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THE OPEN-ENDED APPROACH FOR OPTIMIZING STUDENTS' MATHEMATICAL ABILITIES: DOES IT WORK? (A META-ANALYSIS STUDY)

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Abstract. This study aims to analyze the potential of applying an open-ended approach to students' math skills which contains five skills namely problem-solving, reasoning and proof, representation, communication, and connection. To really know the potential for this application to be effective, statistical analysis is needed so that more objective conclusions can be obtained. Therefore, this study used quantitative as research approach using the Meta-Analysis method. The primary studies obtained were quasi-experimental studies that examined the effect of the open-ended implementation on mathematical skills with a total of 32 articles. The articles were published from 2012 to 2023 on Google Scholar database, Semantic Scholar, and direct URL. This study provides results that the treatment effect of the open-ended approach to mathematical skill has a high effect size of 1.356 and the moderator variable that affects the heterogeneity of the study is the type of mathematical skill, which is most effective on mathematical representation skill. While the level of education and learning combination did not significantly influence the heterogeneity of the effect size.

Keywords**:** Open-ended Approach; Mathematical Skills; Meta-analysis; Effect Size

I. INTRODUCTION

Since the 2013 curriculum was implemented until now, it has changed to an independent curriculum, and learning in class has become student-centred learning. Students are expected to achieve learning outcomes that have been determined in the applied curriculum. The achievements of learning mathematics contain various mastery of mathematical skills according to what is disclosed by NCTM (Kemendikbud, 2016). The next five Standards address the processes of communication, problem-solving, representation, connections, and reasoning and proof (NCTM, 2003). Mathematical problem-solving is an effort where students can find a way out of the mathematical problems, they encounter (Achadiyah et al., 2022; Wahyuni et al., 2021). In mathematics, reasoning is the process of coming at logical conclusions from data or presumptions. Conjecturing and constructing strong logical arguments are examples of mathematical thinking and reasoning skills. These are crucial since they provide the groundwork for future discoveries and encourage more research (NCTM, 2003). Representation is a way that someone uses to communicate answers or mathematical ideas to find solutions (NCTM, 2000) or substitute models for problem situations in the form of objects, pictures, words, or mathematical symbols (Jones & Knuth, 1991). Romberg and Chair (Tinungki, 2015) put forward a clear understanding of mathematical communication, namely relating real items, images, and diagrams to mathematical concepts; verbally or visually describing concepts, scenarios, and mathematical relationships with real objects, images, graphics, and algebra; putting everyday occurrences into words or mathematical symbols; seeing, talking about, and writing mathematical ideas; reading and comprehending a written mathematical presentation; speculating, putting forth arguments, defining terms, drawing conclusions, and posing queries on the material covered. Last but not least is connection skills; every student, regardless of academic skill, has to grasp this crucial component since it helps them understand the connections and advantages of mathematics. By establishing links, previously acquired mathematical concepts are applied as foundational knowledge to comprehend newly learnt concepts rather than being isolated as distinct elements (NCTM, 2000).

The open-ended approach is a problem-based learning that uses open-ended problems, or what are commonly called open-ended problems (Shimada, 1977; Shimada & Becker, 1997). This approach appears to be a solution to improving students' mathematical skills with various problems that require students to focus more on developing problem-solving methods and strategies. This is in accordance with the open-ended problems' characteristics, which have a way of being solved and answers that are not single (Ruseffendi, 1991; Shimada & Becker, 1997). Anthony (1996) suggests that giving routine questions as exercises or assignments places too much emphasis on

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procedures and accuracy and is rarely combined with other concepts, so that it does not train students' higher-order thinking skills. Therefore, using an open-ended in learning mathematics has the potential to enhance students' mathematical proficiency.

The problems presented in open-ended learning are non-routine and open-ended, giving rise to unconventional and different ways of solving problems. This allows students to explore a problem from various perspectives and find many ways to find solutions. Thus, students' mathematical skills related to problem solving will be increasingly honed and well trained through various alternatives that students might think of related to solving the problem (Cifarelli & Cai, 2005). Then from various solutions that may be alternatives, students conduct further analysis carefully to evaluate and consider solutions that may be more efficient and relevant to the mathematical concepts applied through justification and generalization (Medová et al., 2020; Radford, 2008; Vale et al., 2017).

In addition, the presentation of non-routine problems in open ended allows for a variety of problem presentations that need more understanding by students. In understanding these problems, students' mathematical representation skills are needed to identify patterns, relationships, and implications that arise in the problems presented in order to visualize various possible solutions (Phonapichat et al., 2014; Tarigan et al., 2022). In fact, it is not uncommon to need more than one type of representation to develop a mathematical model that accurately describes the real situation in the open-ended problem presented.

