Heterogeneity of Indonesian primary school students' mathematical critical thinking skills using problem-based learning: A meta-analysis

by Suparman .

Heterogeneity of Indonesian Primary School Students' Mathematical Critical Thinking Skills Through Problem-Based Learning: A Meta-Analysis

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Article Info	Abstract
	The synthesis of some empirical studies revealed that the implementation of problem-based learning (PBL) has a heterogeneous effect size on the mathematical critical thinking skills (MCTS) of primary school students in Indonesia. However, it seems that no studies were investigating the causative factors of the heterogeneity of primary students' MCTS through PBL. Therefore, this meta-analysis study was employed to investigate and examine some potential factors such as PBL class capacity, PBL treatment duration, and mathematics topic predicted as the causative factors of the heterogeneity of primary students' MCTS. The synthesis of ten primary studies published in 2015 – 2020 and indexed by Scopus, Google Scholar, Sinta, and Web of Science, showed that PBL treatment duration and mathematics topic were the significant factors causing the heterogeneity of primary students' MCTS. However, PBL class capacity was not a significant factor causing the heterogeneity of primary students' MCTS. Thus, primary school mathematics teachers should consider PBL treatment duration established and mathematics topic selected in cultivating primary students' MCTS by implementing PBL. Keywords: Heterogeneity, Mathematical Critical Thinking Skills; Meta-Analysis; and Problem-Based Learning.

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Introduction

Hoax information, information that is not justified in its truth and trustworthiness (Epafras et al., 2019), is one of the negative effects of information abundance in the 21st – century in which someone deploys it to other individuals without the process of analyzing, filtering, and clarifying. The deployment of hoax information is conducted by some individuals because they have low critical thinking skills in evaluating the truth of the information (Bellamy, 2007). Critical thinking skill is a complex and essential skill of the higher-order thinking process that involves some accurate and precise evaluation processes of information such as analyzing, filtering, clarifying, interpreting, and explaining (Kong, 2015; Sanders, 2016). Since it is one of the 21st – century skills (Sanabria & Arámburo-Lizárraga, 2017; Silber-Varod et al., 2019; Voogt & Roblin, 2012), mathematics learning in the 21st – century should be designed so that students can cultivate their mathematical critical thinking skills (MCTS).

To cultivate students' MCTS, some Indonesian mathematics teachers in primary school select problem-based learning (PBL) as one of the alternative mathematics learnings. It is a learning approach that begins a certain topic with complex problems (Savery, 2006; Suparman, Juandi, & Herman, 2021). It is selected as one of the best solutions because its design can

accommodate the enhancement of learning quality by developing students' critical thinking and problem-solving skills (Suparman, Juandi, & Tamur, 2021b; Yew & Goh, 2016). Also, it can create students as critical individuals who can analyze, verify, and justify the truth and validity of information so that they can employ the information accurately and correctly (Du et al., 2013; Nargundkar et al., 2014; Neber & Neuhaus, 2013). Therefore, primary mathematics teachers implement it to increase students' low MCTS.

Several reports related to the PBL implementation on the primary school students' MCTS in Indonesia revealed that the PBL implementation has a strong effect on the students' MCTS (Ahdhianto et al., 2020; Alnita & Arifin, 2017; Buana et al., 2020; Pramestika et al., 2020; Soraya et al., 2018; Suprapto et al., 2020; Umar et al., 2020). In the other side, some similar reports revealed that the PBL implementation has a moderate effect on the students' MCTS (Haerani et al., 2019; Karyono & Subhananto, 2015; Primayanti et al., 2019). The findings of these reports show that the effect of the implementation of PBL on the primary students' MCTS is heterogeneous. Unfortunately, the factors causing the heterogeneity of the primary students' MCTS through PBL have not been found and reported comprehensively. Meanwhile, clear and accurate information regarding the causative factors creating the heterogeneity of students' MCTS through PBL is required by mathematics teachers in primary school specifically. They need some information such as on what class capacity, with how long the treatment duration, and on what mathematics topic, the PBL implementation is most effective in cultivating primary students' MCTS.

