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Does Students' Demography Cause Heterogeneity of Students' Mathematical Critical Thinking Abilities through Problem-Based Learning? A Meta-Analysis

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Abstract: Some reports related to the problem-based learning (PBL) implementation in the mathematics classroom to improve mathematical critical thinking abilities (MCTA) of Indonesian elementary school students revealed that the PBL effect on the MCTA of students is heterogeneous. However, the study investigating the causative factors of the heterogeneity of students' MCTA has not been conducted. Therefore, this study aims to investigate and examine students' demography predicted as a potential factor causing the heterogeneity of MCTA of Indonesian elementary school students through PBL. To conduct this study, a meta-analysis by selecting the random effect model was employed. All of the data was analyzed by using the application of Comprehensive Meta-Analysis (CMA) version 3.0. The use of search engines such as Google Scholar and Semantic Scholar found ten primary studies: journal or proceeding articles published in 2015 – 2020 and indexed by Scopus, Google Scholar, Sinta, and Web of Science. Heterogeneity analysis of these primary studies showed that the p-value of the Q Cochrane statistic was 0,008. It indicates that the p-value is less than 0,05. It means that students' demography is one of the significant factors causing the heterogeneity of MCTA of Indonesian elementary school students. Furthermore, the PBL effect sizes on the MCTA based on students' demography were g = 1,032* (Bali & East Nusa), g = 2,690* (Java), g = 0,738 (Kalimantan), g = 0,584 (Maluku & Papua), g = 1,261* (Sulawesi), and g = 1,594* (Sumatera). These findings interpret that the PBL implementation in Bali & East Nusa, Java, Sumatera, and Sulawesi has positive effect significantly on the students' MCTA. Meanwhile, the PBL implementation in Kalimantan and Maluku & Papua significantly does not affect the MCTA of students. It means that mathematics teachers of an elementary school in Kalimantan and Maluku & Papua should enhance their effort to improve their students' MCTA through PBL.

Keywords: heterogeneity, mathematical critical thinking abilities, meta-analysis, problem-based learning, students' demography.

学生的人口统计学是否通过基于问题的学习导致学生数学批判性思维能力的异质性？元分析

摘要：一些关于在数学课堂中实施基于问题的学习 (PBL) 以提高印度尼西亚小学生数学批判性思维能力 (MCTA) 的报告显示，PBL 对学生 MCTA 的影响是异质的。然而，似乎还没有开展调查学生 MCTA 异质性的原因的研究。因此，本研究通过 PBL 调查和检查学生人口统计学预测为导致印度尼西亚小学生 MCTA 异质性的潜在因素。为了进行这项研究，采用了选择随机效应模型的荟萃分析。所有数据均使用综合元分析 (CMA) 3.0 版的应用程序进行分析。使用谷歌学术和语义学者等搜索引擎发现了 10 项主要研究，它们是 2015 年至 2020 年发表的期刊或论文，并被斯科普斯、谷歌学术、辛塔和科学网索引。这些主要研究的异质

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性分析表明，问科克伦统计量的 p 值为 0.008。它表明 p 值小于 0.05。这意味着学生的人口结构是造成印尼小学生 MCTA 异质性的重要因素之一。此外，基于学生人口统计学对 MCTA 的 PBL 效应大小为 g = 1,032*（巴厘岛和东努沙）、g = 2,690*（爪哇）、g = 0,738（加里曼丹）、g = 0,584（马鲁古和巴布亚），g = 1,261*（苏拉威西），g = 1,594*（苏门答腊）。这些发现表明，在巴厘岛和东努沙、爪哇、苏门答腊和苏拉威西实施 PBL 对学生的 MCTA 有显着的积极影响。同时，加里曼丹和马鲁古和巴布亚的 PBL 实施对学生的 MCTA 没有显着影响。这意味着加里曼丹和马鲁古和巴布亚小学的数学教师应该加强努力，通过PBL提高学生的MCTA。

