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Problem-Based Learning for Mathematical Critical Thinking Skills: A Meta-Analysis

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Abstract: Many Indonesian researchers have conducted studies regarding the implementation of problem-based learning (PBL) on students' mathematical critical thinking skills (MCTS). However, some reports show an inconsistent result about the effect of problem-based learning (PBL) on students' MCTS. In contrast, education policymakers such as mathematics teachers and lecturers need accurate and clear information about it. Therefore, this study aims to evaluate, summarize, and estimate the PBL implementation for students' MCTS during the last four years. Moreover, this study investigates the characteristics of publication year, research area, education level, and sample size, which will possibly affect the heterogeneous effect size data. Seventeen relevant primary studies published in national or international journals or proceedings during 2017-2020 were analyzed using meta-analysis. The comprehensive meta-analysis (CMA) software was used as the analysis tool with selecting Hedges' formula to determine the size of its effect. The result revealed that the implementation of PBL had a strong positive effect significantly in upgrading the students' MCTS. In addition, the characteristics of publication year significantly caused the heterogeneous effect size data. Thus, these results recommend that Indonesian lecturers and mathematics teachers select PBL as an alternative solution to upgrade students' MCTS.

Keywords: problem-based learning, mathematical critical thinking skills, meta-analysis.

基于问题的数学批判性思维技能学习：一项荟萃分析

摘要：许多印尼研究人员针对学生的数学批判性思维技能（多边贸易体制）实施基于问题的学习（PBL）进行了研究。但是，一些报告显示，基于问题的学习（PBL）对学生的多边贸易体制产生的影响不一致。相反，诸如数学老师和讲师之类的教育政策制定者需要关于它的准确而清晰的信息。因此，本研究旨在评估，总结和评估过去四年来学生的多边贸易体制的 PBL 实施情况。此外，本研究调查了出版年份，研究领域，教育水平和样本量的特征，这可能会影响异质效应量数据。使用荟萃分析分析了 2017-2020 年在国家或国际期刊或论文集上发表的 17 篇相关基础研究。全面的荟萃分析（CMA）软件用作分析工具，可以选择对冲公式来确定效果的大小。结果表明，PBL 的实施对升级学生的多边贸易体制具有显着的积极作用。此外，出版年份的特征显着造成了异质效应量数据。因此，这些结果建议印尼讲师和数学老师选择 PBL 作为升级学生多边贸易体制的替代解决方案.

关键词：基于问题的学习，数学批判性思维技能，荟萃分析。

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1. Introduction

The rapid development of technology in the 21st century provides abundant information for each individual [1]. The abundance of information for each individual, on the one hand, can have a positive effect in the form of information that contains useful knowledge to develop their talents and potential. However, on the other hand, the abundance of information also negatively affects each individual in the form of spreading information that is not justified by its truth and reliability (hoax information). The spread of hoax information occurs due to the low level of the individual's critical thinking skills in analyzing, clarifying, and filtering the truth of the information obtained [1]. As a result, the information received is consumed without going through proper and accurate analysis, clarification, and filtering processes. Thus, critical thinking skills are very important to be developed and improved for every student in learning mathematics.

Mathematics learning in the 21st century should be designed in such a way that students can develop critical thinking and problem-solving skills, creativity and innovation, and communication and collaboration [2, 3]. Critical thinking skills are one of the 21st-century skills that are urgent to be investigated and evaluated in mathematics learning. Mathematical critical thinking skills (MCTS) are the ability to think logically, reflectively, systematically, and productively which are applied in assessing situations to make good judgments and decisions on the information obtained whose processes are developed in mathematics learning [4-6]. In the mathematics learning process, critical thinking skill is operationalized in several indicators such as basic clarification, providing a reason for a decision, concluding, further clarification, and conjecture and coherence [4]. Students' MCTS are very important to be developed and improved at various levels of education because the process that students go through will build their mindset as critical individuals to adapt to the rapidly moving developments of science and technology.