A meta-analysis is one of the best studies that can provide this clear and accurate information. It is a series of statistical methods that synthesize some similar quantitative primary studies to provide summarization, estimation, and evaluation regarding the effect size of one variable to another variable (Borenstein et al., 2009). Furthermore, several meta-analysis studies regarding the investigation of heterogeneous students' MCTS through PBL have been carried out by some researchers (Suparman, Juandi, & Tamur, 2021a, 2021c; Suparman, Tamur, et al., 2021; Yohannes et al., 2020). However, they study heterogeneity of Indonesian high and vocational school students' MCTS (Yohannes et al., 2020), and heterogeneity of students' MCTS in the various education level in Indonesia (Suparman, Juandi, & Tamur, 2021a, 2021c; Suparman, Tamur, et al., 2021). Meanwhile, this study focuses on the heterogeneity of Indonesian primary school students' MCTS. Therefore, this recent study aims to investigate and examine some potential factors such as PBL class capacity, PBL treatment duration, and mathematics topic predicted as the causative factors of the heterogeneity of students' MCTS.

the Research Methods

This study employed meta-analysis by selecting the random effect model (Borenstein et al., 2009). There were five steps to carry out this study (Cooper et al., 2013; Hunter & Schmidt, 2004). Firstly, we established some inclusion criteria. The inclusion criteria referred to PICOS (Population, Intervention, Comparator, Outcome, and Study Design) approach (Liberati et al., 2009). The inclusion criteria of this study were: (1) every study provided completely statistical data such as t-value, p-value, sample size (N), standard deviation (SD), and mean; (2) every study was journal or proceeding articles published in 2015 – 2020 and indexed by Sinta, Google Scholar, Scopus, and Web of Science; (3) study design of the selected study was quasi-

experiment research with the posttest only control group design; (4) outcome of the selected study was MCTS; (5) comparator of the selected study was conventional learning (CL); (6) intervention of the selected study was PBL, and (7) population of the selected study was primary school students in Indonesia. Primary studies that were not suitable to the inclusion criteria were excluded from this study.

Secondly, we searched for primary study. Semantic Scholar and Google Scholar were search engines used to find primary study. Also, we combined some keywords such as "problem-based learning and mathematical critical thinking skills" or "problem-based learning and mathematical critical thinking abilities" to ease the search for primary study.

Thirdly, we selected every primary study. Liberati et al. (2009) revealed that there were four steps to select the primary studies, namely: (1) identification; (2) screening; (3) eligibility; and (4) inclusion. We selected every primary study based on its title in the identification step. Also, we selected every primary study based on its abstract in the screening step. In addition, we selected every primary study based on the inclusion criteria in the eligibility step. Lastly, we selected every primary study based on the publication bias test in the inclusion step. The unselected primary studies were excluded from this study.

Fourthly, we extracted numerical data and categorical data from every primary study to the coding sheet. To complete the missing numerical and categorical data in the coding sheet, we communicated to the authors by using e-mail. In addition, we involved two coders to verify that the results of data extraction were valid and reliable (Vevea et al., 2019). To measure the consistency of the data extraction results conducted by these coders, we employed Cohen's Kappa test (McHugh, 2012). Furthermore, these Cohen's Kappa values were interpreted as $\kappa = 0,00 - 0,20$ (none), $\kappa = 0,21 - 0,39$ (minimal), $\kappa = 0,40 - 0,59$ (weak), $\kappa = 0,60 - 0,79$ (moderate), $\kappa = 0,80 - 0,90$ (strong), and $\kappa > 0,90$ (almost perfect) (McHugh, 2012). The calculation of Cohen's Kappa test used SPSS software.

Fifthly, we analyzed data. To measure the effect size, we used Hedge's equation (Borenstein et al., 2009), because it accommodated a relatively small sample size (Lipsey & Wilson, 2001). These effect size values were categorized as $g = 0,00 - 0,20$ (weak), $g = 0,21 - 0,50$ (modest), $g = 0,51 - 1,00$ (moderate), and $g > 1,00$ (strong) (Cohen et al., 2018). Also, we conducted publication bias analysis by using Rosenthal's FSN test to justify that the effect size data was resistant to publication bias (Rothstein et al., 2005) and sensitivity analysis by using the "one study removed" tool in CMA software to justify that the effect size data were normal and stable (Bernard et al., 2014). In addition, we employed the Z test to justify the significance of PBL implementation on the primary students' MCTS in every factor (Borenstein et al., 2009). Furthermore, we carried out heterogeneity analysis by using the Q Cochrane test to justify the significance of PBL class capacity, PBL treatment duration, mathematics topic, and students' demography as the causative factors of the heterogeneity of primary students' MCTS (Higgins et al., 2003). All of the data analysis used Comprehensive Meta-Analysis (CMA) software.