关键词：異質性、數學批判性思維能力、元分析、基於問題的學習、學生人口統計學。

1. Introduction

Critical thinking ability is a skill in processing information enabling every individual can evaluate and justify the knowledge to develop and solve some problems [1], [2]. It is one of the 21st-century skills that students should have to adjust to the change of an unpredictable situation [3], [4]. The fast development of technology and science is one of the unexpected situation changes in the 21st century [5], [6]. The rapidly increasing technology development provides much information. One of the adverse effects of abundant information is that people deliver information that is not justified in truth and trustworthiness. They carry it out because they do not identify, clarify, verify, and evaluate the validity and reliability of the information that they get. It indicates that their critical thinking ability is still low [7]. Ennis [8], [9] revealed that students with high essential thinking ability are characterized as identifying, clarifying, verifying, and evaluating something they obtain, such as information. Thus, critical thinking ability is a crucial skill that should be developed and enhanced by teachers, specifically in mathematics learning, so that their students can improve their necessary thinking abilities. To improve elementary school students' mathematical critical thinking abilities (MCTA), some mathematics teachers implement problem-based learning (PBL) as alternative learnings. It is a student-centered learning approach that facilitates students to apply knowledge and skill, integrates theory and practice, and conduct research to determine the best solution to a specific problem [10]. It can develop students' problem-solving skills [11]–[13], critical thinking skills [14]–[16], and collaborative skills [17]. So, it is predicted that it can enhance the MCTA of elementary school students in the mathematics classroom.

Several reports related to the PBL implementation on the elementary school students' MCTA in the journal or proceeding articles revealed that it had a strong positive effect on the MCTA of students [18]–[24]. Meanwhile, other reports showed that it had a moderately positive impact on the MCTA of students [25]–[27]. These reports indicate that the elementary school students' MCTA is heterogeneous. The heterogeneity of MCTA of elementary school students interprets the MCTA level gap between one student and another student. This MCTA gap will affect the difference in students' academic achievement levels in mathematics learning. Therefore, the study that enables investigating and examining the causative factors of the heterogeneous MCTA of elementary school students should be carried out.

A meta-analysis, a series of statistical methods synthesizing the various quantitative preliminary study results to summarize, estimate, and evaluate the overall empirical knowledge on the specific topic [28], [29], can support investigating the causative factors of the heterogeneous students' MCTA. It provides strong evidence in rejecting and accepting hypotheses and strict methodology in the synthesis process [30]. Also, it is more detect and reduces bias and better estimates population parameters than other methods [31]. So, this method provides some advantages in investigating and examining the causative factor of the heterogeneity of elementary school students' MCTA. Some researchers have carried out some meta-analysis studies related to investigating the causative factors of the heterogeneous students' MCTA [14], [32]. Superman et al. [14] have investigated and examined factors such as students' education level, PBL class capacity, and research area that can cause the heterogeneity of primary, secondary, and college students' mathematical critical thinking skills. Also, Yohannes

et al. [32] have investigated and examined four causative factors: class level, school type, research year, and sample size, enabling to cause the heterogeneous high school and vocational school students' mathematical critical thinking skills. However, they have not investigated and examined students' demography predicted as a potential factor causing the heterogeneity of elementary school students' MCTA through PBL. Therefore, this study has to be conducted to contribute to the mathematics teachers in elementary school in solving students' MCTA level gap problem.

2. Methods/Materials

To investigate and examine students' demography as a potential factor causing the heterogeneity of elementary school students' MCTA, we employed meta-analysis by selecting the random effect model [28]. Copper et al. [33] and Hunter & Schmidt [34] revealed seven steps to conduct a meta-analysis study. These steps are presented in Figure 1.

2.1. Inclusion Criteria

In establishing the inclusion criteria, we used PICOS (Population, Intervention, Comparator, Outcome, Study design) approach [35]. The inclusion criteria of this study were as follows:

1. Every study provided statistical data altogether.
2. Every study was journal or proceeding published in 2015 – 2020 and indexed by Scopus, Google Scholar, Web of Science, and Sinta.
3. The study design of the study was quasi-experiment by selecting posttest only control group design.
4. The outcome of the study was students' MCTA.
5. The comparator of the study was conventional learning (CL).
6. The intervention of the study was PBL.
7. The population of the study was elementary school students in Indonesia.