Mathematical communication skills are clearly necessary and important skills in the implementation of open-ended learning (Viseu & Oliveira, 2012). This is because the ability is related to the clear and systematic presentation of mathematical ideas to bring students to the most efficient solution from various alternative solutions that may be expected and appear in understanding to solve the problem. The presentation of mathematical ideas that can be understood is the key for students in communicating ideas on open ended problems presented by the teacher. In addition, strong mathematical connection skills play an important role in dealing with open-ended problems, as it allows students to see the whole picture, integrate knowledge, and find innovative solutions in the context of a given mathematical problem (Fatah et al., 2016; Hendriana et al., n.d.; Munroe, 2015).

Several previous studies examine the effect of the open-ended approach on mathematical skills, including mathematical problem-solving (Yulita et al., 2021), reasoning (Widiartana, 2018), representation (Ulya & Rahayu, 2021), communication (Amalo et al., 2022), and connection (Muchlis et al., 2018).

However, the results of this study do not necessarily guarantee that the use of open-ended has a positive effect on mathematical skill, and there is still a possibility of bias in research, so a thorough study is needed regarding this topic. In terms of the effect of open-ended approach on the five mathematical abilities, there are inconsistencies in the results of previous studies, which lead to inaccurate conclusions regarding the effect of open-ended. Some studies that show no effect in the application of open ended in math learning include Akbar et al., 2017; Palah et al., 2017; Rahmah & Rohaendi, 2020.

The open-ended, as one of the approaches often used in mathematics learning, certainly needs to know its potential. Is the application of this approach effective in improving or optimising students' standard mathematical skills? Searching for studies that focus on researching the effect of open-ended on students' skills in mathematics is certainly not enough to answer this question. The usual systematic literature study is still not objective in providing conclusions related to the potency of the application of this approach to the optimization of students' mathematical skills. Therefore, it is necessary to draw more objective conclusions using statistical analysis. This study will attempt to answer the question regarding the effectiveness of open-ended when applied in mathematics learning to optimize students' mathematical skills. This meta-analysis study will statistically analyze and evaluate primary studies that examine and focus on the application of open-ended to the five standard mathematical skills of problem-solving, representation, communication, connections, and reasoning and proof. There have been many previous studies related to the effectiveness of an approach on mathematical skills (Tamur et al., 2020; Juandi et al., 2022), but for the open-ended approach, there has been no previous meta-analysis study analyzing its potential application in mathematics learning. Although there are studies from Kurniati & Sutiarso, 2021 and Widodo et al., 2021 about meta-analysis on open-ended implementation, the search was not comprehensive using several databases and there was no further analysis related to moderator variables that affect the open-ended approach in implementation.

In addition to aiming to determine the effectiveness of the open-ended approach, this study also analyses the characteristics of the study to find out what moderator variables influence the effect of applying the approach. Therefore, this study is expected to fill the existing research gap from previous studies. This also supports the purpose of learning mathematics, one of which is open ended, which is certainly related to improving overall mathematical abilities (Hancock, 1995).

II. Methods

This research is a meta-analysis study that aims to synthesis the results of primary studies related to the effect of the application of the open-ended approach on mathematical skill. Thus, the steps of meta-analysis research begin with determining the research problem, namely the selection of topics, which is the effect of the open-ended approach on mathematical skill then the researcher determines the inclusion criteria to obtain relevant studies so that it is also necessary to determine the literature search strategy. After searching for articles, a study election was carried out based on the PRISMA protocol. The primary study data to be analysed is then extracted to retrieve the statistical data needed to determine the study effect size. The subsequent phase is statistical data analysis, followed by reporting and result interpretation. The explanation of the steps of the meta-analysis study is based on Cooper et al., (2019), Bernard et al. (2014), Borenstein et al. (2009). If presented in the form of a flow chart, the steps of this

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meta-analysis research will take the form of the following flow chart.

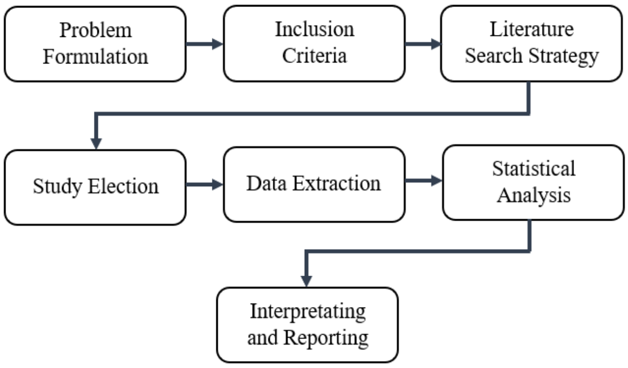

Fig. 1 Flowchart of Meta-Analysis

A. Inclusion Criteria

This stage of determining the inclusion criteria aims to limited the scope of the meta-analysis so that the primary studies obtained are relevant. The inclusion criteria used were guided by the PICOS framework (Liberati et al., 2009; Robinson et al., 2011; Saldanha et al., 2013). The following are the inclusion criteria for this study:

1. The population of primary study used was Indonesian (Population)
2. The treatment used in the primary study was the open-ended learning implementation (Intervention)
3. The primary study compared the experimental class (open-ended approach) with the control class (conventional) (Comparator)
4. The primary study's outcome is students' skill in mathematics (Outcomes)
5. The study primary study used was quasi-experimental (Study Design)
6. The statistical data in the primary study must contain at least one of the following data:
   - Sample size, mean, and standard deviation posttest score of experimental and control class
   - t-value and sample size
   - p-value and sample size
7. Primary study publication years range from 2012-2023 in the form of journals.

