characteristics, such as sample size, year of publication, level of education, demographics, and publication type. The characteristics of the research that results in a large effect size value are an open-ended approach implemented in elementary schools, studies with a sample size of more than 30, studies that are published in 2018 and in journals, and implementation of the approach in regencies.

Keywords: open-ended approach, critical thinking skills, mathematics education, meta-analysis

1. Introduction

Indonesia as a member of ASEAN should contribute to the success of the AEC (ASEAN Economic Community), an ASEAN economic integration To enhance economic stability within the ASEAN region before the free trade agreement between ASEAN countries. One factor that can promote the success of AEC is education (Warsono, 2017). Education aims to maintain, improve, and develop all the potential that exists within a person (Burns, 2020). With an improvement in the educational standards in Indonesia, the quality of human resources will also likely improve. Thus, quality education across the board prepares the country for global competition.

Global competition requires the ability to think logically and critically in pursuit of effective life and work balance. Critical thinking is an essential ability (Brahmana, 2020), and as it can be developed through learning, this ability is a skill that every student must have to perform their role as the future generation responsible for the progress of the nation and state. Critical thinking consists of ideas, concepts, and information from a perspective that questions the accuracy of data in solving a problem (Elder & Paul, 2020). McGregor (Solihati & Hikmat, 2018) mentions that the elements of critical thinking estimation, evaluation, justification, classification, hypothesis formulation, analysis, and reasoning. McGregor (Solihati & Hikmat, 2018) further argues that the nature of critical thinking skills (CTS) is the basis for identifying the elements in a problem, specific reasons and conclusions; identifying and evaluating assumptions; clarifying and interpreting ideas; deciding what to accept, especially regarding opinions to be trusted; evaluating several different views; making judgments; and giving opinions. On that account, students need to have CTS to solve problems encountered in life.

One scientific field closely related to the problems of everyday life is mathematics. It is also an abstract science in which the process of solving mathematical problems contains an archetype where critical thinking and reasoning occur (Harish, 2013, p.14). CTS in mathematics education (ME) are one of the research concentrations studied by researchers around the world, including in Indonesia. Nevertheless, the research results on this matter show that the CTS of Indonesian students still need improvements and that it deserves to be a priority (Sari, 2020; Gunawan et al., 2022). This idea is further emphasized by the low scores in mathematics and CTS of Indonesian students in the 2018 Program for International Student Assessment (PISA) test. According to PISA (Kemendikbud, 2018), the average score of students in Indonesia is below the average score of the OECD. When working on math problems based on direct instruction, Indonesian students can immediately use the mathematical formulas they have learned. Even so, Indonesian students find it difficult in modelling a complex situations mathematically and choose, compare, and assess suitable strategies for solving contextual problems. Developing critical thinking practices among young students in Indonesia is also one of the major research issues in the ME research community (Sachdeva & Eggen, 2021). As such, many researchers focus on how to improve low CTS in ME.

This low critical thinking ability is improved through learning. Aspects to be considered during learning include the instruments, methods, and strategies used by the teacher in conveying material, and these aspects should align with indicators of CTS. According to Sarwanto et al. (2021), the utilization of the direct learning model and the lecture method contributes to students' low CTS. Conventional learning sometimes limits students from practicing higher-order thinking skills, or CTS, because students pose as passive observers of the physical and abstract thinking activities. One learning approach that aims to build and improve students' CTS is open-ended learning (Prihartini et al., 2016). The principle of learning with an OEA is to start the learning process by providing students with problems. This approach is similar to problem-based learning; however, open-ended questions allow for more than one correct answer, and they are called incomplete questions or open-ended questions. Becker and Shimada (1997) also defines a similar idea: there are multiple methods to solve problems presented in an OEA. With open-ended questions, students are encouraged to think analytically, critically, and effectively to assess their understanding and reasoning abilities (Sarwanto et al., 2022). In solving open-ended questions, students must apply their knowledge to contextual problems and think deeply (Feng, 2013). Webb et al. (2019) argues that the advantage of the OEA is that it encourages students to actively participate in the learning process and express their ideas, and to have more opportunities to use their mathematical knowledge and skills. Low-achieving students respond to problems in their own meaningful way, are intrinsically motivated to prove their points, and gain valuable experience in their discoveries, along with recognition or approval from their peers. Although no one learning approach fits all students (NCTM, 2000), with the advantages of an OEA, its implementation can improve students' mathematical-critical thinking skills. Therefore, an OEA is deemed ideal for improving students' mathematical CTS.