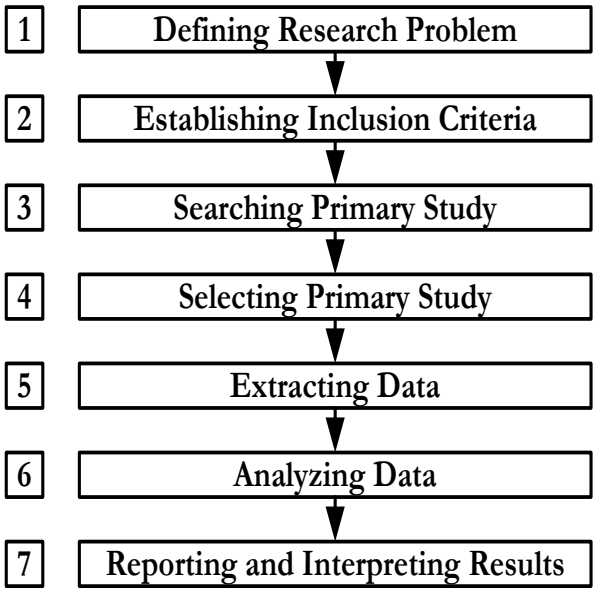

Fig. 1 The steps of the meta-analysis study

Preliminary studies that were not suitable to the inclusion criteria would be excluded from this study process.

2.2. The Search of Primary Study

We used Semantic Scholar and Google Scholar to find primary studies. Also, some keywords such as "problem-based learning and mathematical critical thinking abilities" or "problem-based learning and mathematical critical thinking skills" were employed to ease in searching primary studies. So, the search engines and keywords supported this study in finding preliminary studies.

2.3. Selection of Primary Study

We selected every preliminary study obtained from the search process. This study applied four steps to choose every primary research that was: (1) identification, (2) screening, (3) eligibility, and (4) inclusion [35]. Every primary study was selected based on the title of the study in the identification step, based on the abstract in the screening step, based on the inclusion criteria in the eligibility step, and based on publication bias in the inclusion step.

2.4. Data Extraction

Numerical and categorical data such as citation, statistical data (t-value, p-value, mean, standard deviation (SD), and sample size (N)), students' demography, journal or proceeding name, publisher, indexer, publication type, publication year, and search engine were transferred from every preliminary study to the coding sheet. We communicated with the authors via email to complete the data. Also, we involved two coders in verifying and justifying that the data extracted was valid [36]. We employed Cohen's Kappa test to measure the consistency of data extraction results carried out by two coders. Cohen's Kappa values obtained were interpreted as $k = 0 – 0.20$ (none), $k = 0.21 – 0.39$ (minimal), $k = 0.40 – 0.59$ (weak), $k = 0.60 – 0.79$ (moderate), $k = 0.80 – 0.90$ (strong), and $k > 0.90$ (almost perfect) [37].