In developing and improving MCTS, researchers collaborating with mathematics teachers select problem-based learning (PBL) as a solution to improve students' low MCTS. PBL is student-centered learning that facilitates students to conduct research, integrate theory and practice, and apply knowledge and skills in determining the best solution of certain problems that can develop problem-solving skills, critical thinking, communication, and working cooperatively [7]. The PBL process consists of several stages, namely: (1) orienting students to the problem, (2) organizing students, (3) guiding investigations, (4) developing and presenting work, and (5) analyzing and evaluating the problem-solving process [8]. The selection of PBL as a solution is due to PBL design can develop and improve students' critical thinking skills so that PBL can shape students as critical individuals who can analyze, verify, and justify the truth and validity of the information obtained so that they can adapt to various conditions and situations [9, 10]. Thus, PBL is adopted as a model of mathematics learning at various formal education levels to develop and improve students' MCTS.

Until now, the MCTS facilitated by PBL has been widely studied by Indonesian researchers. However, several reports of study results show the inconsistent effect of PBL implementation on students' MCTS. This inconsistency is shown through the reports of researchers who state that PBL has a significant positive effect in upgrading students' MCTS [11-24], while other researchers state. In contrast, BL has no significant effect and even harms enhancers [26, 27]. In fact, education policymakers need precise and clear information on the sample size of how many students, with the minimum treatment duration, and at what level of education PBL is very effective in improving students' MCTS. Therefore, study that evaluate, estimates, and summarizes the effect of PBL implementation on the MCTS of student evaluated in solving and providing solutions to this problem through the synthesis of various relevant primary studies.

One of the research methods that can synthesize various study results with relevant themes through a quantitative approach is a meta-analysis (MA). MA is a research method that comprehensively synthesizes various relevant primary studies using a quantitative approach to summarize, estimate, and evaluate information on a single unit regarding the strength of the effect of mean, correlation, and association between variables, which using the effect size as the unit of measurement [28, 29]. MA provides several advantages such as more transparency, detects and reduces bias, better at estimating population parameters, able to assess outcomes in multiple domains, provides strong evidence of significant rejection and provides a rigorous methodology in the synthesis process [30]. Thus, these advantages make this MA study of higher quality.

Several previous MA studies related to the effect of PBL implementation on critical thinking skills have been conducted in the disciplines of physics, chemistry and biology [31], social sciences, mathematics and gifted education [32], nursing science [33], social sciences and health professions [34], gifted education [35], social sciences, health, computers, and science [36], and various disciplines at primary school [37], while, this MA study only focuses on mathematics learning. Moreover, some previous MA studies do not seem to apply sensitive analysis [31, 32, 34-37] and give information about the clear and systematic study selection based on PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analysis) [39]. However, this MA study applies sensitive analysis and gives a clear and systematic selection study.

The urgency of this MA study to be conducted is to provide accurate and clear information for educational policymakers especially for mathematics teachers at various levels of education in Indonesia, regarding the effect of PBL implementation on students' MCTS which until now still shows various reports that are inconsistent study results. Thus, this MA study aims to estimate, evaluate, and summarize the effect of PBL implementation on students' MCTS. In addition, this MA study investigates the study characteristics such as research area, education level, publication year, and sample size that are likely to cause the heterogeneous effect size data.

2. Methods

Meta-analysis was a method used in this study to synthesize several relevant primary studies regarding the influence of PBL implementation on MCTS. As a method, MA had several stages, namely: (1) defining research problems, (2) inclusion criteria, (3) literature search strategy, (4) study selection, (5) data extraction, (6) statistical analysis, and (7) interpretation and report [28], [38]. Thus, these stages were used in this MA study.

2.1. Inclusion Criteria

The problem of inconsistency of the effect of PBL implementation on MCTS was still very broad and general; therefore, this MA study needed to be limited by inclusion criteria and be more focused and specific, which results in a more in-depth and detailed analysis process. The PICOS approach (Population, Interventions, Comparator, Outcomes, and Study Design) could be used to define specific inclusion criteria [39]. Thus, the determination of inclusion criteria in this MA study was based on the PICOS approach, namely:

1. The population in the primary study was students at the elementary school (ES), junior high school (JHS), senior high school (SHS), and college in Indonesia.
2. The intervention in the primary study was the implementation of PBL.
3. The comparator of the intervention in the primary study was the implementation of conventional learning.
4. The output in the primary study was MCTS.
5. The research type in the primary study was quasi-experimental research with a causal-comparative type.
6. The primary study reported statistical data such as mean, standard deviation, sample size, t-value, and p-value in both the intervention and control groups.
7. The primary study was published during the last four years (2017 – 2020) in the form of a journal and proceeding indexed by Sinta, Scopus, Web of Science, or Google Scholar.