Testing the effectiveness of an open approach on students' critical mathematical thinking skills is essential because of its potential to improve higher-order thinking skills. Meta-analysis is employed as a research method to examine findings from prior studies. It involves quantitatively summarizing the impact sizes of independent variables manipulated by experimental groups on dependent variables (Anthony et al., 2015). Kraft (2020) argues that effect sizes are standard values and are compared to one another.

Juandi and Dahlan (2024) added that by synthesizing data from multiple studies, meta-analysis allows for a more holistic assessment of the effectiveness of an open approach in improving CTS. This method allows researchers to draw stronger conclusions regarding the benefits of implementing an open approach in ME. Some of the functions of the meta-analysis are to identify the heterogeneity of effects in different research types, draw conclusions, increase statistical power and precision for detecting effects, develop, refine, and test hypotheses, and reduce the subjectivity of comparisons between studies. A meta-analysis employs systematic procedures and explicit comparisons to identify gaps in data across fundamental knowledge and provide directions for further research, such as determining its sample size (Apino et al., 2018). In addition, Mansyur and Iskandar (2017) highlight the benefits of meta-analysis, including: (1) objectivity in its approach, (2) enhanced representativeness of results, (3) integration of diverse findings from previous research, (4) emphasis on summarizing both significant and insignificant impacts, and (5) clarification of discrepancies among similar studies' outcomes. Meta-analysis is a quantitative method used to consolidate various research outcomes through the analysis of effect sizes. Effect sizes quantify the impact of an independent variable, acting as an intervention in the experimental group, on the dependent variable. Thus, meta-analysis is used to summarize research in an integrative manner (Kraft, 2020). In the process of synthesizing meta-analyses, research studies become transparent, bias is detected and reduced, and there are better estimates of population parameters as it provides robust methodologies, assess outcomes across multiple domains, combat significant resistance, and provide robust evidence (Shelby & Vaske, 2008). The synthesis process of meta-analysis also allows for higher-quality results.

The research aims to ascertain the effect of utilizing an open-ended approach on students' critical thinking skills, and to determine the magnitude of this impact through rigorous empirical analysis and statistical testing. The researchers suggest that the research characteristics, namely sample size, publication year, level of education, demographics, and types of research publications affect the variations in the effectiveness of the OEA in improving CTS. Through the results of an in-depth analysis, education policymakers in Indonesia, especially in ME, will gain insights on accurate information related to improving students' CTS in ME through an OEA, which has so far shown conflicting research result.