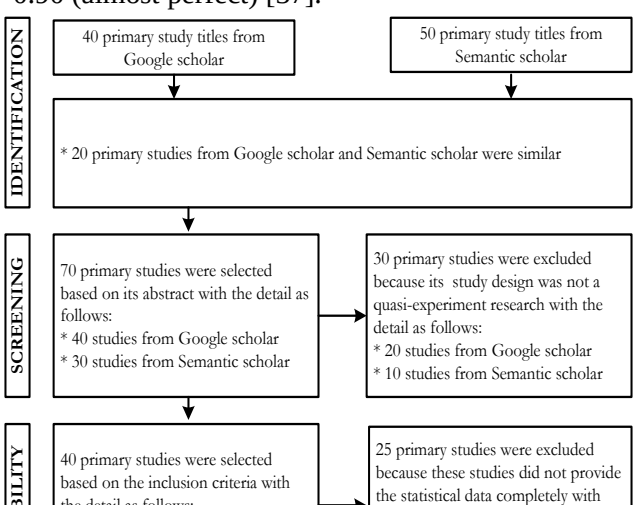

Fig. 2 The selection process of primary studies

2.5. Data Analysis

To measure the effect size of PBL on the students' MCTA, we used Hedge's equation [28] because it accommodated the relatively small sample size [38]. Every effect size value was classified as g = 0 – 0.20 (weak effect), g = 0.21 – 0.50 (modest effect), g = 0.51 – 1.00 (moderate effect), and g > 1.00 (strong effect) [39]. In addition, we conducted a publication bias test using Rosenthal's fail-safe N (FSN) test to verify that the effect size collection was resistant to publication bias [40]. Also, to verify normality and stability of the effect size collection, we carried out an analysis of sensitivity utilizing the "one study removed" tool on Comprehensive Meta-Analysis (CMA) software [41]. Furthermore, we used the Z test to examine the significance of the PBL effect on the MCTA based on students' demography [28]. Finally, we conducted the Q Cochrane test to examine the significance of students' demography factor in causing the heterogeneity of elementary school students' MCTA through PBL [42].

3. Results and Discussion

3.1. Search and Selection of Primary Study

We found 40 primary studies from Google Scholar and 50 primary studies from Semantic Scholar by using these keywords. Furthermore, the selection process of these studies is presented in Figure 2.

Ten primary studies obtained from Google Scholar and Semantic Scholar consisted of two studies carried out in Bali & East Nusa [18], [21], two studies carried out in Java [20], [23], one study carried out in Kalimantan [25], two studies carried out in Maluku & Papua [26], [27], one study carried out in Sulawesi [24]. Two studies were carried out in Sumatera [19], [22].

3.2. Data Extraction

The results of Cohen's Kappa test are presented in Table 1.

Table 1 Cohen's Kappa value of every item

Item	Kappa Value	Agreement Level	Significance Value
Citation	0.814	Strong	0.003
Mean of PBL group	0.956	Almost perfect	0.012
SD of PBL group	0.916	Almost perfect	0.007
Sample size of PBL group	0.934	Almost perfect	0.013
Mean of CL group	0.923	Almost perfect	0.017
SD of CL group	0.945	Almost perfect	0.009
Sample size of CL group	0.937	Almost perfect	0.008
t-value	0.967	Almost perfect	0.001
p-value	0.971	Almost perfect	0.008
Students' demography	0.891	Strong	0.019
Publication type	0.861	Strong	0.009
Publication year	0.856	Strong	0.016
Search engine	0.704	Moderate	0.034
Journal and proceeding name	0.761	Moderate	0.041
Publisher	0.724	Moderate	0.026
Indexer	0.799	Moderate	0.027

The agreement level of two coders on every item was classified as moderate agreement, strong agreement, and almost perfect agreement. Table 1 reveals that every p-value of the Z statistic of every item was less than 0.05. The findings indicate that two coders significantly agree on every item that is numerical and categorical data transferred from every primary study to the coding sheet.

Primary studies were journals or proceedings. The detail of the publication type of every primary study is presented in Figure 3.

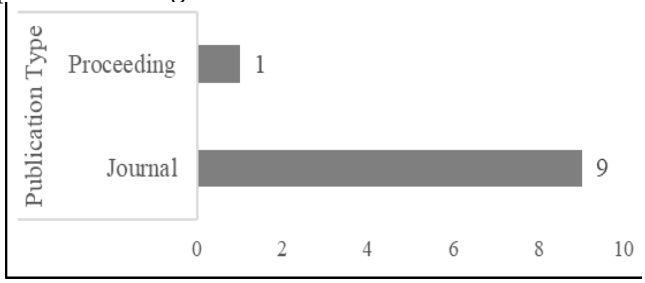

Fig. 3 Publication type of primary study

Fig. 3 reveals that the primary study consisted of nine journal articles and one proceeding article. It indicates that the study in journal articles is more dominant than the study in proceeding articles.

