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Meta analysis study: Effectiveness of problem based learning on Indonesian students' mathematical reasoning ability

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ABSTRACT

Problem-Based Learning has been studied over three decades in various subjects and schools, This meta-analysis study aimed to synthesize the most recent findings of the effect of Problem-Based Learning (PBL), specifically on students' mathematical reasoning ability. The data were obtained from relevant primary studies published in national and international journals or proceedings during 2014-2021. Ten effect sizes from eight studies that fulfilled the inclusion criteria were analyzed using a systematic review and meta-analysis. JASP 0.15.0.0 software was used to measure the formula of Hedges g to determine the effect size. The result showed that PBL has a strong effect on students' mathematical reasoning ability (g--RE = 2.062, 95% CI [1.436, 2.689], $p < 0.001$) when compared to traditional learning. The results of the analysis of moderator variables revealed that publication year ($Qb = 5.460$, $p < 0.05$) and sampling technique ($Qb = 9.032$, $p < 0.05$) had significant effect on the effectiveness of PBL on students' mathematical reasoning ability, while educational levels ($Qb = 1.649$, $p > 0.05$), sample size ($Qb = 2.081$, $p > 0.05$) and publication sources ($Qb = 0.573$, $p > 0.05$) did not show any significant effect. The result of this study provides important information for further meta-analysis study and the implementation of PBL in mathematics learning.

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INTRODUCTION

Reasoning ability is the most crucial part of students' mathematics' complex skills (Hendriana et al., 2017; Sugandi et al., 2020). It is because of not only remembering facts, rules, and problem-solving procedures but making conjectures based on experience (Barrody, 1993; Bieda et al., 2013; Santosa et al., 2020; Syafrizal et al., 2020). Therefore, students will understand the correlation between mathematics concepts, and the learning process will be meaningful. Based on the result of TIMSS 2015 showed that Indonesian students' mathematics reasoning ability is still lower than knowledge and application domain. This is followed by PISA 2018, where Indonesians ranked 63 of 70 countries with a mathematics average of 379 (OECD, 2018). Seeing these factors, using the appropriate learning model is one of the teachers' efforts to enhance students' mathematics reasoning ability.

The practical learning model for developing students' mathematics reasoning ability is problem-based learning (PBL) (Napitupulu et al., 2016; Sugandi et al., 2020; Sumartini, 2015). According to Sari et al. (2020) PBL model has a significant effect on enhancing students' mathematics reasoning ability. Awan et al. (2017) revealed that PBL is an inquiry method where students solve problems in real contexts. In addition, PBL allowed students to develop curiosity and intelligence in solving problems. The PBL model, which is student-centered, gives routine problems, and students actively conduct a factual investigation until a solution is obtained to affect students' reasoning ability (Sugandi et al., 2020). Therefore, students' reasoning ability will develop if the PBL model is applied routinely.

In the pedagogical techniques of the PBL model, students' thinking and learning processes were pushed by problems and thinking skills that were oriented from the beginning of the learning (Awan et al., 2017). Thus, the PBL model is designed to assist students in developing thingking skills, problem-solving, and intellectual skills (Sumartini, 2015). The PBL syntax includes (1) identification of problems; (2) setting a problem; (3) independent and group investigation; (4) developing and presenting reports; and (5) analyzing and evaluating the problem-solving process (Lestari et al., 2021). This shows that during the learning process, students not only listen but also take notes and memorize materials; however, actively higher-order thinking with their reasoning competencies, communicating, and working together to reach some conclusion. Based on that process, indirectly, PBL stimulates students to enhance their reasoning ability.

Implementing PBL in the learning process affected the improvement of student's reasoning ability. However, several previous studies showed relatively different results. Sari et al. (2020), Sugandi et al. (2020), and Syafrizal et al. (2020) found that the implementation of PBL has a significant effect on enhancing students' reasoning ability. Syazali et al. (2019) claimed that *Guided Discovery Learning* (GDL) is more significant than PBL for enhancing reasoning ability. Meanwhile, Madio (2016) showed that PBL only positively affected mathematics reasoning ability for students with moderate and low initial mathematics ability. These results indicate inconsistencies regarding the effectiveness of PBL on students' mathematics reasoning ability.