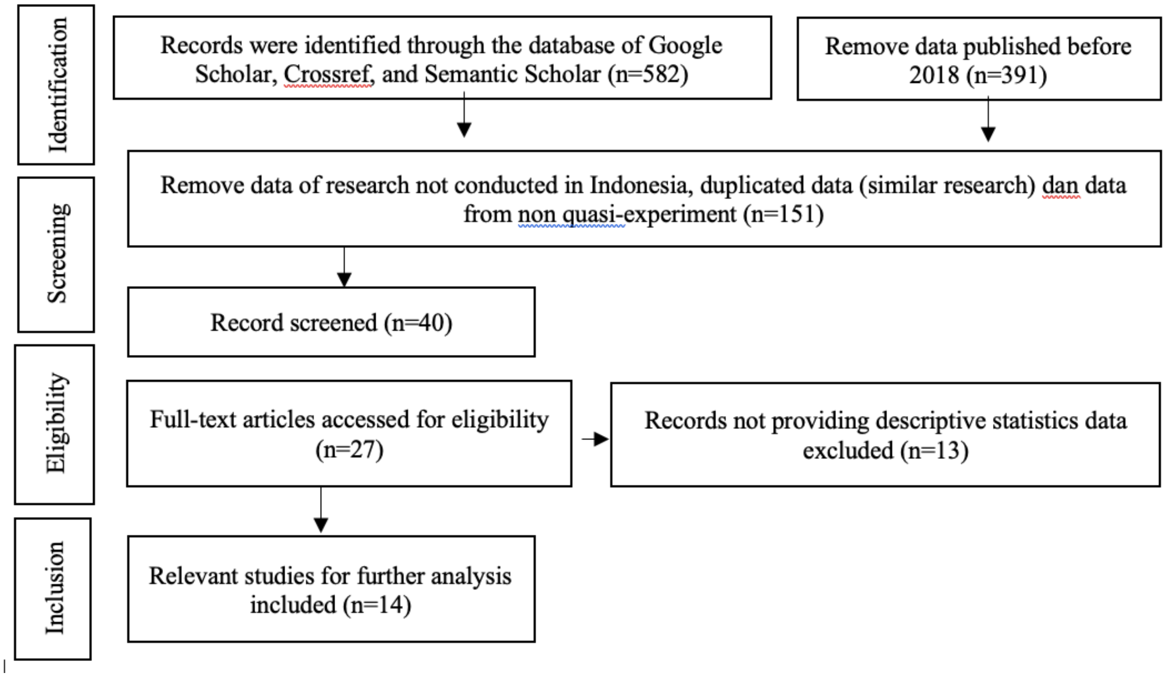
2. Methods

This study is a meta-analysis, in which Glass (1976) is a pioneer of meta-analysis, stated as an effective statistical technique for summarizing and analyzing the results of several previous studies on similar topics and then making general conclusions that are more significant. In other words, this research uses a method for synthesizing several primary research that are quantitatively relevant to the effectiveness of an OEA to mathematical CTS. In conducting a meta-analysis, we must assume that the studies to be analyzed investigate the same idea. Thus, this research is a replication of similar research, even though the replication level varies, ranging from the exact (pure) replication to those that only replicate the concept. Research that is close to "pure replication" is easier to compare. According to Ahn and Kang (2018) and Borenstein et al. (2021), the meta-analysis process includes several stages, namely (1) defining the research problem, (2) formulating research questions, (3) determining criteria, (4) searching for literature, (5) extracting data, (6) analyzing data using statistical analysis, and (7) interpreting data and reports.

Meta-analyses cannot be used to theoretically summarize presented papers, and review qualitative studies and policy proposals (Apino et al., 2020). To provide a detailed and in-depth analysis, the selected primary research were pre-determined by PICOS (Population, Interventions, Comparator, Outcomes, and Study Design) as specific inclusion criteria (Amir-Behghadami & Janati, 2020). The criteria used are as follows:

1. The primary research population is students from elementary to tertiary levels in Indonesia.
2. The primary research is a quasi-experimental study using an OEA as the independent variable and mathematical critical thinking skills as the dependent variable, as well as the control group.
3. The primary research provides comprehensive descriptive statistics, including the sample sizes, means, and standard deviations of both the experimental and control groups.
4. Primary research are research results in the form of journal articles, proceedings, and theses or dissertations published within the last five years (2018 – 2023)

Figure 1
PRISMA flow chart



Data collection was identified from three sources, namely Google Scholar, Crossruff, and Semantic Scholar. The keywords used to search for key studies in the database are "open-ended approach" AND "critical thinking skill" OR "mathematical critical thinking skill". However, then we use the "publish or perish" application to detect similar research. Furthermore, the inclusion criteria to select the primary research of this meta-analysis refer to Sharma and Bhattarai (2022), in which there are four stages following the PRISMA guidelines, namely: (1) identifying problems, (2) screening irrelevant studies, (3) selecting relevant studies, and (4) inclusion of studies for analysis. Furthermore, referring to Marsden et al. (2018) concept of data collection, the collected numerical or categorical data from each study, such as authorship, publication year, level of education, type of publication, specific demographics, and download links of the primary research, were recorded and extracted into a coding sheet.