The studies were published in 2015 – 2020. Fig. 4 shows that the trend of research related to the PBL implementation on the MCTA of elementary school students increased from year to year. It indicates that the PBL implementation in mathematics classrooms is more massive from year to year. The detail of the publication year of every primary study is presented in Figure 4.

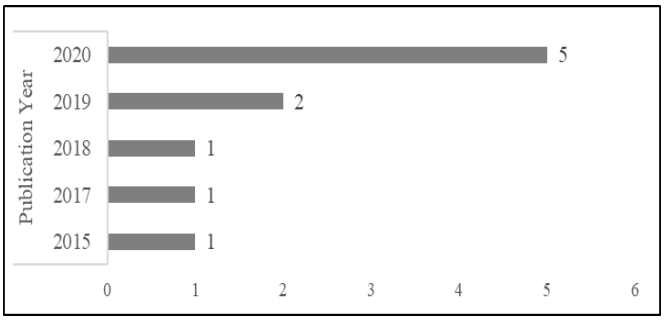

Fig. 4 Publication year of primary study

Primary studies were indexed by some indexes such as Scopus, Google Scholar, Sinta, and Web of Science. The detail of the indexer of every primary study is presented in Figure 5.

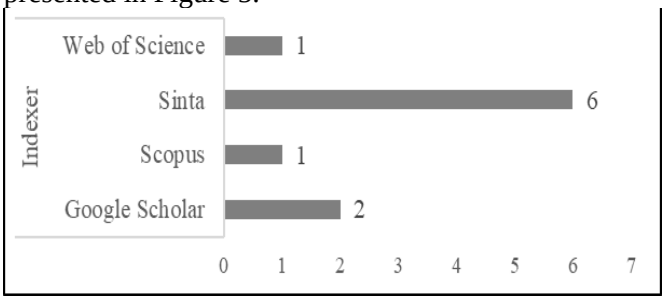

Fig. 5 The indexer of the primary study

Fig. 5 reveals that two studies were indexed by Google Scholar, one study indexed by Web of Science, one study indexed by Scopus, and six studies indexed by Sinta. It interprets that primary study indexed by Sinta is more than primary study indexed by Scopus, Google Scholar, or Web of Science.

The results of numerical data extraction such as t-value, p-value, SD, N, and mean are presented in Figure 6.

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	-14.757	
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

Fig. 6 Numerical data extraction

3.3. Sensitivity and Publication Bias

The "one study removed" tool on CMA application reported that the lowest effect size was g = 1.112, and the highest effect size was g = 1.447. Meanwhile, the overall mean of effect size was g = 1.350. The findings showed that the overall effect size is between the smallest and highest effects. It interprets that the effect size collection is regular and stable on effect size and sample size change. It means that the effect size collection is not sensitive [41].

Furthermore, the results of Rosenthal's FSN test are presented in Table 2.

Table 2 The results of the FSN test

Classic Fail-Safe N	
Z-value	14.366
P-value	0.000
FSN value	528

Table 2 reveals that the FSN value was 528. It indicates that this study needs 528 null effect sizes so that the p-value can exceed $\alpha = 0.05$. Moreover, the p-value of the Z statistic was less than 0.05. It interprets that the effect size collection is resistant to publication bias. It means that the collection of effect size does not indicate publication bias [40].

3.4. Effect Size

The overall effect size of PBL implementation on the MCTA of elementary school students is presented in Figure 7.

