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Does Treatment Duration of Problem-Based Learning Moderate Heterogeneity of Students' Mathematical Critical Thinking Skills? A Meta-Analysis

Suparman[1*], Dadang Juandi[1], Bambang Avip Priatna Martadiputra[1]

1 Department of Mathematics Education, Faculty of Mathematics and Sciences Education, Universitas Pendidikan Indonesia

*Corresponding author: Jalan Dr. Setiabudhi No. 229, Bandung, Jawa Barat, 41054, Indonesia. e-mail addresses: arman95@upi.edu

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abstract

This study aims to investigate and examine PBL treatment duration predicted as a potential factor moderating heterogeneity of students' MCTS. A meta-analysis by selecting the random effect model was employed to conduct this study. Data analysis used the Q Cochrane test and Z test supported by Comprehensive Meta-Analysis (CMA) software. A literature search found 220 documents, and the final literature selection established 23 documents in journal articles and 4 documents in proceeding articles indexed by Scopus, Google Scholar, or Web of Science and published in the period of 2013 – 2021. The results revealed that the p-value of the Q statistic related to the factor of PBL treatment duration was less than 0,05 (p = 0,535). It indicates that PBL treatment duration is not a significant factor moderating heterogeneity of students' MCTS. It interprets that the gap of students' MCTS level through PBL is not caused by the treatment duration factor. Furthermore, PBL treatment in the period of 3 – 6 months was more effective to enhance students' MCTS than PBL treatment duration was less than 3 months or more than 6 months. For a further similar meta-analysis study, other researchers should investigate and examine other potential factors such as PBL class capacity and students' demography that are able to moderate heterogeneity of students' MCTS.

Keywords:
Heterogeneity, Mathematical Critical Thinking Skills, Meta-Analysis, Problem-Based Learning, Treatment Duration

INTRODUCTION

Critical thinking skill, one of the essential 21st-century skills (Sanabria & Arámburo-Lizárraga, 2017; Silber-Varod et al., 2019), is a thinking process carefully to clarify every individual's understanding of received information and make a smart and logical decision on the information (Chaffee, 2017; Sanders, 2016). The cultivation of students' critical thinking skills through formal education such as mathematics learning in school or college is one of the ways to minimize the deployment of hoax information. It is a piece of information that is not justified in its truth and trustworthiness (Epafras et al., 2019). Deployment hoax information carried out by students can be happened because of the low critical thinking skills that they have (Bellamy, 2007). Therefore, students' critical thinking skills have to be cultivated in mathematics learning specifically by implementing supporting learning such as problem-based learning (PBL) (Hanum et al., 2019; Tabun et al., 2020).

The cultivation of mathematical critical thinking skills (MCTS) through PBL is one of the best solutions that mathematics teachers can conduct. Some theoretical evidence in various literature (e.g., Hmelo-Silver (2004), Othman et al. (2013), Savery (2006), Torp & Sage (2002), Yew & Goh (2016)) revealed that PBL could facilitate students in developing their MCTS through the design of its phases supporting them to think critically. Some empirical studies related to the PBL implementation for students' MCTS showed that PBL had a strong positive effect on students' MCTS (Ahdhianto et al., 2020; Buana et al., 2020; Ramadhani et al., 2020; Umar et al., 2020; Zetriuslita et al., 2017; Zetriuslita & Ariawan, 2021). Other empirical studies also showed that PBL had a moderate positive effect on students' MCTS (Arviana et al., 2018; Apriliana et al., 2019; Ayuni et al., 2021; Darhim et al., 2020; Haerani et al., 2019; Prihono & Khasanah, 2020; Yolanda, 2019). Some empirical studies, however, revealed that PBL had a modest positive effect on students' MCTS (Hendriana et al., 2013; Islahuddin et al., 2018; Ratnawati et al., 2020; Sunaryo, 2014; Widada et al., 2019). Moreover, other empirical studies revealed that PBL had a weak positive effect on students' MCTS (Arifin et al., 2020; Marinda et al., 2018; Sari et al., 2020; Sumarmo, 2012). These findings indicate that the effect of PBL on students' MCTS is heterogeneous.

Heterogeneity of students' MCTS through PBL indicates that there is a gap in students' MCTS levels. The students' MCTS level gap is very possible to be moderated by some substantial factors such as students' education level, PBL treatment duration, students' demography, PBL class capacity, and mathematical content. Lipsey & Wilson (2001) mentioned that there were three factors that could cause heterogeneous effect size, namely: substantial factor, extrinsic factor, and methodological factor. So, these substantial factors have to be investigated and examined the significance of their role in moderating heterogeneity of students' MCTS through PBL.