We obtained 528 articles at the beginning of a manual search on the database, then the search was limited to research published after 2018, and 391 studies were removed as a result. The data were subsequently re-examined to focus solely on studies conducted in Indonesia, with an emphasis on quasi-experimental designs, and eliminating duplicate research sourced from various databases. 151 studies were removed from this database and there were 40 studies left for their eligibility check. Out of 40 studies, there were 27 incomplete articles and 13 studies with incomplete descriptive statistics data. These data become irrelevant since this research requires descriptive statistics data in the form of sample size, mean value, and standard deviation of the two groups: the experimental group and the control group. The researchers tried to contact the authors to obtain the desired data. However, until the analysis process was performed there was no answer from the aforementioned authors. Finally, based on the inclusion results, 14 studies were eligible to be analyzed in this meta-analysis.

The research results of the 14 primary research used in this study are in the form of effect sizes of the implementation of an OEA to CTS. Effect size is a value that reflects the magnitude of the influence of treatment or the strength between two variables. To standardize the classification or category of effect sizes, a specific classification is used. Effect size data with interpretation based on Cohen et al. (2018) are obtained from the results of selected primary research. The classification of effect size that describes the impact of an OEA on mathematical CTS is presented in Table 1.

Table 1
Classification of the effect size

Effect Size	Interpretation
0 - 2,0	Weak
0,21 - 0,50	Modest
0,51 - 1,00	Moderate
> 1,00	Strong

In addition, the p-value of the Q-Cochran statistical data was employed to support the diversity in effect sizes observed in this study. Heterogeneous analysis indicates a diversity of effect size data which is important for further investigation. The dimensions to be analyzed are study characteristics in the form of sample size, publication year, level of education, demography of the research area, and type of publication. In the process of data analysis, the authors use JASP software. JASP is an open-sourced statistical analysis software developed by the Department of Psychological Methods at the University of Amsterdam, Netherlands. JASP provides many Bayesian statistical methods and converts data into tables and plots that are easy to understand.

3. Result and Discussion

3.1. Results of literature search and data extraction

This research collects primary research data contained in articles, proceedings, theses, and dissertations related to the implication of an OEA in improving mathematical CTS published in 2018-2023. Data collection was performed from February 25th, 2023 to April 3rd, 2023 through the Google Scholar, Crossref, and Semantic Scholar databases, and 582 primary research were identified to be used as research material. After going through the inclusion and exclusion process, the researchers obtained 14 primary research that met the requirements for further processing. Table 2 presents a summary of the descriptive statistical data from each of the 14 primary research.

Table 2
Data extractions result

Code of Study	Statistic Descriptive					
	Open-Ended			Not Open-Ended		
	Total Sample	Mean	Standard Deviation	Total Sample	Mean	Standard Deviation
QEs_01	35	76,31	1,78	35	70,62	2,87
QEs_02	40	67,13	18,04	40	51,25	19,04
QEs_03	28	79,43	11,73	27	54,33	13,46
QEs_04	36	21,49	6,72	36	13,47	4,64
QEs_05	49	73,18	15,50	50	66,72	18,23
QEs_06	33	41,71	2,48	26	25,73	2,99
QEs_07	25	82,00	11,64	25	76,60	12,64
QEs_08	38	80,40	8,49	38	61,45	12,57
QEs_09	36	79,61	10,69	36	73,00	11,25
QEs_10	30	73,23	11,46	30	67,90	11,34
QEs_11	36	80,14	5,10	36	67,12	8,71
QEs_12	36	72,85	7,81	36	67,12	8,71
QEs_13	28	38,90	14,23	29	24,63	19,36
QEs_14	30	81,00	10,29	30	66	7,24

Table 2 displays the smallest sample used of 25 students and the largest sample of 40 students. Meanwhile, the lowest average score of students assessed in a class with an OEA was 21.49 and the highest was 82.00.

Furthermore, this meta-analysis investigated the characteristics of the 14 primary research as shown in Table 3. The research characteristics used in this study were sample size, publication year, level of education, demography of the study area, and type of publication.