Primary studies that do not fulfil the above criteria of inclusion will be excluded in this meta-analysis study.

B. Literature Search Strategy

In searching for relevant articles, researchers used online databases, including Google Scholar, Semantic Scholar, and direct journal URLs. The keywords used in the search were "open-ended" and keywords related to all mathematical skills, including "mathematical connection", "mathematical reasoning", "mathematical communication", "mathematical representation" and "mathematical problem-solving".

C. Study Election

The selection of primary studies to be analysed in this meta-analysis study used the PRISMA protocol guidelines, which consisted of four stages, namely identification, screening, eligibility, and inclusion. In the identification stage, researchers excluded the duplicate primary studies, then selected studies by applying inclusion criteria, mainly focusing on the research design used in the primary study. At the eligibility stage, researchers began to focus on the adequacy of statistical data available in primary studies as listed in the inclusion criteria, then continued with publication bias testing to obtain primary studies that would be statistically analyzed in this study (included step).

D. Data Extraction

Primary studies that were selected and included in the study were extracted to obtain information such as the author's name and study year and also effect size statistics. These statistics included size of sample, mean and standard deviation, p-value, and t-value.

E. Statistical Analysis

There are two kinds of effect model used in meta-analysis studies: fixed effect models and random effects models. In education research, random effects model is used because there may be differences in educational interventions where the magnitude of impact may be different and vary for each primary study (Borenstein et al., 2010). The heterogeneity test results serve as a foundation for the assumptions used in constructing the effects model, in addition to providing insight into the research that will be done. If the set of effect sizes of each study is heterogeneous, then a random model is most suitable since under random effects model the primary studies' effect sizes can vary and be unique for each (Siddiq & Scherer, 2019).

Effect size calculations for each primary study used hedges's g formula due to the tendency for bias when using other formulas for small samples (Juandi & Tamur, 2020). However, a publication bias test was also conducted previously. The publication bias test itself is very important to ensure primary studies are valid for data analyzed. This study used three tests to ensure the absence of publication bias, namely funnel plot, trim and fill, and fail-safe N test by Rosenthal method (Rothstein et al., 2005). Sensitivity testing is also important to see the robustness of the test results to bias, this can be reviewed by using the "one removed study" feature in the CMA version 4 application (Bernard et al., 2014).

The pooled effect sizes of the primary studies analyzed will result in average effect sizes classified according to the following Table I (Cohen et al., 2018).

TABLE I
EFFECT SIZE CLASSIFICATION

Effect Size	Interpretation
0.00-0.20	Low
0.21-0.50	Modest
0.51-1.00	Moderate
>1.00	High

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This categorization is important in determining how much effect is resulted in the application of the open-ended approach to improve mathematical skills.

III. Result and Discussion

Articles obtained through literature searches and meeting the inclusion criteria were 32 primary studies. These primary studies came from the databases Google Scholar, Semantic Scholar, and direct journal URLs. Statistical data from these primary studies were then inputted into the CMA application to compute the effect size for each study. The six articles used the same study design, namely experimental research with a quasi-experimental design. All articles examined the effect of implementing an open-ended on mathematical skill by comparing experimental classes that were given treatment and control classes that used conventional learning. From the CMA-assisted analysis process, the study effect sizes are presented in the following table.