Meta-analysis is a series of statistical methods synthesizing some similar studies to provide summarization, estimation, evaluation, and prediction regarding the strength between two variables or more by using effect size as a measurement unit (Borenstein et al., 2009; Cumming, 2012). It is the best way to investigate and examine the role of these potential factors in moderating heterogenous MCTS of students by implementing PBL because some literature (e.g., Littell et al. (2008), Shelby & Vaske (2008)) stated that meta-

analysis provided some advantages such as providing strong evidence in rejecting significance and a rigorous methodology in the synthesis process.

Several meta-analysis studies regarding the role of substantial factors in moderating heterogeneity of students' MCTS through PBL have been carried out massively (Nugraha & Suparman, 2021a, 2021b; Suparman et al., 2021a, 2021b, 2021c; Suparman, Juandi, et al., 2021a, 2021b, 2021c). Some literature (e.g., Suparman, Juandi, et al. (2021a, 2021b), Suparman et al. (2021a, 2021b), Nugraha and Suparman (2021a)) reported that PBL class capacity was not a significant factor moderating the heterogeneous MCTS of students. In addition, Suparman, Juandi, et al. (2021a) reported that students' education level was not a significant moderating factor related to the heterogeneity of students' MCTS through PBL, meanwhile, other literature reported that the heterogenous MCTS of students through PBL were moderated by education level factor (Suparman, Juandi, et al., 2021b; Suparman et al., 2021c). Also, some literature reported that students' demography moderated the heterogeneous MCTS of students through PBL (Nugraha & Suparman, 2021b; Suparman, Juandi, et al., 2021b), other literature, however, reported that students' demography did not moderate heterogeneity of students' MCTS through PBL (Suparman et al., 2021b; Suparman, Juandi, et al., 2021a). Nugraha and Suparman (2021a) have been studied related to the role of PBL treatment duration in moderating the students' heterogeneous MCTS. However, they only focus on the heterogeneity of elementary school students' MCTS. Meanwhile, this current study focuses on the role of PBL treatment duration in moderating the heterogeneous MCTS of primary, secondary and college students.

PBL treatment duration is one of the possible potential factors moderating the heterogeneous MCTS of students. This factor is related to the period established in implementing PBL that its duration is customized based on the breadth and difficulty of mathematics material. This factor is interesting and important to be explored because the results regarding whether treatment duration established are suitable or unsuitable to mathematics material breadth and difficulty provide beneficial information for mathematics teachers and lecturers specifically. Also, Nugraha and Suparman (2021a) have reported that PBL treatment duration significantly moderated the heterogeneity of elementary students' MCTS. Therefore, the purpose of this recent study is to investigate and examine PBL treatment duration as a possible potential factor in moderating the heterogeneous MCTS of students in various education levels.

METHODS

To conduct this study, we employed meta-analysis by selecting the random effect model (Borenstein et al., 2009; Cumming, 2012). Some literature (e.g., Cooper et al. (2013), Hunter & Schmidt (2004)) stated that there were seven steps to conduct a meta-analysis study. These steps are presented in Figure 1.

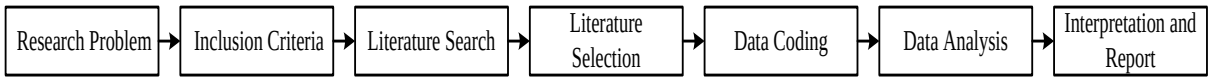

Figure 1
Meta-Analysis Steps

Inclusion Criteria

To provide accurate and clear solutions to this study's problems, we established some inclusion criteria to limit them. We referred PICOS (Population, Intervention, Comparator, Outcome, Study design) approach to establish it (Liberati et al., 2009). Some inclusion criteria were: (1) document was published in the period of 2013 – 2021; (2) document was journal or proceeding articles indexed by Scopus, Web of Science, or Google Scholar; (3) document reported the sufficient statistics to compute an effect size such as sample size (N), standard deviation (SD), mean, t-value, or p-value; (4) population was elementary, secondary, and college students in Indonesia; (5) study design was a quasi-experiment; (6) intervention was PBL; (7) outcome was MCTS; and (8) comparator was conventional learning (CL). The inclusion criteria were expected to focus on searching and selecting literature.