Other previous research on the same topic sometimes gives different results. This makes it challenging to build objective conclusions. Therefore, it is necessary to conduct a meta-analysis study. Meta-analysis study is seen as quantitative research and uses effect sizes from the relevant studies with the same topic to generate comprehensive and in-depth conclusions, whether about the strength of the effect, correlation, and the relation between variables (Cumming, 2012; Suparman et al., 2021; Young, 2017; Young et al., 2016; Yunita et al., 2020). Generally, this study is carried out by calculating the effect size's average, testing the homogeneity and publication bias, and detecting the heterogeneity of the study from moderator variables (Sánchez-Meca & Marín-Martínez, 1998; Young, 2017). However, until now, no meta-analysis studies have been found on the effect of the PBL model on students' mathematics reasoning ability. Even though the reasoning for the industrial revolution 4.0 is essential, especially for achieving the 4th target of quality education on the SDGs. So that educators, especially teachers, need information accuracy about the effectiveness of PBL in enhancing students' mathematics reasoning ability.

Meta-analysis studies in Indonesia with the PBL domain are various. Suparman et al. (2021) analyzed the effectiveness of PBL on problem solving ability using seven moderator variables: sample size, educational level, research area, sampling technique, publication year, publication source, and publication type. The result showed that sample size, sampling technique, publication year, publication source, and publication type had no significant effect on implementing PBL to enhance problem-solving ability in Indonesia. At the same time, the results of the meta-analysis study conducted by Paloloang et al. (2020) revealed that publication year, educational level, sample size, and publication source positively affected the implementation of PBL for enhancing students' mathematics literacy ability. Based on these two contradictory studies, this research will expand and complement the previous meta-analysis studies, with a different dependent variable focused on Indonesian students' mathematics reasoning ability. In addition, it will disclose whether different dependent variables will positively affect the selected moderator variables (sample size, publication year, educational level, publication source/type, and sampling technique). Based on the background, this meta-analysis study aims to synthesize effect of Problem-Based Learning model (PBL) on students' mathematics reasoning ability.

METHOD

Literature Search

The studies included in the analysis used electronic databases, namely Google Scholar, ProQuest, ERIC, IOP Science, and SAGE. The following keywords were used: "*problem-based learning*", "pembelajaran berbasis masalah", "PBL", "*reasoning*", "penalaran matematis", and "kemampuan penalaran matematis". Search results using electronic databases found 2.914 studies. Furthermore, these studies were screened based on the inclusion criteria set by the researcher.

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Inclusion Criteria

The inclusion criteria were referenced to check and assess the quality of the studies obtained in the literature search. This meta-analysis uses the following criteria:

1. The publication year range from 2014-2021;
2. The research area of study in Indonesia;
3. The primary study was published in the form of national and international journals or proceedings indexed by SINTA or SCOPUS;
4. The primary study used at least one PBL classroom as the experimental class and one traditional classroom as the control class;
5. The preliminary study reported sufficient data to calculate effect sizes.

Upon screening the initial set of 2.914 studies, eight primary studies were used as a source of meta-analysis data. Of these eight studies, two assessed more than one effect of PBL on mathematics reasoning ability, namely the study of Sugandi et al. (2020) and Abidin et al. (2021), so ten studies were analyzed in this meta-analysis study.

Coding and Selection of Moderator Variables

The researcher then coded the inclusion criteria for the studies that have been appropriate to identify quantitative data and potential moderator variables that it could analyze. The following moderator variables were categorized based on the typical characteristics of the selected studies.

