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Does Discovery Learning Enhance Secondary Students' Mathematical Critical Thinking Skills?

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Abstract.
The implementation of the discovery learning (DL) model in Indonesia is believed to improve the mathematical critical thinking skills of the secondary students, so that it becomes the recommended learning model in the national curriculum. Several previous similar types of research have found that DL can enhance secondary students' mathematical critical thinking skills. However, there were inconsistencies in the effect size of these primary studies. The meta-analysis was carried out to obtain a comprehensive analysis result and investigate the effect of study characteristics. Comprehensive meta-analysis (CMA) is a tool used to calculate hedge's effect size (ES). An analysis of 25 relevant primary studies that met the inclusion criteria revealed that, based on the random-effects model, the implementation of the DL model had a high positive effect (ES = 0.981) on secondary students' critical thinking skills compared to the conventional model. The duration of treatment and indexed publication are important factors that affect the effectiveness of implementing DL on students' mathematical critical thinking skills. Based on the analysis, DL is recommended for use by secondary school teachers, taking into account the characteristics of the study.

Keywords: iscovery learning, mathematical critical thinking skills, secondary students'.

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1. INTRODUCTION

In the last decade, the Discovery Learning (DL) model in mathematics learning has been widely used because it is recommended in the national curriculum. The DL model supports learning activities that involve students actively making observations, investigations through experiments with scientific steps, and concluding the findings of the processes independently [1]. Therefore, this model has the opportunity and potential to improve mathematical thinking skills, including mathematical critical thinking skills. Critical thinking skills is one of the high-level thinking skills [2]; competencies that are important to have to be able to face and adapt in the present and future globalization era [3]; as well as a skill that one must-have skill to become qualified human resources.

Ennis explained that critical thinking skills are skills that a person has to make effective decisions about what to believe and do [4].

Many studies have examined implementing the DL model to improve students' mathematical critical thinking skills. The majority of the findings in the study agree that the mathematical critical thinking skills of students taught by using the DL model are better than those led by conventional learning [5–28]. However, several other research findings show the opposite results [29, 30]. These differences in findings also indicate that there are multiple measures of effectiveness and tend to reflect inconsistencies in the conclusions from one another. In addition, the influence of study characteristics such as: level of education, research class, treatment duration, and publication index cannot be answered by primary studies, even though in the practice of learning in schools, these characteristics also play a role in influencing learning objectives. Therefore, to obtain more comprehensive and holistic information regarding the effect of applying the DL model on students' mathematical critical thinking skills, meta-analysis can be relied on to achieve these goals [31].

Meta-analysis involves the process of summarizing, reviewing, and analyzing relevant data from previous research and then combining the results to obtain a comprehensive summary of empirical knowledge [32]. Meta-analysis relies on quantitative calculations to get information about the magnitude of influence between variables [33] through the use of the effect size (ES) as the measurement index [34]. Meta-analysis can also analyze the existence of central trends and variability in the findings of previous studies. It can make corrections to errors and biases in research [35].

Meta-analysis research on applying the DL model has been conducted before and found that the application of DL model has a positive effect on students' mathematical critical thinking skills [12]. However, the findings of their meta-analysis study are still limited to the primary school level. They have not analyzed the various characteristics of the study that may affect the effectiveness of applying the DL model. In addition, analysis of sensitivity and publication bias also had not been explicitly described by the authors. Thus, there needs to be further research that is more comprehensive to determine the effectiveness of DL, especially on the mathematical critical thinking skills of secondary school students. Therefore, the authors are motivated to conduct research that aims to evaluate the effect of applying the DL model to secondary school students' mathematical critical thinking skills. This research will fill the gaps in previous research to provide a broader and more contemporary repertoire of information regarding the influence of the DL model in mathematics learning in schools.