Literature Search and Selection

Some databases such as Google Scholar, Semantic Scholar, and DOAJ were used to search literature. By using some combinational keywords such as mathematical critical thinking skills and problem-based learning or mathematical critical thinking abilities and problem-based learning, we found 81 documents from DOAJ, 157 documents from Semantic Scholar, and 191 documents from Google Scholar. These documents were selected by referring to study selection steps (Moher et al., 2009). The selection process of documents is presented in Figure 2.

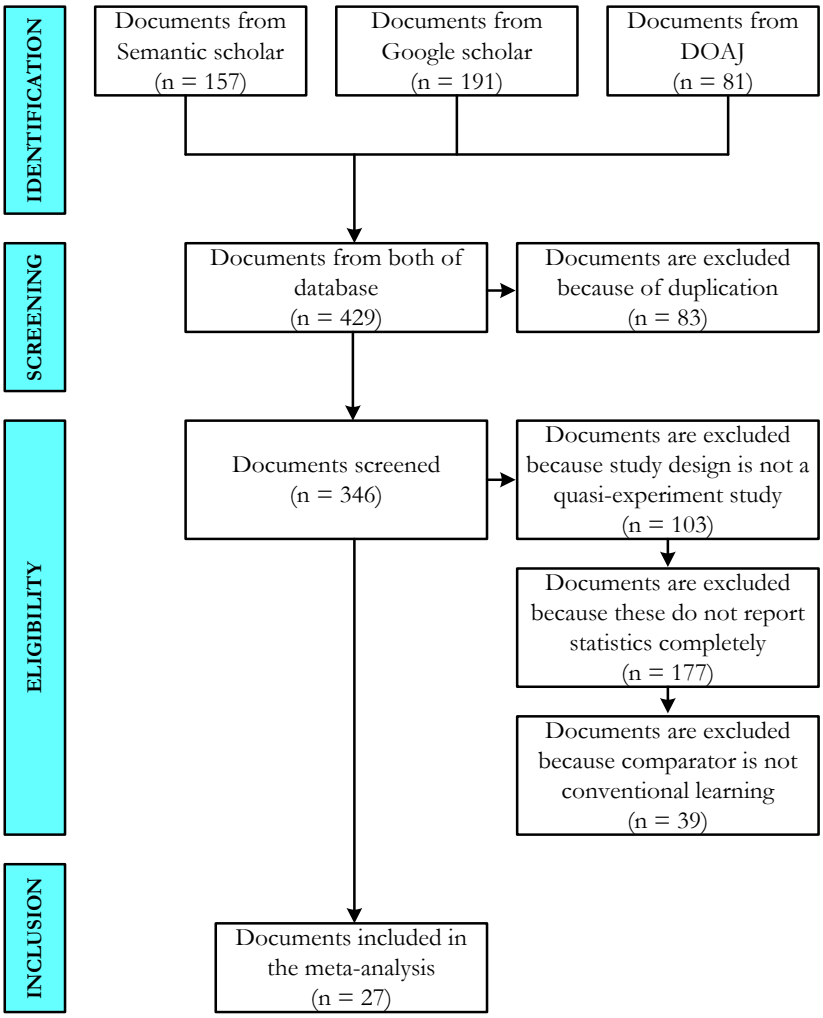

Figure 2
Literature Selection Process

From four steps of the document's selection process stated by Moher et al. (2009), the title of document was used to select those in the identification step. Furthermore, the document was selected based on the content of abstract in the screening step and based on the inclusion criteria established in the eligibility step. Every document that had filled the inclusion criteria was included to be coded and analyzed. From the document selection process, we included 27 documents to be coded and analyzed. From these documents, there was one documents in Maulana (2016) providing two effect sizes. So, these documents provided 28 effect sizes.

Data Coding

Some data such as author, statistics information, PBL treatment duration, database, indexer, publication year, and publication type were coded from every document to coding form developed by the lead author. In detail, the document was opened and the coding sheet also was prepared. The data was transformed from every document to the coding sheet. Specifically, some information such as author and publication year was obtained in the document identity, followed by statistics information in the results part and PBL treatment duration in the method part. In addition, some information such as database, indexer, and publication type were obtained when the author was searching the document.