TABLE III
Primary Studies' Effect Size

Citation	**Effect Size**	**Variance**	**Confidence Interval**	
			Lower Limit	**Upper Limit**
(Herdiman, 2017)	1.016	0.065	0.516	1.517
(Ridha, 2017(a))	0.513	0.046	0.091	0.934
(Ridha, 2017(b))	0.968	0.050	0.530	1.406
(Damayanti et al., 2023)	0.543	0.057	0.075	1.012
(Fernando et al., 2020)	0.599	0.064	0.104	1.094
(Junita et al., 2022)	2.145	0.146	1.395	2.895
(Saputri & Kamsurya, 2020)	0.842	0.068	0.332	1.351
(Ulya & Rahayu, 2020)	2.889	0187	2.041	3.736
(Syahrin & Azis, 2021)	2.717	0.266	1.705	3.729
(Hartono et al., 2019)	0.958	0.146	0.209	1.708
(Nuraini et al., 2022)	2.153	0.147	1.401	2.904
(Rahmah & Rohaendi, 2021)	-0.490	0.105	-1.126	0.147
(Nuraini et al., 2021)	0.949	0.096	0.342	1.556
(Mahuda, 2017)	1.436	0.074	0.904	1.969
(Yulita et al., 2021)	4.558	0.181	3.724	5.392
(Utami et al., 2016)	0.586	0.071	0.063	1.110
(Tarigan & Wirevenska, 2019)	1.292	0.079	0.741	1.842
(Wahyuningtyas et al., 2020)	0.828	0.084	0.259	1.398
(Mariam et al., 2019)	2.206	0.117	1.536	2.876
(Taufik, 2014)	1.319	0.078	0.771	1.867
(Gordah, 2012(a))	0.786	0.070	0.267	1.305
(Gordah, 2012(b))	0.214	0.065	-0.287	0.715
(Handini et al., 2015)	4.401	0.282	3.360	0.895
(Widiartana, 2018)	0.597	0.023	0.300	0.895
(Amalo et al., 2022)	0.841	0.071	0.320	1.363
(Haryani, 2016)	0.414	0.059	-0.061	0.889
(Kadarisma, 2018)	0.637	0.070	0.120	1.154
(Assabanny et al., 2018)	0.939	0.054	0.484	1.394
(Wulandari et al., 2020)	3.703	0.215	2.795	4.611
(Ermawati & Zuliana, 2020)	2.591	0.176	1.769	3.412
(Lubis et al., 2019)	0.787	0.075	0.251	1.324
(Muchlis et al., 2018)	1.797	0.075	1.261	2.333

Each primary study has a different effect size, with only one study showing a negative effect. Based on the classification of effect sizes previously presented in Table I, there are 14 studies with high effect size category, 15 studies are in the moderate category, two studies with modest effect size, and one study shows a negative effect. This means that most of the applications of the open-ended approach in mathematics learning have a positive effect on mathematical skill.

Before conducting further analysis of the effect size of the primary study collection in this research, first we determine the effect model that will be used in analysing the effect size. We assumed a random effects model because the effect size will vary from one study to another. To support this assumption, the effect size transformation between the two models was compared. The following table presents the comparison of results based on the meta-analysis effect model in the CMA application.

TABLE IIIII
Comparation of Effect Size Based on Estimation Model

Estimation Model	**N**	**Effect Size**	**Standard Error**	**Lower Limit**	**Upper Limit**
Fixed	32	1.039	0.094	0.942	1.135
Random	32	1.356	0.155	1.053	1.660
Z	**Qb**	**p-value**	**I-Squared**		
21.057 8.754	294.1 45	0.000	89.461		

The criteria for determining the model are Qb and p-value, with α = 0,05 and the null hypothesis to be tested is that the distribution of the set of study effects is homogeneous. From the table above, Qb = 294.145 dan p-value equal 0.000 less than 0,05 it means H0 is rejected or the distribution of the effect size is heterogeneous. Then viewed from the I-squared value which shows the variation of the analysed study obtained by 89.461 which means 89.461% variation of the observed effect size shows that a percentage of the variability is due to heterogeneity rather than sampling error. Thus, random effects model used in accordance with the assumptions and supported by statistical test results that show rejection of the null hypothesis and an I-squared value of more than 89%.

Furthermore, a publication bias test was aimed to ensure that the overall effect size analysis was valid and not vulnerable to bias. Publication bias can be seen directly from the funnel plot generated from the unite of the primary studies' effect size. The criterion for determining the presence of publication bias is based on the symmetry of the resulting plot. The following is the funnel plot generated in the publication bias test.

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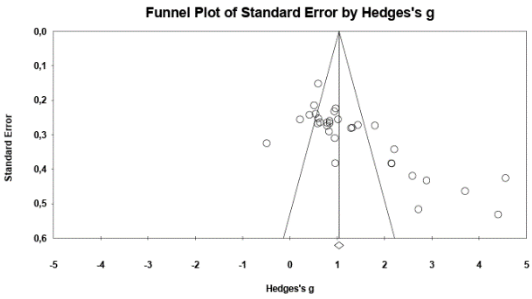