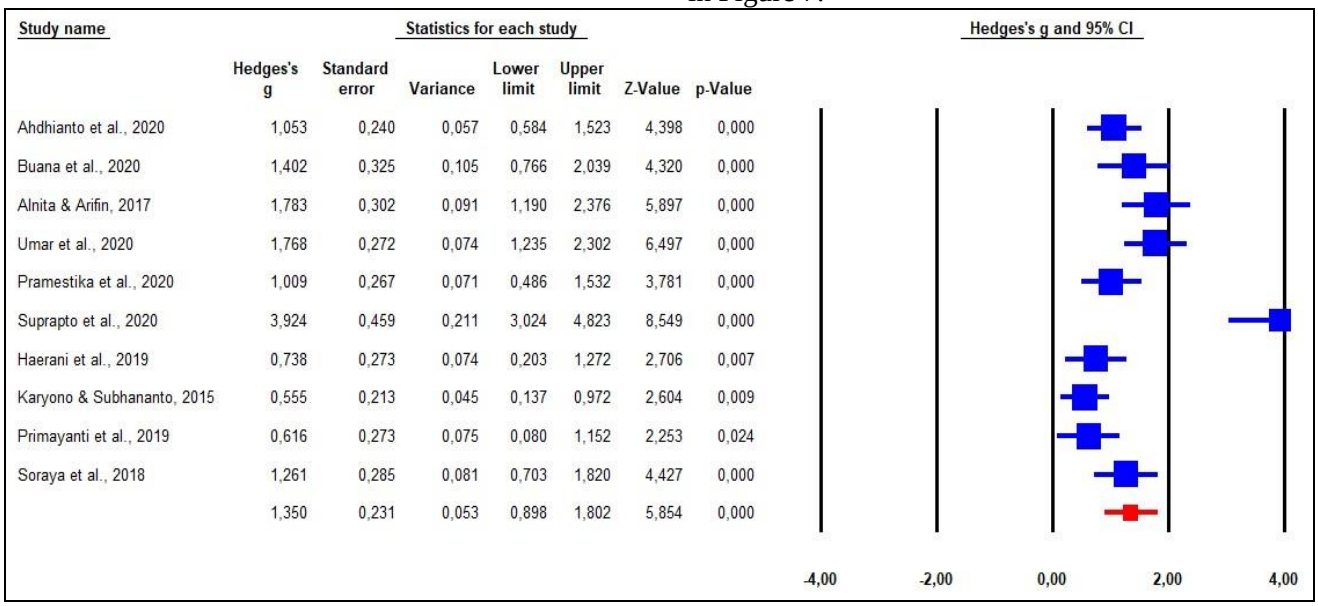

Fig. 7 The overall PBL effect size on the MCTA of elementary school students

Fig. 7 shows that the overall PBL effect size on the MCTA of elementary school students from ten primary studies synthesized was g = 1.350, and it was classified as a strong effect [39]. Also, the p-value of the Z statistic was less than 0.05. It interprets that the PBL implementation significantly affects elementary school students' MCTA. Several meta-analysis studies also revealed that PBL had a positive effect significantly on students' mathematical critical thinking skills in the various education levels such as primary school, secondary school, and college/university [14]–[16]. These reports support strong evidence that the PBL implementation effectively enhances the MCTA of elementary school students.

The significance of PBL in enhancing MCTA of elementary school students because that PBL is a learning approach designed to improve the learning quality by developing students' collaborative and critical thinking skills [17]. Also, one of the characters of PBL is cooperative learning [10], [43], [44]. The synthesis result of some studies revealed that students' academic achievement could be improved when students collaborate in a cooperative learning environment [45]. Therefore, elementary school students' MCTA that enhance by implementing PBL because it is cooperative learning.

Several theoretical studies reported that PBL is one of the learning models supporting the cultivation of student's critical thinking skills [46]–[48]. Also, PBL is a learning approach promoting higher-order thinking skills such as critical thinking and creative skills [49]. The student's necessary thinking skills are by stimulating some problems in the learning process [10], [50]. These problems require them to think creatively and critically in solving them to find concepts and principles from mathematics learning by solving these problems. It means that indirectly PBL implementation process in mathematics learning stimulates students to cultivate their MCTA.