2. RESEARCH METHOD

This study uses a systematic review method with formal quantitative statistical analysis, namely meta-analysis. Referring to the PICOS (Population, Interventions, Comparator, Outcomes, and Study Design) approach proposed by [34], the inclusion criteria to be used in this study, including: (1) Population: mathematics education research articles on secondary school students in Indonesia; (2) Intervention: treatment by applying the DL model; (3) Comparator: application of conventional models; (4) Outcomes: mathematical critical thinking skills; (5) Study design: quantitative research; (6) The primary study is limited to research conducted within the last 8 year (from 2013-2020) and has been published in journals and proceedings indexed by Scopus, Thomson Reuter, or Sinta; (7) The studies analyzed in this study contain adequate statistical information, namely the average value, standard deviation, sample size, t-value, and p-value of both the experimental group and the comparison/control group.

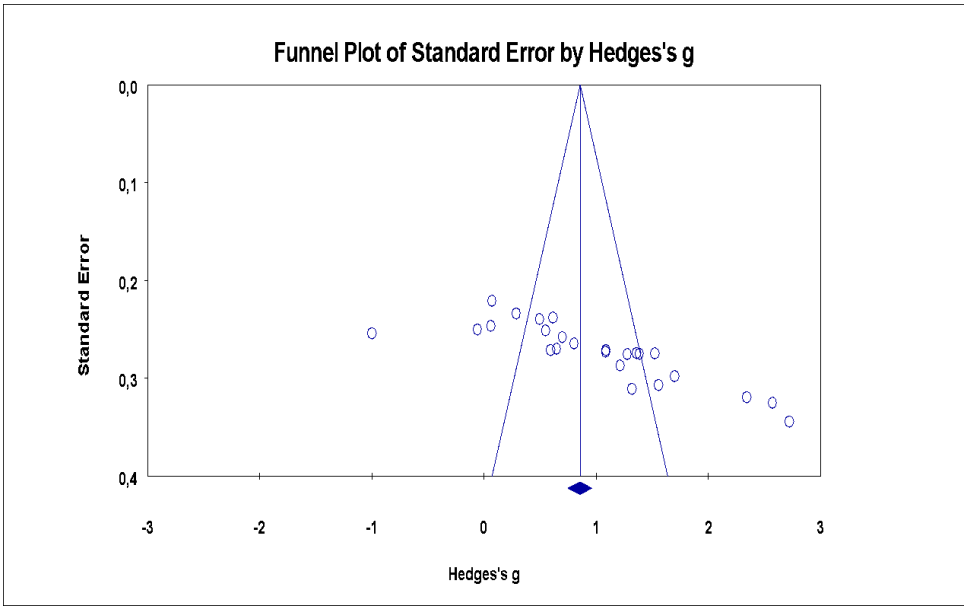

Figure 1: Steps of meta-analysis.

The meta-analysis instrument used was the coding category form to be used for data extraction. The data extraction process was carried out by two coders tested for inter-rater reliability using the Kappa test. In this study, the stages of the meta-analysis method refer to the expert's steps [32, 35], presented in the flow chart in Figure 2. In contrast, the effect size category refers to [36] is shown in Table 1.

TABLE 1: Effect size (es) category.

ES	ES ≤ 0.15	0.15 □ ES ≤ 0.40	0.40 □ ES ≤ 0.75	0.75 □ ES ≤ 1.10	1.10 □ ES ≤ 1.45	1.45 □ ES
Category	Negligible effect	Small effect	Moderate effect	High effect	Very high effect	High influence

3. RESULTS AND DISCUSSION

Searches for relevant primary study articles were carried out through electronic databases related to the DL model's effect on secondary students' critical thinking skills. Based on the initial search with the there were 85 articles. However, through a selection process based on the inclusion criteria specified in the coding protocol, 25 primary studies were obtained that were included in the analysis. Then, data from the 25 primary studies were extracted by two coders. The Kappa coefficient value was 0.85, with the significance of the agreement level of the two coders being in the good category [37]. Subsequently, with assistance from CMA V.3, a sensitivity and publication bias analysis was performed. The bias analysis was performed by interpreting the funnel plot results shown in Figure ??.