Primary studies that did not correspond to the inclusion criteria in the study selection process would be excluded from this MA study process.

2.2. Literature Search Strategy

Google Scholar, Semantic Scholar, Education Resources Information Center (ERIC), Science Direct, IOP Sciences, and Atlantis Press were databases used to track primary studies. Primary studies were traced using the keywords "problem-based learning" and "mathematical critical thinking skill" or "mathematical critical thinking ability". If a primary study that matched the inclusion criteria had been found but cannot be accessed or downloaded directly, https://sci-hub.scihubtw.tw site was used to access it. Thus, the use of databases, keywords, and download assistance sites could help find and obtain primary studies that matched the inclusion criteria.

2.3. Study Selection

The inclusion criteria defined were used as a guideline for selecting primary studies. The literature review given in [39] revealed that the primary study selection process through four stages guided by PRISMA, namely: (1) identification, (2) screening, (3) eligibility, and (4) inclusion. Thus, the study selection stages were used in this MA study.

2.4. Data Extraction

Primary studies that had met the inclusion criteria and went through the study selection stage were extracted into some data or information that would be used in the MA process. The data or information such as author, statistical data, education level, research area, publication year, publication type, publication indexer, and download link of primary studies. Incomplete information or data were traced via email to co-authors included in each primary study. The extraction process was used a coding sheet to transform data or information from each study into numerical or categorical data [36]. The extraction process involved two coding experts in a MA study intending to ensure that the data or information generated from the extraction process was valid and credible [40]. Thus, valid and credible data or information helped this MA study of higher quality.

2.5. Statistical Analysis

This MA study used effect size based on mean because the primary study analysis focused on the mean of two groups, namely the intervention group and the control group. The Hedges equation was used to calculate the effect size [28] because the sample size in the intervention group (PBL) was relatively small [41]. The effect size obtained was interpreted using the effect size classification developed by [42], presented in Table 1.

Table 1 Classification of the effect size

Effect Size	Interpretation
0 – 0.20	Weak Effect
0.21 – 0.50	Modest Effect
0.51 – 1.00	Moderate Effect
> 1.00	Strong Effect

Publication bias and sensitivity analysis were very important to justify that the statistical data of the MA process were valid and credible. This MA study used Rosenthal's fail-safe N test, fill and trim test, and funnel plot analysis to analyze publication bias [41]. On the other hand, the sensitivity analysis used the "One study removed" tool in the CMA software [38].

The p-value of the Q Cochran statistic was used to justify the effect model (fixed effect model or random effect model) used in the MA process and to justify the heterogeneity of effect size data [28]. On the other hand, in this MA study, the p-value of Z statistic was used to justify the significant effect of PBL implementation on students' MCTS [28].

Heterogeneity analysis showed that effect size data were heterogeneous, indicated that the analysis of study characteristics was very important to investigate [43]. The study characteristics investigated in this MA study were research area, education level, publication year, and sample size.

3. Results and Discussion

3.1. The Result of Literature Search

From the database of google scholar, semantic scholar, ERIC, science direct, IOP science, and Atlantis press, 512 primary studies were identified. However, there were 200 primary studies with a similar title, so that they were not included in the screening process. In addition, 150 primary studies were not relevant from the abstract screening process, so that only 162 primary studies were left and eligible for entry into the eligibility stage. Based on the inclusion criteria, 50 primary studies did not completely report statistical data, 60 primary studies did not involve conventional learning as a comparison group, and 20 primary studies reported that critical thinking skills studied were not in mathematics. 15 primary studies tended to have a large risk of publication bias of the remaining 32 primary studies, so that 15 primary studies had to be excluded from the MA process. Therefore, only 17 primary studies met the inclusion criteria and went through the study selection stage to be eligible to be involved in this MA study process.