Table 3
Data of Characteristic Study

Code of Study	Sample Size	Level	Specific Demographics	Type of Publication	Year of Publication
QE_01	>30	Collage	City	Journal	2019
QE_02	>30	Collage	City	Journal	2022
QE_03	<=30	Junior High School	City	Journal	2022
QE_04	>30	Junior High School	City	Journal	2021
QE_05	>30	Collage	City	Proceeding	2018
QE_06	>30	Elementary School	District	Journal	2018
QE_07	<=30	Senior High School	District	Thesis	2019
QE_08	>30	Junior High School	City	Thesis	2018
QE_09	>30	Senior High School	City	Journal	2019
QE_10	<=30	Junior High School	District	Thesis	2019
QE_11	>30	Junior High School	District	Journal	2019
QE_12	>30	Junior High School	District	Journal	2019
QE_13	<=30	Junior High School	City	Journal	2018

QE_14	<=30	Senior High School	District	Dissertation	2020

3.2. Analysis of primary research heterogeneity results of literature search and data extraction

The next step of this meta-analysis was a heterogeneity test as the initial requirement was to conduct calculations of the effect sizes and the standard errors and to draw conclusions from the 14 primary research. Table 4 shows that the results of the heterogeneity test from 14 primary research using JASP software for the variables of the implication of an OEA are heterogeneous, as shown from the p-value <0.001 where p <α. Thus, the Random Effects model is more suitable to estimate the average effect sizes of the 14 studies. This also demonstrates the moderator variables that need to be examined because they have the potential to influence the relationship between the two variables, namely the OEA and CTS.

Table 4

Heterogeneity test results with the parameter Q

Fixed and Random Effects

	Q	df	P-value
Omnibus test of Model Coefficients	18,363	1	< 0,001
Test of Residual Heterogeneity	135,828	13	< 0,001

Note. p -values are approximate.
Note. The model was estimated using the Restricted ML method.

This result is also supported by the heterogeneity test results of the 14 primary research using T^2 and I^2 parameters presented in Table 5.

Table 5

Heterogeneous test results with parameters T^2 and I^2

Residual Heterogeneity Estimates

		95% Confidence Interval	
	Estimate	Lower	Upper
τ^2	1,499	0,766	4,819
τ	1,224	0,875	2,195
I^2 (%)	95,342	91,279	98,504
H^2	21,471	11,467	66,823

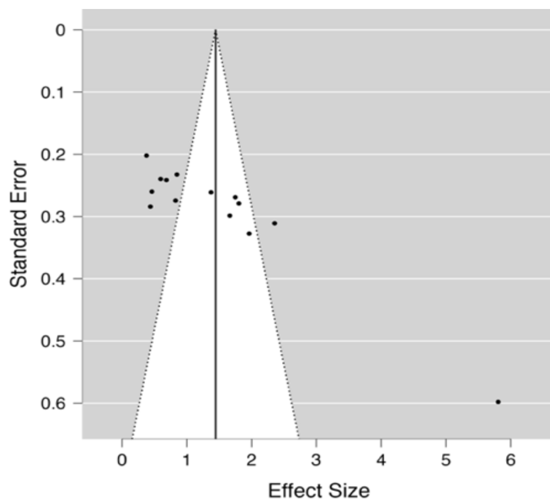
Table 5 displays the T^2 value of 1.499 > 0 or $T^2 > 0$ and that the I^2 value in this study is 95.342 % with a confidence interval between 91.279% - 98.504. The result indicates that the primary research are heterogeneous because the value of I^2 is close to 100%.

3.3. Analysis of publication bias and overall effect sizes of primary research

The limitation of meta-analysis is the possibility of bias in sampling and publication. The cause of bias in sampling is the selection of primary research without certain criteria which results in inconsistent data, whereas publication bias usually occurs when researchers tend to only publish studies with significant results (Apino et al., 2020). To avoid publication bias, this study only includes published research and unpublished research in the form of articles such as theses or dissertations obtained from repositories and proceedings so as not to produce an overly optimistic meta-analysis model.