Table 1
Distribution of Document by PBL Treatment Duration, Publication Year, Publication Type, Database, and Indexer

Variables	Groups	Frequency	Percentage
PBL Treatment Duration	$t \leq 1$ month	13	48,15
	1 month $< t \leq 3$ months	9	33,33
	3 months $< t \leq 6$ months	3	11,11
	$t > 6$ months	2	7,41
Publication Year	2013	1	3,70
	2014	3	11,11
	2015	3	11,11
	2017	3	11,11
	2018	2	7,41
	2019	6	22,22
	2020	7	25,93
	2021	2	7,41
Publication Type	Proceeding article	4	14,81
	Journal article	23	85,19
Database	DOAJ	3	11,11
	Google Scholar	8	29,63
	Semantic Scholar	16	59,26
Indexer	Scopus	6	22,22
	Web of science	2	7,41
	Google Scholar	19	70,37

We involved two coders in which they were mathematics lecturers who focused on the meta-analysis study, to verify that data coding was valid and credible (Vevea et al., 2019). Cohen's Kappa test was used to measure the consistency of these coders (Cooper et al., 2013). The calculation of Cohen's Kappa used the formula referring McHugh (2012) as follows:

$$\kappa = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)}$$

Where Pr(a) is actual observed agreement and Pr(e) is chance agreement.

Table 2
The Results of Cohen's Kappa Test

Items	Kappa Value	Agreement Level	Sig. Value
Author	0,817	Strong	0,000
Statistics Information	1,000	Almost perfect	0,000
PBL Treatment Duration	0,925	Almost perfect	0,000
Publication Year	0,734	Moderate	0,000
Publication Type	0,792	Moderate	0,000
Database	0,806	Strong	0,000
Indexer	1,000	Almost perfect	0,000

Table 2 reveals that the agreement level of two coders in coding data was quite varied. In addition, every significance value of items was less than 0,05. This finding interprets that these coders agree significantly on every item in data coding. It means that the Cohen's Kappa test provides strong evidence that the data coding is valid and credible (Cooper et al., 2013).

Data Analysis

Hedge's equation was used to measure the effect size because it could accommodate a relatively small sample size (Lipsey & Wilson, 2001). Borenstein et al. (2009) mentioned that Hedge's equation was formulated as follows:

$$g = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}} \times \left(1 - \frac{3}{4df - 1}\right)$$

The effect size obtained was classified to be some categories. Cohen et al. (2018) classified it to be four categories that were: g = 0,00 – 0,20 (weak effect), g = 0,21 – 0,50 (modest effect), g = 0,51 – 1,00 (moderate effect), and g > 1,00 (strong effect).

We categorized the factor of PBL treatment duration to be four groups (see Table 1). To justify the significance of PBL treatment duration as the potential factor moderating the heterogeneous MCTS of students, we employed the Q Cochrane test because the test examined mean difference of two or more categorical data (Higgins et al., 2003). Also, we employed the Z test to justify the significance of PBL treatment on students' MCTS in every category of treatment duration because the Z test accommodated sample size of studies that were more than 30 participants (Borenstein et al., 2009).

Published studies tended to report significant results statistically and were included in meta-analysis studies so that publication bias was able to occur. As a consequence, publication bias analysis had to be carried out. To analyze publication bias, we used funnel plot analysis (Rothstein et al., 2005), and fill and trim test (Duval & Tweedie, 2000).

Table 3
The Fill and Trim Test

	Studies Trimmed	Random Effect Model			Q-value
		Effect Size (g)	Lower Limit	Upper Limit	
Observed Values		1,068	0,873	1,263	102,471
Adjusted Values	0	1,068	0,873	1,263	102,471