From 17 primary studies, there were two primary studies indexed by Google Scholar, seven primary studies indexed by Sinta, seven primary studies indexed by Scopus, and one primary study indexed by Web of Science. Moreover, four primary studies were of the proceeding type, and three teen primary studies were of the journal type. In addition, seven primary studies indexed by Scopus were published in Journal of Physics: Conference Series, Universal Journal of Education Research, International Journal of Instruction, International Education Studies, and Journal of Technology and Science Education.

Table 2 The result of data extraction

		Statistical Data							
Code	Reference	PBL			Conventional Learning			T-value	P-value
		Mean	Sample Size	Standard Deviation	Mean	Sample Size	Standard Deviation		
J01	[23]	42.16	37	13.72	35.27	37	11.90		
J02	[20]	0.69	34	0.178	0.48	38	0.151		
J03	[25]	58.67	39	9.96	55.79	39	10.67		
J04	[13]	39.04	23	7.45	29.62	23	5.79		
J05	[11]	70.03	30	10.19	52.73	30	8.92		
J06	[15]	84.08	36	12.3	66.72	26	9.33		
J07	[27]	13.77	22	2.1	12.69	21	2.62		
J08	[21]	51	36	9.8	36	38	6.8		
J09	[18]	79.93	30	4.24	74.17	30	4.91		
J10	[24]	0.87	25	0.2	0.65	26	0.22		
J11	[26]	49.68	48	15.72	55.36	59	15.03		
J11	[26]	62.04	49	14.78	51.78	43	17.45		
J12	[19]	38.7	30	1.62	33.6	30	1.47		
J13	[17]	81.25	32	11.2	75.26	32	11.05		

J14	[16]	81.47	32	17.24	64.17	30	16.6		
J15	[12]	10.4	35	5.25	7.11	35	3.7		
J16	[22]		34			36		10.23	
J17	[14]		42			43			0.012

3.2. The Result of Data Extraction

The result of data extraction from 17 primary studies is presented in Table 2, and the study characteristics of each primary study are presented in Table 3.

Table 3 The study characteristics of each primary study

Code	Sample Size	Education Level	Research Area	Publication Year
J01	>30	JHS	Java	2019
J02	>30	SHS	Sulawesi & Maluku	2020
J03	>30	ES	Java	2020
J04	<=30	ES	Bali & Nusa Tenggara	2020
J05	<=30	ES	Java	2017
J06	>30	JHS	Java	2019
J07	<=30	JHS	Sumatera	2018
J08	>30	ES	Sulawesi & Maluku	2020
J09	<=30	SHS	Sumatera	2020
J10	<=30	Collage	Sumatera	2017
J11	>30	SHS	Java	2020
J12	<=30	JHS	Java	2018
J13	>30	JHS	Java	2020
J14	>30	ES	Bali & Nusa Tenggara	2020
J15	>30	JHS	Java	2019
J16	>30	SHS	Sumatera	2017
J17	>30	Collage	Java	2020

3.3. Publication Bias and Sensitivity Analysis

The funnel plot diagram showed the distribution of effect size data from the 17 primary studies included in this MA study. The distribution of effect size data is presented in Figure 1.

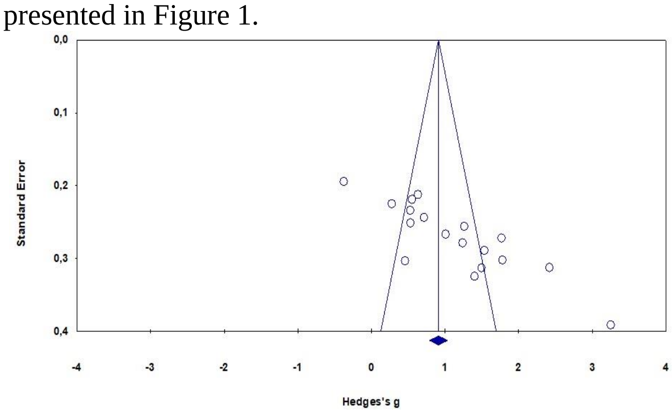

Fig. 1 The funnel plot of the standard error of Hedges

Figure 1 shows that the distribution of effect size data from the 17 primary studies analyzed in this MA study was symmetric. These findings indicate that effect size data carry a small risk of publication bias. This finding is supported by the fill and trim test result, which justifies that the effect size data on the funnel plots were symmetrical. This finding was demonstrated through no effect size data to be added or excluded from the MA process. The result of the fill and trim test is presented in Table 4.