Figure 2

Funnel Plot Diagram of Standard Error



In this meta-analytic study, publication bias is evaluated through funnel plot analysis, depicted in Figure 2. Research with $p < 0.05$ is often more likely to be published in journals with high impact factors. Consequently, there is a small potential for publication bias in the distribution of effect sizes across the 14 primary research studies.

The results of Egger's test clarified the data as shown in Table 6 since the p-value on Egger's test is <0.001, and the funnel plot tends to be symmetrical.

Table 6

Egger's test value

Regression test for Funnel plot asymmetry ("Egger's test")		
	z	p
sei	7,596	< 0,001

In addition, the fail-safe value shown in Table 7 is 1513,000, which means there is no bias between the two variables from each of the primary research used in this meta-analysis.

Table 7
The value of failsafe-N

File Drawer Analysis

	Fail-safe N	Target Significance	Observed Significance
Rosenthal	1513,000	0,050	< 0,001

Table 8 provides a comprehensive overview of the effect sizes observed in each primary research. In this study, the effect sizes ranged from 0.38 (the lowest) to 5.81 (the highest) with an average effect size of 1.44, which is included within the high range. Due to the various effect sizes of the selected studies, as shown in Table 8, these primary research were analyzed using the Random Effects method. There are two studies with the same author and publication year, namely (Winarso & Hardyanti, 2019). Since these studies use two types of experimental groups based on different characteristics, we included both as our primary research data in this study.

Table 8
The Overall Value of The Effect Size

Code of Study	Author	Effect Size (ES)	Standard Error of ES	Category of ES
QEs_01	(Sapta et al., 2019)	2,36	0,31	Strong
QEs_02	(Panggabean, 2022)	0,85	0,23	Moderate
QEs_03	(Noviyana et al., 2022)	1,96	0,33	Strong
QEs_04	(Ibrahim et al., 2021)	1,37	0,26	Strong
QEs_05	(Rhosyida et al., 2018)	0,38	0,20	Modest
QEs_06	(Siswanti et al., 2018)	5,81	0,60	Strong
QEs_07	(Ritonga, 2019)	0,44	0,28	Modest
QEs_08	(Ramadhani, 2018)	1,75	0,27	Strong
QEs_09	(Sukmawati et al., 2019)	0,60	0,24	Moderate
QEs_10	(Handayani, 2019)	0,46	0,26	Modest
QEs_11	(Winarso & Hardyanti, 2019)_1	1,80	0,28	Strong
QEs_12	(Winarso & Hardyanti, 2019)_2	0,69	0,24	Moderate
QEs_13	(Vebriana & Ariyanti, 2018)	0,83	0,27	Moderate
QEs_14	(Tiara Zulfi Eka, 2020)	1,66	0,30	Strong
	Mean of Effect Size	1,44		Strong

Table 8 indicates that 50% of the articles, specifically 7 studies, fall into the high category for the average effect size of the OEA on students' mathematical cognitive thinking skills (CTS), 30% belongs to the medium category or equal to 4 studies, and 20% belongs to a low category or equal to 3 studies. Consequently, the implementation of the OEA generally has a notable positive impact on enhancing students' mathematical CTS.

The magnitude of the effect of the OEA on students' mathematical CTS with high effect categories and medium categories is due to the various advantages of the OEA. According to Becker and Shimada (1997), an OEA through presenting open-ended problems offer students opportunities to acquire knowledge and experience in identifying, recognizing, and resolving problems through various techniques. On the contrary, the effect sizes with a low effect category on the use of an OEA on students' mathematical CTS are due to the weaknesses of the approach itself. Koriyah and Harta (2015) argue this approach's weaknesses include the teacher's difficulty in compiling meaningful mathematical problem situations, students finding it difficult to understand and respond to the problems given, high achieving students doubting the answers they get, and students finding that learning is difficult and not fun because they are used to conventional learning.

3.2. Analysis of primary research characteristics

The effect size of each primary research is heterogeneous as shown in Table 4 and Table 5. This indicates that there are factors that cause heterogeneity and is a cause for further research. Several types of study characteristics to calculate the effect sizes were selected for this study, namely sample size, education level, specific demographics, publication year, and type of publication. The results of the analysis of the study characteristics were presented in Table 9.