the Results of the Research and the Discussion

Search and Selection of Primary Study

The search process using some keywords such as "mathematical critical thinking skills and problem-based learning" or "mathematical critical thinking abilities and problem-based learning", we found 40 primary study titles from Google scholar and 50 primary study titles from Semantic scholar. Furthermore, the selection process of primary studies is presented in Figure 1.
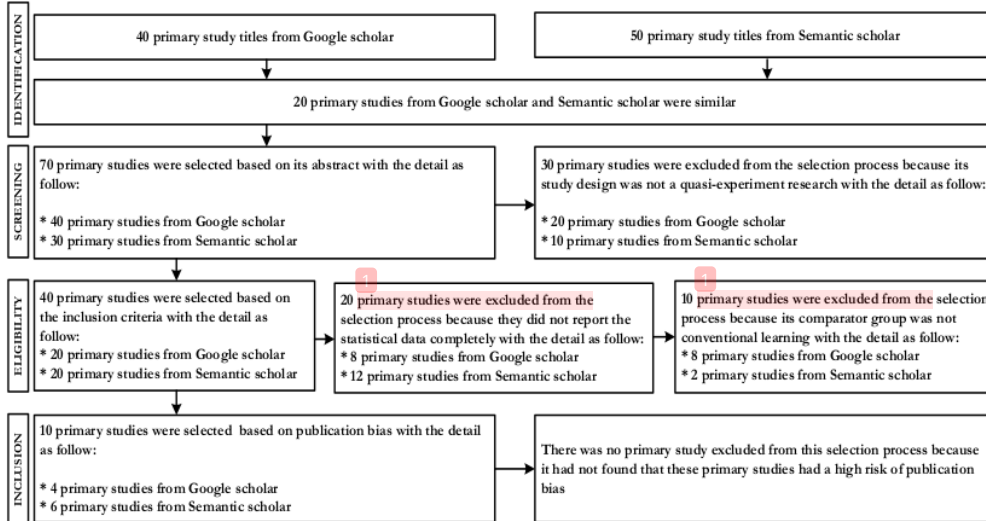

Figure 1. The Selection Process of Primary Study

Based on the results of the primary study selection process, we established ten primary studies consisting of four primary studies from Google scholar (Haerani et al., 2019; Karyono & Subhananto, 2015; Primayanti et al., 2019; Soraya et al., 2018) and six primary studies from Semantic scholar (Ahdhianto et al., 2020; Alnita & Arifin, 2017; Buana et al., 2020; Pramestika et al., 2020; Suprapto et al., 2020; Umar et al., 2020) to be used as the data in this study.

Data Extraction

The results of numerical data extraction such as t-value, p-value, SD, N, and mean are presented in Table 1.

Table 1. the Results of Numerical Data Extraction

Citation	Numerical Data						t-value	P-value
	PBL			CL				
	Mean	SD	N	Mean	SD	N		
(Ahdhianto et al., 2020)	76,74	10,90	39	64,83	11,48	39		
(Buana et al., 2020)	39,04	7,45	23	29,52	5,79	23		
(Alnita & Arifin, 2017)	70,03	10,19	30	52,73	8,92	30		
(Umar et al., 2020)	51,00	9,80	36	36,00	6,80	38		
(Pramestika et al., 2020)	81,47	17,24	32	64,17	16,60	30		

(Suprapto et al., 2020)	27	28	-14,76	
(Haerani et al., 2019)	28	28	2,799	
(Karyono & Subhananto, 2015)	45	45	2,654	
(Primayanti et al., 2019)	25	30		0,025
(Soraya et al., 2018)	27	31		0,000

The results of categorical data extraction such as PBL class capacity, PBL treatment duration, mathematics topic, indexer, and publication type are presented in Table 2.