Furthermore, Fig. 7 reveals that the PBL implementation had a substantial effect on the MCTA of elementary school students. Meanwhile, Fig. 7 also shows that the PBL implementation has a moderate impact on the MCTA of elementary school students. These findings interpret that the effect of PBL implementation on the MCTA of elementary school students is heterogeneous. Moreover, the Q Cochrane test results showed that the Q-value was 61.123, and its p-value was 0,000. It indicates that the MCTA of elementary school students through PBL is heterogeneous [42]. It provides a strong justification for an MCTA level gap of elementary school students in mathematics classrooms using PBL. Therefore, this recent study investigates and examines students' demography predicted as a potential factor causing the heterogeneity of elementary school students' MCTA through PBL.

3.5. Investigation of Students' Demography Factor

The factor of students' demography consisted of six groups that were Java, Sumatera, Kalimantan, Sulawesi, Bali & East Nusa, and Maluku & Papua. The detail of students' demography of every primary study is presented in Figure 8.

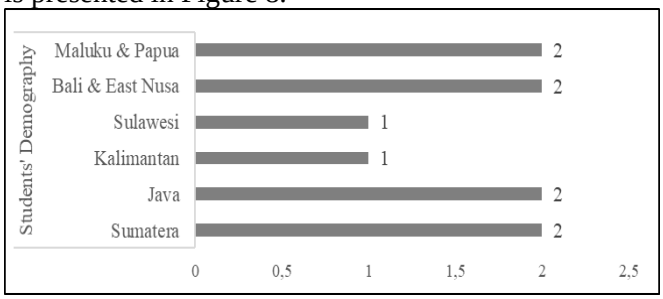

Fig. 8 Students' demography of every primary study

The effect size of PBL implementation on the MCTA of elementary school students based on students' demography is presented in Figure 9.