Fig. 2 Funnel Plot

From this figure, it can be seen that the distribution of the treatment effect data of the prime studies is symmetrical. This implies that there is no risk of bias of publication in this set of effect sizes (Sternberg & Funke, 2019; Sterne & Egger, 2001). However, the illustration from the funnel plot was not sufficient to declare the results of the effect size analysis to be free from publication bias, so two more tests were conducted to confirm this. The trim and fill test was conducted to ensure that there were no studies that caused bias and needed to be excluded from this meta-analysis study. To decide the number of trimmed studies, the effect model and the direction used in finding missing data in the set of effect sizes must be known. The model is a random effects model as previously concluded and left of mean in looking for missing data. Through the application of CMA, zero results were obtained in many trimmed studies so that it can be ascertained that there is no need for studies to be excluded from the analysis because they cause publication bias. In addition to these two tests, the robustness of the analysis results to publication bias is also important to know. The Rosenthal Fail-safe N test is used in testing the robustness of publication bias with the ad-hoc rule criterion. The rule state that if $N < 5k+10$ then the effect set is vulnerable to bias (Rothstein et al., 2006) which k is the studies' number analyzed. In this research, number of studies (k) is 32 studies so the value of N must be more than $5k + 10 = (5\times32) + 10 = 170$ to be resistant to bias. Based on the calculation of the N value using CMA, N = 4613 is obtained, so since it is more than 170, it can be concluded that the study effect set is resistant to publication bias (Mullen et al., 2001). Moreover, the last calculation in answering the research question is the mean treatment effect with 95% confidence level and determining the category of the effect of the application of the open-ended on math skill.

Based on the output in the CMA application in Table III, the mean effect size is 1.356 with 1.053 to 1.660 of CI (Confidence Interval). Then, the Z-value obtained when testing the null hypothesis is 8.754 with a p-value of less than 0.001. The null hypothesis that will be tested states that there is no effect of the open-ended approach towards mathematical skills. Applying the criterion of $\alpha = 0.05$ results in the rejection of H0, indicating that studying mathematics through an open-ended approach has an effect on mathematical skills. From the calculation of the mean effect size of 1.356 and viewed from the categorization table, it can be concluded that the effect resulting from the application of the treatment is high, meaning that the application of the open-ended give a strong effect towards mathematical skills. Thus, the implementation of the open-ended approach in learning mathematics has more potential to improve mathematical skills compared to conventional learning.

Several research factors undoubtedly contribute to the difference in effect size shown in the collection of primary studies pertaining to the application of open-ended to mathematical skills. Therefore, we will analyze the heterogeneity of the studies in terms of moderator variables that could potentially cause variability in the magnitude of the treatment effect primary studies. The researcher has determined some of the moderator variables including education level, learning combination, and improved mathematical skills. The heterogeneity test based on moderator variables was conducted using the CMA application with 95% confidence interval, hedges's g, Z and p-value effect sizes that will be seen to look for the potential of moderator variables to affect the effect of implementing an open-ended approach. The following outputs were generated from the heterogeneity test for the three moderator variables.

TABLE V
HETEROGENEITY TEST BASED ON CHARACTERISTICS OF STUDY

Moderator Variable	Group	N	Effect Size	Other Heterogeneity Statistics	
				Q-value	p-value
Education Level	Elementary	5	2.353	5.064	0.079
	Junior High	9	0.951		
	Senior High	18	1.301		
Learning Combination	Just OE	22	1.407	0.232	0.630
	OE + other	10	1.256		
Mathematical Skill Types	Problem-solving	12	1.628	13.568	0.009
	Reasoning	5	1.349		
	Representation	7	1.704		
	Communication	5	0.485		
	Connection	3	1.122		

From the test results in Table V, we can obtain some information related to the moderator variables that are expected to cause variations in the treatment effect of the primary study. Education level as moderator variable is divided into three groups, namely senior, junior high school, and elementary. Of the three levels of education, the effect of applying open-ended has the largest effect size when applied at the elementary level, which is 2.353 and is in the high category. The application of this approach at the junior and senior high school levels also has a high effect, 0.951 and 1.301 respectively. Although there is a differentiation in the treatment effect of each level of education, the heterogeneity statistics column obtained Q-value = 5.064 and p-value = 0.079 > 0.05, so the null hypothesis about the homogeneity of the study is accepted at a significant level of 5%. This means, there is no significant difference in the effect on students' mathematical skills by applying open-ended in terms of education level.

In addition to the education level, the learning combination is also suspected as a moderator variable that causes variation in effect. The learning combination in this case is the implementation of the open-ended approach in the experimental class, whether combined with other learning methods or models or just purely using open-ended itself, so there are two groups on this moderator variable, namely just OE and the combination of OE with others. The resulting effect size is not much different, namely 1.407 for the implementation of the open-ended approach alone and 1.256 for the implementation that uses a combination of other methods, for example cooperative learning (Mahuda, 2017), CORE (Saputri & Kamsurya, 2020), CIRC (Haryani, 2016), and the others. Both effect sizes are in the high category. Q-value = 0.232 and p-value = 0.630 > 0.05 were obtained in the study heterogeneity hypothesis test. It is indicating that there is no significant difference between the effect sizes produced by the experimental class using the open-ended approach alone and the experimental class using of open-ended combines with other learning models or methods.