Table 2. the Results of Categorical Data Extraction

Citation	Potential Factor			Indexer	Publication Type
	PBL Class Capacity	PBL Treatment Duration	Math Topic		
(Ahdhianto et al., 2020)	> 28	3 < t <= 6	Number	Scopus	Journal
(Buana et al., 2020)	<= 28	t > 6	Number	Sinta	Journal
(Alnita & Arifin, 2017)	> 28	1 < t <= 3	Geometry	Google Scholar	Journal
(Umar et al., 2020)	> 28	1 < t <= 3	Geometry	Web of Science	Proceeding
(Pramestika et al., 2020)	> 28	3 < t <= 6	Number	Sinta	Journal
(Suprapto et al., 2020)	<= 28	t > 6	Geometry	Google Scholar	Journal
(Haerani et al., 2019)	<= 28	t <= 1	Statistics	Sinta	Journal
(Karyono & Subhananto, 2015)	> 28	t <= 1	Statistics	Sinta	Journal
(Primayanti et al., 2019)	<= 28	t <= 1	Statistics	Sinta	Journal
(Soraya et al., 2018)	<= 28	1 < t <= 3	Number	Sinta	Journal

Table 3 reveals that the agreement level of two coders on the items in the coding sheet was moderate, strong, or almost perfect (McHugh, 2012). Moreover, these results showed that all of significance values of Cohen's Kappa test in every item were less than 0.05. These findings interpret that these coders significantly agree the data extraction results of every item in the coding sheet (Cooper et al., 2013).

Table 3. The Results of the Cohen's Kappa Test

Item	Kappa Value	Agreement Level	Significance Value
Citation	0,814	Strong	0,023
PBL group mean	0,956	Almost perfect	0,004
PBL group standard deviation	0,916	Almost perfect	0,007
PBL sample size	0,934	Almost perfect	0,005
CL group mean	0,923	Almost perfect	0,006
CL group standard deviation	0,945	Almost perfect	0,004
CL group sample size	0,937	Almost perfect	0,005
t-value	0,967	Almost perfect	0,003
p-value	0,971	Almost perfect	0,002
PBL class capacity	0,854	Strong	0,021
PBL treatment duration	0,887	Strong	0,019
Mathematics topic	0,831	Strong	0,022
Publication type	0,861	Strong	0,020

Publication year	0,856	Strong	0,021
Indexer	0,799	Moderate	0,030
Search engine	0,704	Moderate	0,034
Journal and proceeding name	0,761	Moderate	0,032
Publisher	0,724	Moderate	0,033
Author's email	0,754	Moderate	0,033
Tracing link	0,722	Moderate	0,033

Sensitivity and Publication Bias

Rosenthal's FSN test was carried out to verify that the effect size collection was resistant of publication bias (Rothstein et al., 2005). The results of Rosenthal's FSN test are presented in Table 4.

Table 4. The Results of the FSN Test

Classic Fail-Safe N	
Z-value	14,366
P-value	0,000
FSN value	528,00

Table 2 reveals that the p-value of the Z statistics was less than 0.05. It interprets that the effect size collection is resistant of publication bias indication.

Sensitivity analysis was conducted to verify that the effect size collection was normal and stable from the change of sample size and effect size (Bernard et al., 2014). Analysis of effect size data using the "one study removed" tool in CMA software shows that the highest effect size was $g = 1,447$ and the lowest effect size was $g = 1,112$. Meanwhile, the overall effect size was $g = 1,350$. These findings indicate that the overall effect size is between the lowest effect size and the highest effect size. It interprets that the effect size collection is stable and normal from the change of sample size and effect size. Thus, the effect size collection is not sensitive.

Heterogeneity of Primary School Students' MCTS Through PBL

In this study, we investigated and examined four factors that were predicted as the causative factors of the heterogeneity of primary students' MCTS through PBL. These factors were PBL class capacity, PBL treatment duration, and mathematics topic. These factors were selected because they were substantive factors (Lipsey & Wilson, 2001).