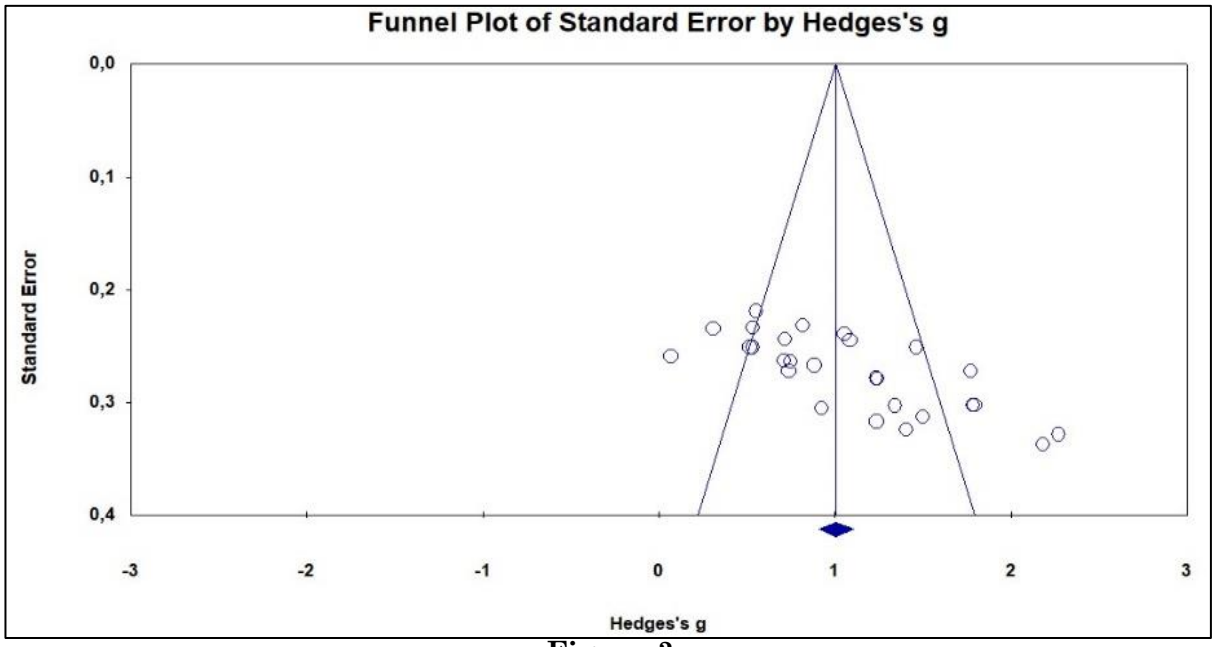

Figure 3
The Funnel Plot

Figure 3 shows that the distribution of effect size data in the funnel plot was symmetrical. It was also supported by the fill and trim test in Table 3 revealing that there was no effect size data that should be added and removed in this study. It indicates that the collection of the effect size data does not indicate publication bias.

RESULT AND DISCUSSION

Average of Effect Size Based on PBL Treatment Duration Category

The overall results of the PBL effect on students' MCTS based on its treatment duration are presented in Figure 4.