Table 9

The Results of The Analysis of The Characteristics of The Primary Research

Study Characteristic	Group	Studies Number	Effect Size	Null Hypothesis Test		Heterogeneity		
				Z-Value	P-Value	Qb	Df	P-Value
Sample Size	<=30	5	1,054	3,407	< 0,001	1,090	1	0,296
	>30	9	1,635	3,261	< 0,001			
Level	Elementary School	1	5,807	7,577	< 0,001	55,936	3	<0,001
	Junior High School	7	1,271	5,518	< 0,001			
	Senior High School	3	0,888	2,369	0,018			
	College	3	1,171	1,997	0,046			
Specific Demography	Regency	6	1,727	2,200	0,028	0,391	1	0,532
	City	8	1,237	4,986	< 0,001			
Publication Year	2018	4	2,081	1,773	0,076	2,724	4	0,602
	2019	6	1,046	3,197	0,001			
	2020	1	1,664	6,530	< 0,001			
	2021	1	1,374	5,893	< 0,001			
	2022	2	1,380	2,489	0,013			
Type of Publication	Journal	9	1,753	3,493	< 0,001	7,961	2	0,019

Proceeding	1	1,664	6,530	< 0,001
Thesis and Dissertation	4	1,075	2,955	0,003

Table 9 indicates that study characteristics, particularly educational levels, significantly contribute to the heterogeneity of effect sizes in the data. Additionally, factors such as sample size, specific demographics, publication year, and publication type also contribute to the variability in research findings. However, these factors did not significantly contribute to heterogeneity in the effect sizes of the data. Based on Piaget's theory of cognitive development, a person's learning process will follow patterns and stages of development according to their age (Oogarah-Pratap et al., 2020). This implies that as a person's level of education increases, their cognitive thinking skills also improve. Therefore, students' cognitive thinking skills will vary across different educational levels.

Characteristics of the level of education are divided into 4 groups: elementary, junior high, high school, and tertiary education. Each educational level has the p-value of the Z statistic less than 0.05, indicating that the implementation of an OEA in elementary, middle, high school, and tertiary institutions significantly improves students' mathematical CTS. Among these levels, the elementary school implementation of the OEA shows the largest effect size compared to junior high school, high school, and university levels. One of the possible causes is that students perceive multiple valid ways to approach problems, making learning enjoyable. Classroom activities in which students find possible alternative answers can develop their CTS. As stated by Siswanti et al. (2018), elementary school students taught with an OEA exhibit very high critical thinking ability scores, whereas conventionally taught students fall into the medium category. This is in line with the findings of research conducted by Caesario (2020) in which the OEA has a significant effect based on the level of education in elementary schools. Table 9 also shows that the implementation of the OEA at the high school level has the smallest effect size of 0.888. From the perspective of age, students at the high school level belong to the adolescent age. Adolescence is the stage when one begins to think logically about abstract ideas. They take part in high-level cognitive activities such as making plans and coming up with strategies, making decisions, and solving problems. High school students can use abstraction, distinguish between concrete and abstract, can reason scientifically, and learn to test hypotheses (Suralaga & Solicha, 2010). However, the effect sizes of the implementation of the OEA are different at the tertiary level. Piaget in Suralaga and Solicha (2010) argue that the adults' level of cognitive development should be on par with their high school counterparts. One of the factors that might cause this is the level of difficulty of the material provided. At the university level, the material is more complex than that at the high school level. It requires students to comprehend and have the initial knowledge to construct solutions to a given open-ended problem.

Furthermore, based on research characteristics of the publication year, the primary research of statistics Z for the years 2019, 2020, 2021, and 2022 has a p-value of less than 0.05. The results of studies on the implementation of the OEA to improving students' mathematical CTS published in

2019, 2020, 2021, and 2022 have a significant positive effect. Meanwhile, the Z statistic for the 2018 primary research has a p-value of more than 0.05. These findings suggest that the results of research published in 2018 have no significant impact. Therefore, the magnitude of the influence of open-ended learning on improving students' mathematical CTS tends to decrease from 2018-2023.