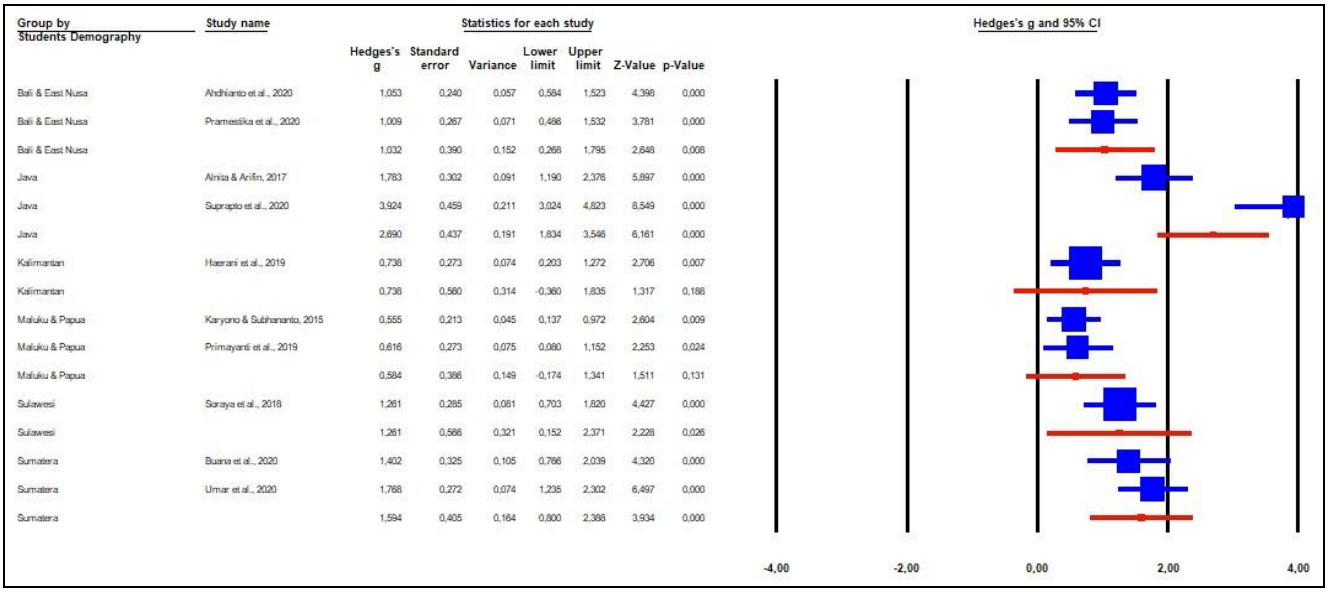

Fig. 9 The effect size based on students' demography

Fig. 9 reveals that the effect sizes of PBL on the MCTA based on students' demography were g = 1.032 (in Bali & East Nusa), g = 2.690 (in Java), g = 1.261 (in Sulawesi), and g = 1.594 (Sumatera). These effect sizes were categorized as a strong effect [39]. Meanwhile, other effect sizes of PBL on the MCTA based on students' demography were g = 0.738 (in Kalimantan) and g = 0.584 (in Maluku & Papua). These effect sizes were categorized as moderate effects [39]. In addition, every p-value of the Z statistic of the PBL implementation in Java, Sulawesi, Sumatera, and Bali & East Nusa was less than 0.05. These findings interpret that the implementation of PBL in Java, Sulawesi, Sumatera, and Bali & East Nusa has positive effect significantly on the elementary school students' MCTA. Suparman et al. [14] also found that the PBL implementation in Java, Sumatera, Sulawesi, and Bali & East Nusa positively affected the mathematical critical thinking skills of primary school students and secondary school and college students. It means that the implementation of PBL is effective in cultivating elementary school students' MCTA in these locations. However, every p-value of the Z statistic of the PBL implementation in Kalimantan and Maluku & Papua was more than 0.05. These results indicate that the implementation of PBL in Kalimantan and Maluku & Papua does not significantly affect elementary school students' MCTA. It means that mathematics teachers of an elementary school in these locations should improve their effort in implementing PBL to enhance their students' MCTA.

Table 3 shows that the p-value of the Q Cochrane statistic was less than 0.05. It indicates that students' demography is one of the significant factors affecting the heterogeneity of elementary school students' MCTA. It means that the moderate or vigorous effect of PBL on the elementary school students' MCTA is caused by students' demography. Meanwhile, Suparman et al. [14] found that the heterogeneity of mathematical critical thinking skills of primary school students, secondary school students, and college students was not affected by students' demography factor. These reports interpret that students' demography is not the causative factor consistently affecting the heterogeneity of students' MCTA. In addition, the effect of PBL in Java was more substantial than the effect of PBL in other locations in Indonesia in cultivating elementary school students' MCTA. It means that the implementation of PBL in Java is more effective than the implementation of PBL in Bali & East Nusa, Kalimantan, Maluku & Papua, Sulawesi, and Sumatera to cultivate elementary school students' MCTA.

The results of the Q Cochrane test of the PBL effect on the MCTA of elementary school students based on students' demography are presented in Table 3.

Table 3 The results of the Q Cochrane test

Students' Demography	Number Studies	Effect Size	Heterogeneity Analysis		
			Q-value	df(Q)	P-value
Java	2	2.690	15.572	5	0.008
Sumatera	2	1.594			
Sulawesi	1	1.261			
Kalimantan	1	0.738			
Bali & East Nusa	2	1.032			
Maluku & Papua	2	0.584			

4. Conclusion

This meta-analysis study provides some information that students' demography factor is one of the significant factors causing the heterogeneity of MCTA of elementary school students. Also, the PBL implementation on the MCTA of elementary school students in Java is more effective than the PBL implementation on the MCTA of elementary school students in Sumatera, Kalimantan, Sulawesi, Bali & East Nusa, and Maluku & Papua. This study suggests that mathematics teachers of an elementary school in Kalimantan and Maluku & Papua should improve their effort in teaching mathematics material using PBL to enhance their students' MCTA. In addition, this study only investigates and examines one potential factor causing the heterogeneity of elementary school students' MCTA through PBL. So, for further meta-analysis study related to this topic, researchers should investigate and examine other potential causative factors of the heterogeneous elementary school students' MCTA through PBL, such as students' prior mathematics skills and professional and pedagogical mathematics teacher skill level.

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