As previously known, mathematical skills are divided into five including problem-solving, reasoning, representation, communication, and connection. These five types of skills are grouped into moderator variables that are also suspected to cause variability. The use of the open-ended strategy showed a high effect size on four mathematical skills and a small impact on one other skill. The biggest impact size happened when open-ended was implemented towards students' representation skills which equal to 1.704. Then when viewed from the results of the heterogeneity test, the Q-value obtained is 13.568 with a p-value = 0.009 < 0.05, which means that the homogeneity hypothesis is rejected at the significance level 5%. This gives the conclusion that there is a significant difference in the effect of the application of the open-ended approach on mathematical skills in terms of the type of mathematical skills of students who are being optimized.

The limitations in this study are similar to previous meta-analysis studies, namely related to the inclusion criteria applied. To produce broader conclusions, of course, more databases are needed or the application of broader inclusion criteria.

IV. Conclusion

Through this meta-analysis study, the potential of open-ended implementation on students' mathematical skills can be identified. After synthesizing, analyzing, and estimating, a high effect size was obtained, which means that the implementation of open-ended in mathematics learning has helped improve students' mathematical skills. Thus, open-ended can be one of the alternatives in learning that is useful for the achievement of students' mathematical skills. Although the level of education is not a factor that affects the effectiveness of open-ended in improving mathematical skills, the application of this approach at the elementary school level is highly recommended. As for the combination of learning in its application, it is not required to have a combination or pure application of this approach, but it can be adjusted to the students' needs. Then based on the type of mathematical skills, the application of open-ended is more recommended in improving students' mathematical representation skills.

Some recommendations for further research consist of adding databases used in the search so that more primary studies can be reached, especially international journals such as the Scopus and ERIC databases. In addition, it is necessary to identify other moderator variables that may have a significant effect such as sample size and time period of open-ended implementation.

References

Achadiyah, L., Prastyo, D., Rusminati, S. H., Pgri, U., & Surabaya, A. B. (2022). Analisis Kemampuan Matematis Siswa dalam Pemecahan Masalah Matematika Luas dan Keliling Bangun Datar di Sekolah Dasar. *Edukatif : Jurnal Ilmu Pendidikan*, *4*. https://doi.org/10.31004/edukatif.v4i4.3295

Akbar, S., Kodirun, & Busnawir. (2017). Pengaruh Pembelajaran Berbasis Masalah dengan Pendekatan Open-Ended terhadap Kemampuan Berpikir Kreatif Matematik Ditinjau dari Kemandirian Belajar Siswa SMA. *Jurnal Pendidikan Matematika*, *8*(2), 117–128.

Amalo, S. I., Mamoh, O., & Salsinha, C. N. (2022). Pengaruh Pendekatan Open-Ended terhadap Kemampuan Komunikasi Matematis Siswa Kelas VIII SMP pada Materi SPLDV. *Math-Edu: Jurnal Ilmu Pendidikan Matematika*, *7*(3), 175–184.

Anthony, G. (1996). *Classroom Instructional Factors Affecting Mathematics Students' Strategic Learning Behaviors*. https://www.researchgate.net/publication/282613348

Bernard, R. M., Borokhovski, E., Schmid, R. F., Tamim, R. M., & Abrami, P. C. (2014). A meta-analysis of blended learning and technology use in higher education: From the general to the applied. *Journal of Computing in Higher Education*, *26*(1), 87–122. https://doi.org/10.1007/s12528-013-9077-3

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2009). *Introduction to Meta-Analysis* (First Edition). John Wiley & Sons, Ltd.

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2010). A basic introduction to fixed-effect and random-effects models for meta-analysis. *Research Synthesis Methods*, *1*(2), 97–111. https://doi.org/10.1002/jrsm.12

Cifarelli, V. V., & Cai, J. (2005). The evolution of mathematical explorations in open-ended problem-solving situations. *The Journal of Mathematical Behavior*, *24*(3–4), 302–324. https://doi.org/10.1016/j.jmathb.2005.09.007

Cohen, L., Manion, L., & Morrison, K. (2018). *Research Methods in Education* (8th Edition). Routledge. https://doi.org/10.4324/9781315456539

Cooper, H., Hedges, L. V., & Valentine, J. C. (2019). *The Handbook of Research Synthesis and Meta-Analysis* (H. COOPER, L. V. HEDGES, & J. C. VALENTINE, Eds.). Russell Sage Foundation. https://doi.org/10.7758/9781610448864

Fatah, A., Suryadi, D., Sabandar, J., & Turmudi. (2016). Open-Ended Approach: An Effort in Cultivating Students' Mathematical Creative Thinking Ability and Self-Esteem in Mathematics. *Journal on Mathematics Education*, *7*(1), 11–20.