In addition, the results of 14 primary research show that the sample size characteristics also provide different effect sizes. There are two sample size groups, namely a sample of more than 30 students and a sample of less than or equal to 30 students. Table 9 displays the Z statistic for each sample size, and it has a p-value of less than 0.05. These findings indicate that both categories of sample size have a significant positive effect. This is because the OEA provides opportunities for students to actively participate and encourages them to express their ideas, which in turn gives them more opportunities to utilize knowledge and skills through mathematics (Siswanti et al., 2018). The findings indicated that implementing an OEA with more than 30 students resulted in larger effect sizes compared to implementations with sample sizes of 30 students or fewer. Groups with students over 30 allow for more discussion partners to express various opinions. In solving open-ended problems in groups, students can communicate and collaborate effectively. Discussions allow students to create and update problem-solving methods by developing their creativity to produce innovative breakthroughs (Rachmantika & Wardono, 2019). This is supported by the concept that sample size is the dominant factor in determining accuracy and that large samples have more precise results than small samples (Apino et al., 2020).

Based on the study characteristics of the type of publication, which are divided into three types, namely theses, dissertations, and articles in journals, the primary research Z statistic for each type of publication shows a p-value of less than 0.05. These findings indicate that this type of journal or thesis publication has a significant positive effect. The effect size of implementing the OEA based on the type of journal publication is 1,753 which has a more significant effect size compared to the effect size of the implementation of the OEA based on proceedings, theses, or dissertations publication type. This is in line with the results of Polanin et al. (2016), in which published research produces more significant effect sizes than unpublished research. Based on their type, the thesis and dissertation are published to a limited audience, and only certain communities consume these publications. Journal publication, on the other hand, certainly has a wider reach and is read by many. In short, research published in journals tends to be studies with a high effect size.

Based on demographic characteristics, as Indonesia consists of urban and rural areas, we will refer to the urban demographic category as a city and the rural demographic category as a regency. The Z statistic for each demographic category has a p-value of less than 0.05. The implementation of an OEA in both regencies and cities significantly enhances students' mathematical CTS. Specifically, the effect size of the OEA implementation in regencies is 1.727, which is greater than the effect size observed in cities, which is 1.237. One interesting point is that OEA implementation in regencies has a higher impact than in cities, even though from a regional development standpoint the information and communication technology in regencies is not more advanced than in cities. Cities, on the other hand, are the center of government and national economic development, especially in the capital area. One factor that might determine the CTS of students in the city is their reading habits. According to Karahan and İskifoğlu (2020), students in cities possess a good compartmentalization of thinking in a way that is analytical, systematic, curious, critical, and confident, and they possess a maturity of judgment. With relatively good initial abilities, the implementation of an OEA to improving students' thinking skills results in an effect size that is not too large.

4. Conclusion

In conclusion, the meta-analysis reveals several key findings regarding the Open-Ended Approach (OEA) in enhancing students' critical thinking skills in mathematics. Firstly, the synthesis of 14 primary studies indicates that OEA consistently produces positive outcomes with moderate effects across various educational settings. Secondly, the implementation of OEA results in substantial improvements in students' critical thinking skills in mathematics, with effect sizes ranging from 0.381 to 5.81, averaging 1.44, thus categorizing it as highly effective. Thirdly, factors contributing to variability in effect sizes include sample size, publication year, educational level, demographics, and type of publication, with elementary school settings and studies published in recent years demonstrating the largest effects. These findings suggest that OEA holds significant promise as a practical educational approach to address students' deficiencies in critical thinking skills. However, the study also identifies limitations, such as the relatively limited number of primary studies over a short period and the lack of comprehensive consideration of certain research characteristics like the frequency of meetings or treatments and the specific educational materials used. Future research should therefore extend over a longer timeframe, include more detailed treatment variables, and explore a wider range of educational contexts and materials to better understand the factors influencing the effectiveness of OEA in enhancing critical thinking skills.

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