PBL Class Capacity

The factor of PBL class capacity consisted of two groups that were PBL class with a maximum capacity of 28 students and PBL class with a minimum capacity of 29 students (Indonesian Minister of education & culture regulation No.17, 2017). The overall effect size of PBL on the students' MCTS based on PBL class capacity is presented in Figure 2.
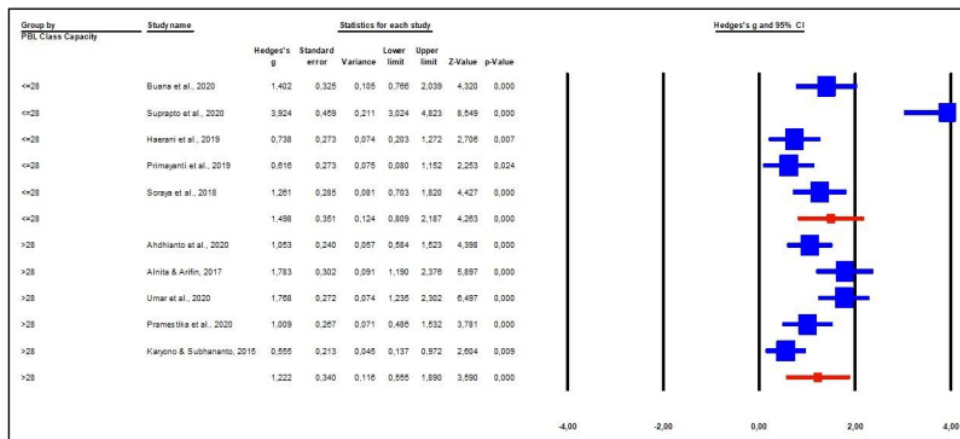
Figure 2. The Effect Size of PBL on the Primary Students' MCTS Based on PBL Class Capacity

Figure 2 reveals that the effect size of PBL on the students' MCTS in the class with a maximum capacity of 28 students was g = 1,498 and it was categorized as a strong effect (Cohen et al., 2018). Meanwhile, the effect size of PBL on the students' MCTS in the class with a minimum capacity of 29 students was g = 1,222 and it was categorized as a strong effect (Cohen et al., 2018). Moreover, the p-values of the Z statistic in the class with a maximum capacity of 28 students and the class with a minimum capacity of 29 students were less than 0,05. These findings interpret that the PBL implementation has a positive effect significantly on the primary students' MCTS in the class with a maximum capacity of 28 students and the class with a minimum capacity of 29 students. Also, some meta-analysis studies showed that the PBL implementation had a positive effect significantly on the students' MCTS in the class with a maximum capacity of 30 students and the class with a minimum capacity of 31 students (Suparman, Juandi, & Tamur, 2021a, 2021c; Suparman, Tamur, et al., 2021; Yohannes et al., 2020). These reports give strict evidence that the PBL implementation in the class with a maximum capacity of 28 students and the class with a minimum capacity of 29 students is effective to cultivate students' MCTS.

The results of heterogeneity analysis based on the factor of PBL class capacity are presented in Table 5.

Table 5. The Results of the Q Cochrane Test of PBL Class Capacity Factor

PBL Class Capacity	Studies Number	Hedge's g	Heterogeneity Analysis		
			Q-value	df(Q)	P-value
n ≤ 28 students	5	1,498	0,318	1	0,573
n > 28 students	5	1,222			

Note: n = class capacity

Table 3 reveals that the p-value of the Q Cochrane statistic was more than 0,05. It indicates that PBL class capacity is not the significant factor causing the heterogeneity of students' MCTS. It means that the strong effect or the moderate effect of PBL on the students' MCTS are not

affected by the factor of PBL class capacity. Also, Suparman et al. (2021a) and Yohannes et al. (2020) revealed that the heterogeneity of students' MCTS through PBL was not caused by the factor of PBL class capacity. In addition, the effect size of PBL on the students' MCTS in the class with a maximum capacity of 28 students was stronger than the effect size of PBL on the students' MCTS in the class with a minimum of 29 students. Moreover, several meta-analysis studies revealed that the PBL implementation in the class with a maximum capacity of 30 students was greater than the PBL implementation in the class with a minimum capacity of 31 students in enhancing students' MCTS (Suparman et al., 2021; Suparman, Juandi, & Tamur, 2021a; Yohannes et al., 2020). These findings support that the PBL implementation in the class with a maximum capacity of 28 students is more effective than the implementation of PBL in the class with a minimum capacity of 29 students to cultivate primary students' MCTS.