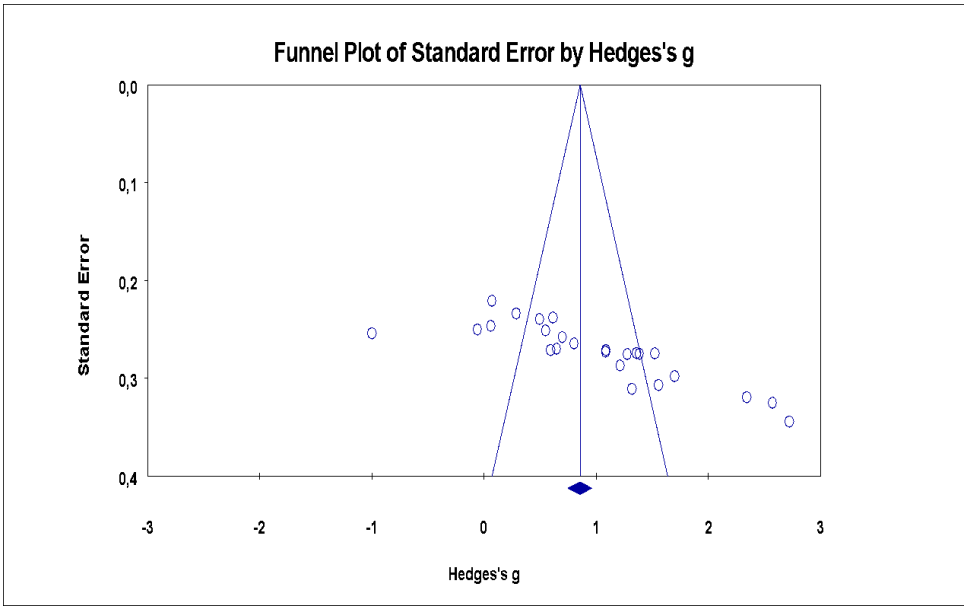

Figure 2: Funnel plot of effect size distribution.

The effect size distribution on the funnel plot spreads fairly evenly and is symmetrical on the left and right of the funnel plot. However, one effect size is on the left, and three effect sizes are pretty far from the distribution of other effect sizes. Therefore, a Trim and Fill test was performed to show whether any studies should be excluded from

the analysis because of their potential to cause bias and Rosental's FSN test to see if included studies were resistant to publication bias.

The Trim and Fill test results show that, for both the right and left sides of the mean effect size, no study needs to be excluded from the analysis. In other words, all primary studies used are feasible and bias-free. This finding is also supported by the results of the third publication bias test, namely the Rosental's FSN test where the value is 13.91 greater than 1. This condition confirms the previous finding that all primary studies used in the meta-analysis were resistant to publication bias. Then, sensitivity analysis using the "One Study Removed" based on the random-effects model, it is found that the most significant mean is ES = 1.025, while the most minor mean is ES = 0.911. This finding reveals that the effect size data set used in this meta-analysis is still stable even when removing one or more effect sizes. The following analysis is to investigate the effect size for each study and the overall effect size. Table 2 presents the effect sizes of the 25 primary studies and their category of effect sizes.

Based on Table 2, four studies with negligible effects, one study with low effect, six studies with moderate effect, three studies with high effects, five studies with very high effects, and six studies with high influence. The most significant effect size is 2.724, while the smallest is -0.995. The next step is to identify the heterogeneity of the effect size distribution to select the appropriate estimation model to test the hypothesis [32]. Referring to the output, the heterogeneity test results of the effect size distribution are presented in Table 3.

Table 3 shows that the overall effect size differs significantly between the two models. Q-value that is greater than the Q-table (df = 24; α = 5%), namely 213.927 > 36.415, indicates that there is heterogeneity in the effect size of the data so that the random-effects model becomes the estimation model used to test the hypothesis [38]. The null hypothesis investigate the significance of the effect of applying the DL model compared to the conventional models on secondary students' mathematical thinking skills. The effect size and null hypothesis test acccording to the random effect model are presented in Table 4.