Table 4a The fill and trim test based on the random effect model

	Studies Trimmed	Random Effect Model		Q-value
		Hedges g	95% CI	
Observed Values		1.109	[0.743; 1,475]	154.895
Adjusted values	0	1.109	[0.743; 1,475]	154.895

Table 4b. The fill and trim test based on the fix effect model

	Studies Trimmed	Fixed Effect Model		Q-value
		Hedges g	95% CI	
Observed Values		0.910	[0.790; 1.030]	154.895
Adjusted values	0	0.910	[0.790; 1.030]	154.895

The result of Rosenthal's fail-safe N test is presented in Table 5.

Table 5 The result of Rosenthal's fail-safe N test

Classic Fail-Safe N	
Z-value for observed studies	16,418
The P-value for observed studies	0,000
Alpha	0,050
Tails	2,000
Z for alpha	1,959
Number of observed studies	18,00
Number of missing studies that would bring p-value to > alpha	1.246

The result of Rosenthal's fail-safe N test showed that the combined p-value exceeded $\alpha = 0.05$. These findings indicate that the effect size data in this MA study are resistant to publication bias. Thus, the various publication bias analysis conducted provides strong evidence that the effect size data from the 17 primary studies included in this MA had a small risk of publication bias.

Sensitivity analysis can be used to identify potential sources of abnormal effect size data sets [38]. Through the use of the "One study removed" tool in the CMA software, it was found that the highest mean was 1.195, and the lowest mean was 0.994, which was based on a random effect model. Table 4 shows that the overall effect size based on the random effect model was 1,109. These findings indicate that the effect size data are extremely stable and reasonable for changes in sample size. Thus, these findings interpret that the effect size data are not sensitive to an abnormality of effect size and sample size.

3.4. The Overall Effect Size of Each Primary Study

The overall effect size of PBL implementation on improving students' MCTS from each primary study is presented in Table 6.

Table 6 The overall effect size of each primary study

Reference	Statistics for Each Study						
	Hedge's g	**Standard Error**	**Variance**	**Lower Limit**	**Upper Limit**	**Z-value**	**P-value**
[23]	0,531	0,234	0,055	0,072	0,990	2,267	0,023
[20]	1,265	0,256	0,066	0,762	1,767	4,936	0,000
[25]	0,278	0,225	0,051	-0,164	0,719	1,232	0,218
[13]	1,402	0,325	0,105	0,766	2,039	4,320	0,000
[11]	1,783	0,302	0,091	1,190	2,376	5,897	0,000
[15]	1,536	0,289	0,084	0,969	2,103	5,312	0,000
[27]	0,458	0,304	0,092	-0,137	1,053	1,509	0,131
[21]	1,768	0,272	0,074	1,235	2,302	6,497	0,000
[18]	1,239	0,279	0,078	0,693	1,786	4,445	0,000
[24]	1,497	0,313	0,098	0,884	2,111	4,782	0,000
[26]	-0,374	0,195	0,038	-0,756	0,008	-1,921	0,055
[26]	0,633	0,212	0,045	0,216	1,049	2,979	0,003
[19]	3,254	0,391	0,153	2,487	4,021	8,314	0,000
[17]	0,532	0,251	0,063	0,039	1,025	2,116	0,034
[16]	1,009	0,267	0,071	0,486	1,532	3,781	0,000
[12]	0,716	0,244	0,060	0,238	1,195	2,936	0,003
[22]	2,419	0,313	0,098	1,806	3,032	7,738	0,000
[14]	0,552	0,219	0,048	0,123	0,982	2,520	0,012
Combined Effect	1,109	0,187	0,035	0,743	1,476	5,939	0,000

The analysis of heterogeneity in Table 7 shows that the p-value of the Q Cochran statistics was less than 0,05. These findings interpret that the effect size data differ significantly from one another. These findings also indicate that the random effect model is significantly better than the fixed effect model. Thus, the MA process in this study uses a random effect model. The result of the analysis of heterogeneity and null hypothesis in this MA study is presented in Table 7.