PBL Treatment Duration

The factor of PBL treatment duration consisted of four groups that were $t \leq 1$, $1 < t \leq 3$, $3 < t \leq 6$, and $t > 6$ in which t was treatment duration in month unit (Indonesian Minister of Education and Culture Regulation No. 22, 2016). The overall effect size of PBL on the students' MCTS based on PBL treatment duration is presented in Figure 3.
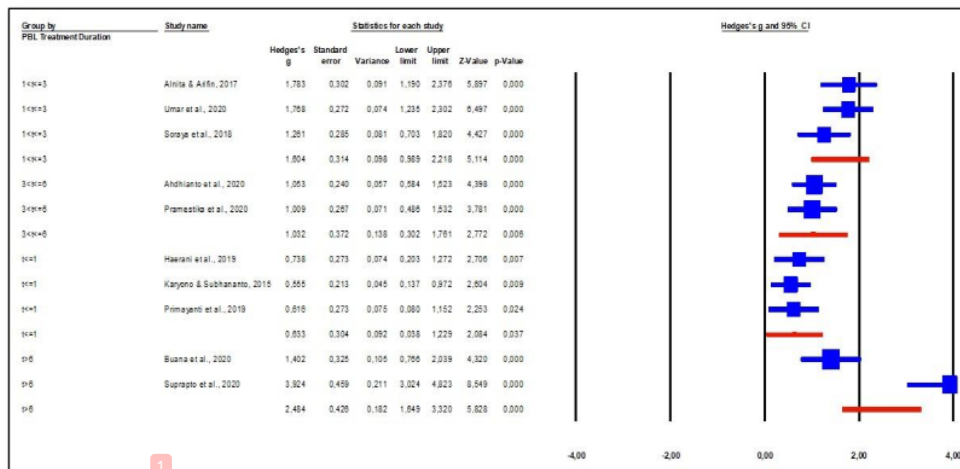

Figure 3. The Effect Size of PBL on the Primary Students' MCTS Based on PBL Treatment Duration

Figure 3 reveals that the effect size of PBL with a maximum treatment duration of 1 month on the students' MCTS was g = 0,633 and it was categorized as a moderate effect (Cohen et al., 2018). Meanwhile, other effect sizes of PBL on the students' MCTS based on PBL treatment duration were g = 1,604 (PBL with a maximum treatment duration of 3 months and a treatment duration of more than 1 month), g = 1,032 (PBL with a maximum treatment duration of 6 months and a treatment duration of more than 3 months), and g = 2,484 (PBL with a treatment duration of more than 6 months). These effect sizes were categorized as a strong effect (Cohen et al., 2018). In addition, every p-value of the Z statistic of PBL treatment duration groups was less than 0,05. It interprets that the PBL implementation in every treatment duration category

has a positive effect significantly on the primary students' MCTS. Dagyar & Demirel (2015) also revealed that in every category of PBL treatment duration, the PBL implementation affected positively the students' mathematics achievement. It means that the implementation of PBL based on its treatment duration is effective to cultivate primary students' MCTS.

The results of heterogeneity analysis based on the factor of PBL treatment duration are presented in Table 6.

Table 6. The Results of the Q Cochrane Test of PBL Treatment Duration Factor

PBL Treatment Duration	Studies Number	Hedge's g	Heterogeneity Analysis		
			Q-value	df(Q)	P-value
t ≤ 1 month	3	0,633			
1 month < t ≤ 3 months	3	1,604	13,986	3	0,003
3 months < t ≤ 6 months	2	1,032			
t > 6 months	2	2,484			

Note: t = treatment duration

Table 6 reveals that the p-value of the Q Cochrane statistic was less than 0,05. It interprets that the factor of PBL treatment duration is one of the significant factors causing the heterogeneity of primary students' MCTS. Yunita et al. (2020) also found that PBL treatment duration was one of the significant factors affecting the heterogeneity of students' mathematical creative thinking skills. It means that the strong or moderate effect size of the PBL implementation on the primary students' MCTS is affected by the factor of PBL treatment duration. In addition, the effect of PBL on the students' MCTS tended to be stronger if its treatment duration was longer. Moreover, the effect size of PBL with a treatment duration of more than 6 months was stronger than the effect size of PBL with a maximum treatment duration of 6 months in cultivating primary students' MCTS. It interprets that the implementation of PBL with a treatment duration of more than 6 months is more effective than the implementation of PBL with a maximum treatment duration of 6 months in cultivating primary students' MCTS.

Mathematics Topic

The factor of mathematics topic consisted of three groups that were geometry, number, and statistics (Indonesian Minister of Education and Culture Regulation No. 21, 2016). Figure 4 reveals that the effect size of PBL on the students' MCTS in number topic was g = 1,171 (strong effect). Moreover, the effect size of PBL on the students' MCTS in geometry topic was g = 2,295 (strong effect). Meanwhile, the effect size of PBL on the students' MCTS in statistics topic was g = 0,632 (moderate effect) (Cohen et al., 2018). Also, every p-value of the Z statistic in every mathematics topic group was less than 0,05. These findings indicate that the PBL implementation in geometry topic, number topic, and statistics topic has positive effect significantly on the primary students' MCTS. Dagyar and Demirel (2015) also found that the implementation of PBL based on a scientific field such as natural sciences, mathematics, health sciences, social sciences, and computer sciences affected positively students' mathematics achievement. It interprets that to cultivate primary students' MCTS, the PBL implementation in geometry, numbers, and statistics topic is effective.