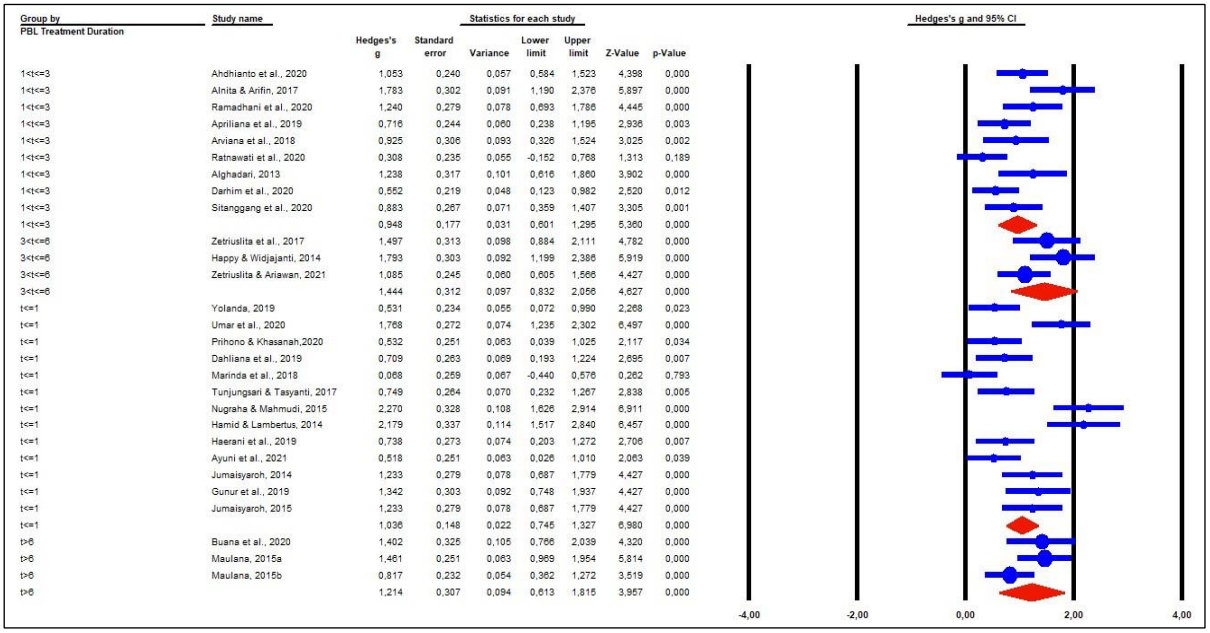

Figure 4
The Effect Size of PBL on Students' MCTS Based on Treatment Duration

Figure 4 shows that there were 13 literature in which its PBL treatment duration was less than or equals 1 month. From these literatures, six literatures reported that PBL had a moderate effect on students' MCTS (Ayuni et al., 2021; Dahliana et al., 2019; Haerani et al., 2019; Prihono & Khasanah, 2020; Tunjungsari & Tasyanti, 2017; Yolanda, 2019). Moreover, six other literature reported that PBL had a strong effect on students' MCTS (Gunur et al., 2019; Hamid & Lambertus, 2014; Jumaisyaroh et al., 2014, 2015; Nugraha & Mahmudi, 2015; Umar et al., 2020). One literature, however, reported that PBL had a weak effect on students' MCTS (Marinda et al., 2018). So, from this literature, the overall effect size of PBL implementation that its treatment duration was less than or equals 1 month, on students' MCTS was g = 1,036 and it was classified as a strong effect (Cohen et al., 2018). Also, the Z test in Figure 4 shows that the significance value was less than 0,05. It interprets that PBL implementation that its treatment duration is less than or equals 1 month, has a positive effect significantly on students' MCTS. Nugraha and Suparman (2021a) also revealed that the PBL implementation that its treatment duration was less than or equals 1 month, had a positive effect significantly on elementary students' MCTS. The findings provided rigorous evidence that the PBL implementation that its treatment duration was less than or equals 1 month, could affect positively students' MCTS.

In addition, Figure 4 reveals that there were 9 pieces of literature where its PBL treatment duration was more than 1 month and less than or equals 3 months. From these literature, four literatures reported that PBL had a moderate effect on students' MCTS (Apriliana et al., 2019; Arviana et al., 2018; Darhim et al., 2020; Sitanggang et al., 2020). Moreover, four other literatures reported that PBL had a strong effect on students' MCTS (Ahdhianto et al., 2020; Alghadari, 2013; Alnita & Arifin, 2017; Ramadhani et al., 2020). Meanwhile, one literature reported that PBL had a modest effect on students' MCTS (Ratnawati et al., 2020). So, the nine literatures revealed that the overall effect size of PBL implementation that its treatment duration was more than 1 month and less than or equals 3 months, on students' MCTS was g = 0,948 and it was categorized as a moderate effect (Cohen et al., 2018). Also, the significance value of its Z test was less than 0,05. This finding indicates that the PBL implementation that its treatment duration is more than 1 month and less than or equals 3 months, has a positive effect significantly on students' MCTS. This finding was similar to Nugraha and Suparman (2021a) reporting that the PBL implementation that its treatment duration was more than 1 month and less than or equals 3 months, had a positive effect significantly on elementary students' MCTS. It supported this study that the PBL implementation that its treatment duration was more than 1 month and less than or equals 3 months, was effective to cultivate students' MCTS.

Furthermore, Figure 4 also shows that there were 3 literatures that its PBL treatment duration was more than 3 months and less than or equals 6 months. These literatures reported that PBL had a strong effect on students' MCTS (Happy & Widjajanti, 2014; Zetriuslita et al., 2017; Zetriuslita & Ariawan, 2021), in which the overall its effect size was g = 1,444. Moreover, the significance value of its Z test was less than 0,05. It means that the PBL implementation that its treatment duration is more than 3 months and less than or equals 6 months, has a positive effect significantly on students' MCTS. A similar finding in Nugraha and Suparman (2021a) also reported that the PBL implementation that its treatment duration was more than 3 months and less than or equals 6 months, had a positive effect significantly on elementary students' MCTS. So, the finding

supported that the PBL implementation that its treatment duration was more than 3 months and less than or equals 6 months, affected significantly on students' MCTS.