Table 7 The result of heterogeneity and null hypothesis analysis

Model	Hedges g	Null Hypothesis Test		Heterogeneity		
		Z-value	**P-value**	**Q-value**	**df(Q)**	**P-value**
Fixed	0,910	14,839	0,000	154,895	17	0,000
Random	1,109	5,939	0,000			

The null hypothesis analysis in Table 7 shows that PBL implementation strongly affected students' MCTS. [31, 32] in their MA study showed a similar result that the PBL implementation had a very large effect on enhancing critical thinking skills. In addition, other results showed that the p-value of the Z statistic was less than 0,05. These findings interpret that the overall PBL implementation has a significant positive effect in improving students' MCTS. In their MA study that synthesized nine primary studies, [33] reported that nursing students' critical thinking skills by implementing PBL were significantly higher than the critical thinking skills of nursing students by implementing conventional learning. Likewise, [36] in their MA study, which synthesized 98 primary studies, stated that students' academic achievement using PBL was significantly higher than the academic achievement of students using conventional learning. Moreover, other similar findings reported that PBL had a significant effect in enhancing critical thinking skills [32, 34, 35]. These findings provided strong evidence that PBL implementation had a significant positive effect in improving students' MCTS

The implementation of PBL as a learning model has several advantages for developing and enhancing students' competencies or abilities in learning, especially mathematics learning. As revealed in [8], PBL helps improve the quality of learning by developing students' critical thinking and collaboration. Several studies in mathematics learning showed empirical evidence that students' MCTS had increased significantly through the implementation of PBL [14, 18, 20, 22-24, 44]. Therefore, these findings suggest that education policymakers should select PBL as one of the best alternative learnings to enhance students' MCTS in mathematics learning.

3.5. Analysis of Study Characteristics

Heterogeneity analysis showed that the size data effect was heterogeneous. It indicates that there are factors that cause it. Therefore, analysis of study characteristics is very important to investigate the factors that are likely to cause heterogeneous effect size data. The result of the analysis of study characteristics in this MA study is presented in Table 8.

The analysis of study characteristics in Table 8 shows that the characteristics of publication year significantly caused the effect size data to be heterogeneous. In contrast, the characteristics of the research area, education level, and sample size did not significantly cause the effect size data to be heterogeneous.

Table 8 The result of study characteristics analysis

Study Characteristics	**Group**	**Studies Number**	**Hedge's g**	**Null Hypothesis Test**		**Heterogeneity**		
				Z-value	**P-value**	Q_b	**df(Q)**	**P-value**
Sample Size	≤ 30	6	1,582	4,726	0,000	3,139	1	0,076
	> 30	12	0,885	4,274	0,000			
Education Level	ES	5	1,232	3,978	0,000	7,396	3	0,116
	JHS	6	1,133	3,222	0,001			
	SHS	5	1,108	2,241	0,025			
	Collage	2	1,024	3,651	0,006			
Research Area	Bali & Nusa Tenggara	2	1,167	5,664	0,000	3,102	3	0,376
	Java	10	0,902	3,500	0,000			
	Sumatera	4	1,400	3,537	0,000			
	Sulawesi & Maluku	2	1,508	5,989	0,000			
Publication Year	2017	3	1,899	7,040	0,000	11,33	3	0,010
	2018	2	1,845	1,320	0,187			
	2019	3	0,907	3,123	0,002			
	2020	10	0,810	3,898	0,000			

In contrast, the characteristics of the research area, education level, and sample size did not significantly cause the effect size data to be heterogeneous. As stated in [45, 46], sample size characteristics significantly did not cause the heterogeneous effect size data. Another MA studies, [32-36], reported that the characteristics of education level did not cause the heterogeneous effect of the size data. The findings of other MA studies indicated that the characteristics of publication year significantly caused the heterogeneous effect size data [43]. However, the characteristics of the research area significantly caused the effect size data to be heterogeneous [43]. The difference in findings in this MA study with the findings of a MA study conducted by [43] regarding the characteristics of the research area can be caused by the difference in the studies conducted. This MA study focused on students' MCTS while [43] focused on students' attitudes.