Hancock, C. L. (1995). Implementing the Assessment Standards for School Mathematics: Enhancing Mathematics Learning with Open-Ended Questions. *The Mathematics Teacher*, *88*(6), 496–499. https://doi.org/10.5951/MT.88.6.0496

Haryani, R. (2016). Keefektivan Model Pembelajaran CIRC dengan Pendekatan Open-Ended Terhadap Kreativitas dan Komunikasi Matematis Siswa. *Ekuivalen*, *24*(3).

Hendriana, H., Rahmat, U., & Sumarmo, S. (n.d.). MATHEMATICAL CONNECTION ABILITY AND SELF-CONFIDENCE (An experiment on Junior High School students through Contextual Teaching and learning with Mathematical Manipulative). In *Mathematical Connection Ability and Self*.

Jones, B. F., & Knuth, R. A. (1991). *What does research say about mathematics?* http://www.ncrl.org/sdrs/areas/stw_esys/2math.html

Juandi, D., Kusumah, Y. S., & Tamur, M. (2022). A Meta-Analysis of the last two decades of realistic mathematics education approaches. *International Journal of Instruction*, *15*(1), 381–400. https://doi.org/10.29333/iji.2022.15122a

Juandi, D., & Tamur, M. (2020). *Pengantar Analisis Meta*. UPI Press.

Kemendikbud. (2016). *Minister of education and culture regulation number 21 of 2016 concerning content standards for primary and secondary education*.

Kurniati, N., & Sutiarso, S. (2021). The Effect of Problem Based Learning and Open-Ended Learning on Mathematics Creative Thinking Ability: A Meta Analysis Study. *Jurnal Pendidikan MIPA*, *22*(1), 112–120. https://doi.org/10.23960/jpmipa/v22i1.pp112-120

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *BMJ (Clinical Research Ed.), 339*. https://doi.org/10.1136/bmj.b2700

Mahuda, I. (2017). Pembelajaran Kooperatif CO-OP CO-OP Dengan Pendekatan Open-Ended untuk Meningkatkan Kemampuan Pemecahan Masalah Matematis Siswa SMA. *JPPM (Jurnal Penelitian Dan Pembelajaran Matematika)*, *20*(2).

Medová, J., Bulková, K. O., & Čeretková, S. (2020). Relations between Generalization, Reasoning and Combinatorial Thinking in Solving Mathematical Open-Ended Problems within Mathematical Contest. *Mathematics*, *8*(12), 2257. https://doi.org/10.3390/math8122257

Muchlis, A., Komara, E. S., Kartiwi, W., Nurhayati, Hendriana, H., & Hidayat, W. (2018). Meningkatkan Koneksi Matematis Siswa SMP Melalui Pendekatan Open-Ended dengan Setting Kooperatif Tipe NHT. *Kalamatika: Jurnal Pendidikan Matematika*, *3*(1), 81–92.

Mullen, B., Muellerleile, P., & Bryant, B. (2001). Cumulative Meta-Analysis: A Consideration of Indicators of Sufficiency and Stability. *Personality and Social Psychology Bulletin*, *27*(11), 1450–1462. https://doi.org/10.1177/01461672012711006

Munroe, L. (2015). The Open-Ended Approach Framework. *European Journal of Educational Research*, *4*(3), 97–104. https://doi.org/10.12973/eu-jer.4.3.97

NCTM. (2000). *Principles and Standards for School Mathematics*. The National Council of Teachers of Mathematics, Inc.

NCTM. (2003). *Standards for Secondary Mathematics Teacher*. The National Council of Teachers of Mathematics, Inc.

Palah, S., Maulana, M., & Aeni, A. N. (2017). Pengaruh Pendekatan Open-Ended Berstrategi M-RTE terhadap Kemampuan Berpikir Kreatif Matematis Siswa pada Materi Persegi Panjang. *Jurnal Pena Ilmiah*, *2*(1), 1161–1170.

Phonapichat, P., Wongwanich, S., & Sujiva, S. (2014). An Analysis of Elementary School Students' Difficulties in Mathematical Problem Solving. *Procedia - Social and Behavioral Sciences*, *116*, 3169–3174. https://doi.org/10.1016/j.sbspro.2014.01.728

Putu Hendra Widiartana, I. (2018). The Effect of Open-Ended Approach Towards Students' Mathematical Reasoning. *Journal of Physics: Conference Series*, *1028*(1), 1–7. https://doi.org/10.1088/1742-6596/1028/1/012134

Radford, L. (2008). Iconicity and contraction: a semiotic investigation of forms of algebraic generalizations of patterns in different contexts. *ZDM*, *40*(1), 83–96. https://doi.org/10.1007/s11858-007-0061-0

Rahmah, M. A., & Rohaendi, S. (2020). Peningkatan Kemampuan Berpikir Kreatif Siswa SMA dengan Pendekatan Open-Ended. *Jurnal Penelitian Pembelajaran Matematika*, *13*(1), 61–72.