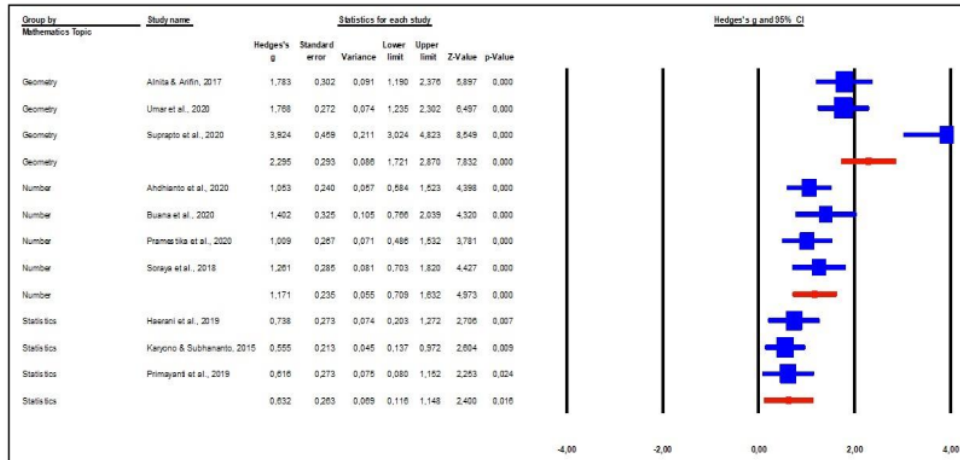The overall effect size of PBL on the students' MCTS based on mathematics topics is presented in Figure 4.

Figure 4. The Effect Size of PBL on the Primary Students' MCTS Based on Mathematics Topic

Table 7 shows that the p-value of the Q Cochrane statistic was less than 0,05. It interprets that the mathematics topic is one of the significant factors affecting the heterogeneity of primary school students' MCTS through PBL. It means that the strong or moderate effect of PBL on the primary students' MCTS is caused by the factor of mathematics topic. Meanwhile, Dagyar and Demirel (2015) found that the factor of the scientific field did not cause the heterogeneity of students' mathematics achievement using PBL. These reports interpret that mathematics topics or scientific fields are not a significant causative factor consistently of the heterogeneous students' mathematics achievement that is specifically students' MCTS. In addition, the effect of PBL in geometry topic on the students' MCTS was stronger than the effect of PBL in number and statistic topic on the students' MCTS. It means that the implementation of PBL in geometry topic is more effective than the implementation of PBL in number and statistic topic on the primary students' MCTS. The results of heterogeneity analysis based on the factor of mathematics topic are presented in Table 7.

Table 7. The Results of the Q Cochrane Test of Mathematics Topic Factor

Mathematics Topic	Studies Number	Hedge's g	Heterogeneity Analysis		
			Q-value	df(Q)	P-value
Geometry	3	2,295			
Number	4	1,171	18,267	2	0,000
Statistics	3	0,632			

Conclusion and Suggestion

The synthesis of ten primary studies provides some information that the heterogeneity of primary students' MCTS through PBL is affected by some factors such as mathematics topic

and PBL treatment duration. Meanwhile, PBL class capacity factor does not affect the heterogeneity of primary students' MCTS. Also, this study provides some information that the most effective PBL implementation in cultivating primary students' MCTS when it is implemented in the class with a maximum capacity of 28 students, on geometry topic, and with a treatment duration of more than six months. Therefore, this study suggests to mathematics teachers in primary school that they should implement PBL in the class with a maximum capacity of 28 students and with a treatment duration of more than six months. Also, they should improve their students' MCTS in other mathematics topic such as statistics topic by enhancing their effort in implementing PBL in the mathematics classroom. In addition, for further meta-analysis study regarding this topic, researchers should investigate and examine another potential causative factor of the heterogeneous primary students' MCTS through PBL such as research year, students' demography, students' prior mathematics skills, and professional and pedagogical mathematics teacher skill level.

Acknowledgement

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