Meanwhile, there were 3 literatures that its treatment duration was more than 6 months. Two of the literatures reported that PBL had a strong effect on students' MCTS (Buana et al., 2020; Maulana, 2016), while another literature reported that PBL had a moderate effect on students' MCTS (Maulana, 2016). So, these literatures reported that the overall effect size of PBL implementation that its treatment duration was more than 6 months, on students' MCTS was g = 1, 214 and it was classified as a strong effect (Cohen et al., 2018). Also, the significance value of its Z test was less than 0,05. This finding indicates that the PBL implementation that its treatment duration is more than 6 months, has a positive effect significantly on students' MCTS. Nugraha and Suparman (2021a) also revealed that the PBL implementation that its treatment duration was more than 6 months, had a positive effect significantly on elementary students' MCTS. These findings provided strong evidence that the PBL implementation that its treatment duration was more than 6 months, was effective to enhance students' MCTS.

Potential Factor Moderating the Heterogeneous Students' MCTS through PBL

The results of the heterogeneity analysis of the PBL treatment duration factor are presented in Table 4.

Table 4
The Results of Q Cochrane Test

PBL Treatment Duration	Number Studies	Effect Size (g)	Heterogeneity Analysis		
			Q-value	df(Q)	Sig. value
$t \leq 1$ month	13	1,036	2,186	3	0,535
1 month $< t \leq 3$ months	9	0,948			
3 months $< t \leq 6$ months	3	1,444			
$t > 6$ months	3	1,214			

Table 4 shows that the significance value of the Q Cochrane statistics was more than 0,05. This finding indicates that PBL treatment duration significantly does not moderate the heterogeneity of students' MCTS. It means that the gap in students' MCTS level is not caused by the factor of PBL treatment duration. Nugraha and Suparman (2021a), however, reported that the heterogeneous elementary students' MCTS were moderated significantly by the factor of PBL treatment duration. The difference between this study and a previous meta-analysis study could be caused by the factor of population difference. Nugraha and Suparman (2021a) only involved elementary students, while this study involved elementary, secondary, and college students.

The insignificance of PBL treatment duration factor in moderating the heterogeneous students' MCTS interprets that the breadth and difficulty of mathematics material used in implementing PBL to cultivate students' MCTS, is suitable to the period of the established duration. It means that the researchers have specified the precise treatment duration for every mathematics material in learning mathematics using PBL. So, PBL treatment duration is one of the factors that should be noticed by mathematics teachers and lecturers in establishing mathematics material because the breadth and difficulty of mathematics material determine the established treatment duration.

Table 4 also shows that the effect size of PBL implementation that its treatment duration was more than 3 months and less than or equals 6 months on students' MCTS, was higher than the effect size of PBL implementation that its treatment duration was less than or equals 3 months and more than 6 months on students' MCTS. It interprets that PBL implementation with its treatment duration of more than 3 months and less than or equals 6 months, is more effective than PBL implementation with its treatment duration of less than or equals 3 months and more than 6 months in cultivating students' MCTS. Nugraha and Suparman (2021a), however, reported that the effect size of PBL implementation that its treatment duration was more than 1 month and less than or equals 3 months on elementary students' MCTS, was higher than the effect size of PBL implementation that its treatment duration was less than or equals 1 month and more than 3 months on elementary students' MCTS. These findings indicate that the effective treatment duration of PBL implementation to cultivate students' MCTS has not been concluded because the treatment duration of learning especially PBL is established by the breadth and difficulty of mathematics material.

CONCLUSION AND IMPLICATION

Conclusion

A meta-analysis study synthesizing 27 relevant literatures reveals that a gap in students' MCTS level is not caused by the factor of PBL treatment duration. It means that the established treatment duration has been adjusted with the breadth and difficulty of the selected mathematics material to be presented in the mathematics classroom by using PBL. Also, this study reveals that for every treatment duration established, the PBL implementation affects positively students' MCTS indicating that it is effective to cultivate students' MCTS.

Implication

This study suggests to mathematics teachers or lecturers that they should notice carefully in establishing the learning treatment duration especially PBL in teaching mathematics material because the breadth and difficulty of a mathematics material has an essential role in the PBL treatment duration established. In addition, this study only focuses on the investigation and examination of the PBL treatment duration factor. So, for a further similar study, we recommend other researchers to investigate and examine mathematics content such as geometry, algebra, data analysis and probability, measurement, and number and operation because mathematics material is also related to the breadth and difficulty of mathematics material so that it has a chance in moderating the heterogenous students' MCTS through PBL.

Disclosure statement

The authors report that there is no potential conflict of interest.

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