The null hypothesis testing in Table 4 show that the p-value for the Z statistic is 0.000 < 0.05, which means that the implementation of the DL model has a significant effect on secondary students' mathematical critical thinking skills compared to conventional models. This influence can be measured through an effect size of 0.981, categorized as a high effect. The calculation of the effect size and null hypothesis testing reveals that the DL model is a suitable learning model for use in secondary school because it can improve mathematical critical thinking skills. The syntax of DL model trains students to

Table 2: Effect size category of primary studies analyzed.

Journal Code and Author(s)	ES	Category of ES
A01 (Setiawan, 2015)	1.524	high influence
A02 (Apriza & Mahmudi, 2015)	1.090	high effect
A03 (Samosir & Surya, 2017)	0.290	low effect
A04 (Sulistiani et al., 2017)	1.560	high influence
A05 (Kurniati et al., 2017)	0.702	moderate effect
A06 (Noer, 2018)	2.574	high influence
A07 (Prasetyawan, 2018)	-0.054	negligible effect
A08 (Samosir & Surya, 2018)	0.618	moderate effect
A09 (Meidinda et al., 2018)	0.499	moderate effect
A10 (Widayati et al., 2018a)	0.554	moderate effect
A11 (Widayati et al., 2018b)	0.064	negligible effect
A12 (Puteri et al., 2018)	0.649	moderate effect
A13 (Putri et al., 2018)	1.703	high influence
A14 (Tambunan et al., 2019)	0.805	High effect
A15 (Umayah, 2019)	1.279	very high effect
A16 (Astuti & Syafitri, 2019)	0.074	negligible effect
A17 (Astuti, 2019)	0.596	moderate effect
A18 (Maryana et al., 2019)	-0.995	negligible effect
A19 (Agus, 2019)	1.217	very high effect
A20 (Nugraha et al., 2020)	1.365	very high effect
A21 (Nabela et al., 2020)	2.724	high influence
A22 (Haliyah et al., 2020)	1.088	high effect
A23 (Nurmayani, 2020)	2.347	high influence
A24 (Janah et al., 2020)	1.387	very high effect
A25 (Hartati, 2020)	1.322	very high effect
Combined Effect Size (ES)	0.981	high effect

Table 3: Heterogeneity of the effect size distribution.

Model	ES	Heterogeneity				
		Q-value	df(Q)	P-value	I-squared	Q-table
Fixed	0.857	213.927	24	0.000	88.781	36.415
Random	0.981					

Table 4: Effect size dan null hypothesis test according to random effect model.

Model	Number Studies	Z	p	Effect Size and 95% Confidence Interval				
				Hedge's g	Standard Error	Variance	Lower Limit	Upper Limit
Random	25	6.083	0.000	0.981	0.161	0.026	0.665	1.297

independently find concepts through activities to search, submit and test hypotheses,

and search for supporting sources [1]. Heterogeneity in the primary study shows that the study characteristics also influence the implementation of the DL model. Subsequent analysis was performed and the recapitulation analysis was displayed in Table 5.

Table 5: Summary of analysis results based on study characteristics.

Characteristic of the Study	Group	Number of Studies	Hedge's g	Test of null (2-Tail)		Heterogeneity		
				Z	p	Q	df(Q)	p
Year of Study	2013-2016	6	0.783	3.196	0.001	0.684	1	0.408
	2017-2020	19	1.046	5.197	0.000			
Level of Education	JHS	16	1.017	6.670	0.000	0.070	1	0.791
	SHS	9	0.911	2.450	0.014			
Duration of Treatment	< 4 weeks	1	2.574	7.898	0.000	24.878	2	0.000
	4 ≤ t < 6 weeks	7	1.102	2.264	0.024			
	≥ 6 weeks	17	0.840	6.955	0.000			
Publication Indexed	Google Scholar	9	0.985	4.617	0.000	6.111	2	0.047
	Scopus/WoS	2	1.948	4.955	0.000			
	Sinta	14	0.841	3.615	0.000			