Robinson, K. A., Saldanha, I. J., & Mckoy, N. A. (2011). Development of a framework to identify research gaps from systematic reviews. *Journal of Clinical Epidemiology*, *64*(12), 1325–1330. https://doi.org/10.1016/j.jclinepi.2011.06.009

Rothstein, H. R., Sutton, A. J., & Borenstein, M. (2005). *Publication Bias in Meta-Analysis* (H. R. Rothstein, A. J. Sutton, & M. Borenstein, Eds.). Wiley. https://doi.org/10.1002/0470870168

Ruseffendi, E. T. (1991). *Pengantar Kepada Membantu Guru Mengembangkan Kompetensinya dalam Pendidikan Matematika untuk Meningkatkan CBSA*. Tarsito.

Saldanha, I. J., Wilson, L. M., Bennett, W. L., Nicholson, W. K., & Robinson, K. A. (2013). Development and pilot test of a process to identify research needs from a systematic review. *Journal of Clinical Epidemiology*, *66*(5), 538–545. https://doi.org/10.1016/j.jclinepi.2012.07.009

Saputri, V., & Kamsurya, R. (2020). Mathematical Representation Ability and Mathematics Self Efficacy in CORE Learning Models with Open-Ended Approach. *ANARGYA: Jurnal Ilmiah Pendidikan Matematika*, *3*(2). http://jurnal.umk.ac.id/index.php/anargya

Shimada, S. (1977). *Open-end Approach in Arithmetic and Mathematics: A New Proposal toward Teaching Improvement*. Mizuumi Shobou.

Shimada, S., & Becker, J. P. (1997). *The Open-Ended Approach: A New Proposal for Teaching Mathematics*. National Council of Teachers of Mathematics.

Sternberg, R. J., & Funke, Joachim. (2019). *Psychology of Human Thought*. Heidelberg University Publishing.

Sterne, J. A. C., & Egger, M. (2001). Funnel plots for detecting bias in meta-analysis. *Journal of Clinical Epidemiology*, *54*(10), 1046–1055. https://doi.org/10.1016/S0895-4356(01)00377-8

Tamur, M., Juandi, D., & Adem, A. M. G. (2020). Realistic Mathematics Education in Indonesia and Recommendations for Future Implementation: A Meta-Analysis Study. *JTAM | Jurnal Teori Dan Aplikasi Matematika*, *4*(1), 17. https://doi.org/10.31764/jtam.v4i1.1786

Tarigan, M. S., Azis, Z., & Nasution, M. D. (2022). Improved Mathematical Representation of Students With The Open-Ended Approach Article Info ABSTRACT. *Journal of Mathematics Education and Application (JMEA)*, *1*(3), 130–134. https://doi.org/10.30596%2Fjmea.v1i3.12096

Tinungki, G. M. (2015). The Role of Cooperative Learning Type Team Assisted Individualization to Improve the Students' Mathematics Communication Ability in the Subject of Probability Theory. *Journal of Education and Practice*, *6*(32). www.iiste.org

Ulya, H., & Rahayu, R. (2021). Students' mathematical representation ability in Kudus local wisdom-based Open-Ended Learning. *Journal of Physics: Conference Series*, *1823*(1), 012102. https://doi.org/10.1088/1742-6596/1823/1/012102

Vale, C., Widjaja, W., Herbert, S., Bragg, L. A., & Loong, E. Y.-K. (2017). Mapping Variation in Children's Mathematical Reasoning: The Case of 'What Else Belongs?' *International Journal of Science and Mathematics Education*, *15*(5), 873–894. https://doi.org/10.1007/s10763-016-9725-y

Viseu, F., & Oliveira, I. B. (2012). Open-ended Tasks in the Promotion of Classroom Communication in Mathematics. In *International Electronic Journal of Elementary Education* (Vol. 4, Issue 2). www.iejee.com

Wahyuni, S., Dahlan, J. A., & Juandi, D. (2021). Students' mathematics problem solving ability through Model Eliciting Activities (MEAs). *Journal of Physics: Conference Series*, *1882*(1). https://doi.org/10.1088/1742-6596/1882/1/012079

Widodo, S., Katminingsih, Y., & Nirwono, B. (2021). Meta Analisis: Pengaruh Model Pembelajaran Berdasarkan Masalah terhadap Kemampuan Berpikir Kreatif. *Indonesian Journal of Educational Development*, *1*(4), 567–577. https://doi.org/10.5281/zenodo.4559716

Yulita, T., Suyitno, H., & Sugiman. (2021). Pembelajaran Matematika Melalui Pendekatan Open-Ended dengan Bantuan Power Point untuk Meningkatkan Kemampuan Pemecahan Masalah di Masa Pandemi. *Jurnal Cendekia: Jurnal Pendidikan Matematika*, *5*(2), 1588–1598.