The sample size characteristics were divided into two groups: a sample size of less or equals 30 students and a sample size of more than 30 students. The p-value of the Z statistic of each sample size characteristic was less than 0,05. These findings interpret that the implementation of PBL on a sample size of less than or equals 30 students, and a sample size of more than 30 students has a significant positive effect in improving students' MCTS. Descriptively, the effect size of PBL implementation on a sample size of less than or equals 30 students was higher than the effect size of PBL implementation on a sample size of more than 30 students related to enhancing students' MCTS. This finding is consistent with the results of previous studies [46-48] who reported similar findings that PBL implementation on a sample size of less than or equals 30 students was better than PBL implementation on a sample size of more than 30 students. Thus, this MA study recommended for mathematics teachers or lecturers to implement PBL on a sample size of less than or equals 30 students in improving students' MCTS.

The education level characteristics were divided into four groups, namely: ES, JHS, SHS, and college. The p-value of the Z statistic of each education level characteristic was less than 0,05. These findings interpret that the implementation of PBL at the education level of ES, JHS, SHS, and college has a significant positive effect in enhancing students' MCTS. The effect of PBL implementation at the education level of ES was larger than the effect of PBL implementation at the education level of JHS, SHS, and college related to the improvement of students' MCTS. [43] in their MA study found a similar thing that the highest effect size of PBL implementation on students' attitudes was at the education level of ES. Thus, descriptively this MA study provided information that the implementation of PBL in improving the MCTS of students was most suitable at the education level of ES.

The research area characteristics were divided into four groups, namely: Java, Sumatera, Bali & Nusa Tenggara, and Sulawesi & Maluku. The p-value of the Z statistic of each research area characteristic was less than 0,05. These findings interpret that PBL implementation in Java, Sumatera, Bali & Nusa Tenggara, and Sulawesi & Maluku has a significant positive effect in improving students' MCTS. The effect of PBL implementation in Sulawesi & Maluku was higher than the effect size of PBL implementation in Java, Sumatera, and Bali & Nusa Tenggara related to enhancing students' MCTS. As reported in [46], the effect of PBL implementation in Bali & Nusa Tenggara was larger than the effect size of PBL implementation in Java, Sumatera, Kalimantan, and Sulawesi & Maluku. The difference in the result of research area characteristics analysis can be caused by the difference in the mathematical ability being studied. This MA study examined students' MCTS while [46] examined students' mathematical problem-solving skills.

The characteristics of the publication year were divided into four groups, namely: 2017, 2018, 2019, and 2020. The p-value of the Z statistic in 2017, 2019, and 2020 was less than 0,05. These findings interpret that the result of studies of PBL implementation on students' MCTS published in 2017, 2019, and 2020 have a significant positive effect. However, the p-value of the Z statistic in 2018 was more than 0,05. These findings confirm that the result of studies related to the implementation of PBL on students' MCTS published in 2018 does not have a significant effect. Descriptively, the effect size of PBL implementation on students' MCTS tended to decrease from year to year in the 2017 – 2020 period. This finding was opposite to the result of a MA study related to the implementation of PBL on students' mathematical problem-solving skills from year to year in the 2010-2020 period, whose effect size tended to increase [46]. Therefore, this MA study provided information to mathematics teachers and lectures to re-evaluate the process of PBL implementation in mathematics learning to obtain more optimal student learning outcomes, especially students' MCTS.

4. Conclusions

This MA study provides some information, namely: (1) the implementation of PBL has a strong positive effect in improving students' MCTS from the synthesis of 17 relevant primary studies, and (2) publication characteristics are one of the factors that affect the heterogeneous effect size data. Therefore, this MA study provides information to mathematics teachers or lecturers that PBL is alternative learning that effectively solves a problem related to students' low MCTS. As a result, they can consider PBL as an alternative solution to improve students' low MCTS. There is some limitation from this MA study, namely: (1) some study characteristics such as treatment duration of PBL, the quality of PBL executor, the topic of mathematics learning and other are not involved, and (2) the number of primary studies is still relatively limited, especially primary studies where research is Kalimantan and Papua. Therefore, for further MA studies related to the implementation of PBL on students' MCTS, researchers should increase the number of primary studies, especially primary studies where research is located in Kalimantan and Papua, and involve the characteristics of treatment duration, the quality of PBL executor, the topic of mathematics learning and another which are possible to cause the effect size data to be heterogeneous.

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