According to Table 5, the p-value on the Z statistic for all study characteristics is less than 0.05. It can be concluded that the implementation of the DL model significantly affects secondary students' mathematical critical thinking skill than the conventional model in terms of all study characteristics. When viewed from the first characteristic, namely the year of study, statistically, the effect size for the 2013-2016 group was a bit higher than the 2017-2020 group, even though both are in the high effect category. The effect size for the 2013-2016 study group was 0.783 (high effect), and the effect size for the 2017-2020 study group was 1.046 (high effect). It is revealed that the use of the DL model in the 2017-2020 timeframe (recent years) is getting better so that teachers can implement the model well and ultimately improve students' critical thinking skills. However, based on the group heterogeneity test, the Q-value was 0.684, while the Q-table (α = 5%; df = 1) was 3.841. Since Q-value < Q-table, it can be concluded that there is no significant difference in effect size between study groups based on the year of study. In other words, the magnitude of the effect of the implementation of the DL model on students' mathematical critical thinking skills between study groups does not differ based on the year of study. This finding is consistent with the previous study result, which found that there were no differences in effects between study groups based on the year of study [29, 39–41].

Based on the level of education, the effect size for both JHS and SHS are not entirely different. ES for JHS was 1.017 and for SHS was 0.911, while both are high effect category. The Q-value is 0.070, which is smaller than the Q-table (α = 5%; df = 1), 3.841. This result means that there is no significant difference in effect size between study groups based on the level of education. This finding is in line with [29, 42], who found that the level of education between study groups was not significantly different.

Meanwhile, according to duration of treatment, the largest effect size was 2.574 (high influence) occurred in studies with treatment duration $<$ 4 weeks, followed by 1.102 (very high effect) at 4 $\leq$ t $<$ 6 weeks, and 0.840 (high effect) at treatment duration $>$ 6 weeks. Descriptively, it can be said that there is a downward trend in the effect of the DL model as the treatment time is longer. In other words, the allocation of discovery learning time that is dense and not too long has the best effect on students' critical thinking skills. The Q-value was 24.878 greater than the Q-table (α = 0.05; df = 2), which was 5.991, indicating a significant difference in effect size between study groups. This result occurred because the implementation of the DL model requires a fairly enough treatment duration of fewer than 4 weeks. Also, adequate duration of treatment and the elaboration will make the retention period longer [29, 42].

In terms of publication indexing, there is a significant difference where the primary study indexed by Scopus/WoS has the most significant effect size of 1.948 (high influence). Meanwhile, the Q-value is 6.111 greater than the Q-table (α = 0.05; df = 2), which was 5.991, indicates a significant difference in effect size between study groups based on the publication indexing. The implementation of the DL model articles published in Scopus are better than those published outside of Scopus. This finding is in line with [39], that the indexer's credibility also affects the benefits of the primary study. Lastly, the findings of this study show that teachers and education practitioners can use the Scopus publication to reference how the DL model can improve secondary students' mathematical critical thinking skills.

4. CONCLUSION

According to the results and findings of the meta-analysis carried out in this study, it could be inferred that the implementation of the DL model positively influences secondary students' mathematical critical thinking skills rather than conventional models. Referring to the combined effect size results with the random effect model, the implementation of the DL model has an effect size of 0.981, which indicates that the

implementation of the DL model contributes a high effect on secondary students' mathematical critical thinking skill. Then, it was found that the magnitude of the effect of the implementation of the DL model on the mathematical critical thinking skill of secondary students between study groups did not differ according to the characteristics of the year of study and level of education. Vice versa, it was found that there were significant differences in effect size between study groups based on the duration of treatment and publisher indexed. Therefore, the implementation of the DL model is powerful and effective in enhancing secondary students' mathematical critical thinking skills by considering the duration of treatment and publisher indexed. This finding contributes information to educators, the government, and other relevant parties regarding the influence of model DL in learning.

However, several weaknesses that follow this meta-analysis study, such as the number of studies included in the analysis, are strongly restricted by inclusion criteria. Only a small number of studies are involved. There are still many other similar studies, but due to the lack of statistical information in the study, this study was not involved in the analysis. Also, the study characteristics discussed in this study are limited to the year of study, level of education, duration of treatment and publisher indexed. It is recommended to consider further research that can analyse more study characteristics such as study area, sampling technique, etc.

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