Publication year

Every year article publication related to the effectiveness of PBL on students' mathematics reasoning are relatively increasing, especially in the last eight years. The moderator variable of publication year was chosen to analyze the differences between study results over time. Therefore, the researchers set the publication year into two categories: studies conducted in the range of 2014-2017 and 2018-2021.

Educational level

In Indonesia, there are four educational levels (1) early childhood education program; (2) basic education program (SD); (3) secondary education program (SMP, SMA, and SMK); and (4) higher education program (University). An analysis of the ten primary studies showed that the studies are spread out at the SD, SMP, SMA, and university levels. Because there was only one study at the university level, the educational level is grouped into two categories: SD-SMP levels and SMA-University levels. Thus, the educational level variable would evaluate whether the effectiveness of PBL on mathematics reasoning varies for each category of educational level.

Sampling technique

There are two sampling techniques (1) *non-random sampling* and (2) *random sampling* (Etikan & Bala, 2017). The sampling technique for ten primary studies is too varied. Therefore, the moderator variable of the sampling technique is grouped into two categories, namely *non-random sampling* and *random sampling*. *Non-random sampling* is a sampling technique without randomizing the population be the research sample. While *random sampling*, there is the randomization of the sample, the research sample.

Sample size

The sample size variable was chosen to analyze the differences between study results based on different sample sizes. The researchers set the sample size into two categories: sample size ≤ 30 and > 30. The number 30 was chosen because, in Indonesia, the number of students in classes is typically 25 to 30.

Publication source

In this meta-analysis study, the publication source comprised two categories: journals and proceedings. The difference between journals and proceedings is that proceedings only publish articles that have been given seminars at a conference, while journals do not. In addition, usually publications

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in some journals must go through a reasonably strict peer-review process by experts. In contrast, peer-revies are not as strict in publications in proceedings as in journals. Thus, in this meta-analysis, the researchers would evaluate whether the publication sources (journals vs. proceedings) impact the effectiveness of PBL on students' mathematics reasoning ability.

Statistical Analysis

In this meta-analysis study, each study's effect size was calculated using the formula of Hedges *g* (Borenstein et al., 2009; Suparman, Yohannes, et al., 2021), following the guidelines of Retnawati et al. (2018) and assisted by JASP 0.15.0.0. A random effect model was used to analyze the combined effect size of all studies. The selection of the random effect model is based on the assumption that the actual effect sizes of the analyzed studies are different and come from different populations, where these populations had their sampling distributions (Borenstein et al., 2009). Table 1 shows a reference for the interpretation of the effect size results.

Table 1. The Cohen's Classification of Effect Size

Effect Size	Interpretation
$ES \leq 0{,}20$	Weak
$0{,}20 < ES \leq 0{,}50$	Moderate
$0{,}50 < ES \leq 1{,}00$	Strong
$ES > 1{,}00$	Very Strong

The heterogeneity test was carried out by examining Q statistic and p value to see the effect size variance between studies. There was no difference variance of the effect size between studies of the null hypothesis (H_o) in the heterogeneity test. While there was a heterogeneity of the variance of effect size between studies was the alternative hypothesis (H_a). If the results reject H_o, it showed that the variance of the effect size of all analyzed studies was heterogeneous, so there was potential to analyze moderator variables to reveal the heterogeneous effect on effect of PBL on mathematics reasoning ability.

Analysis of moderator variables was carried out by JASP and *Microsoft Excel* with the following steps (1) checking the effect size's average and Q statistic or the variance of each category on the moderator variables; (2) counting the within-group variability of effects (Q_w) by adding up the variance of each category; (3) counting the medium variance (Q_b) by subtracting the Q with Q_w; (4) counting the *chi-square* distribution or p-value using the formula "=CHIDIST (Q_b; *df*)." If the $p < 0{,}05$, then the effect size's average of each category on the moderator variables was significantly different so that the moderator variables affected the effectiveness of PBL on students' mathematics reasoning ability compared to the traditional learning model.

Analysis of publication bias was carried out to examine how robust the meta-analysis results were so that misrepresentation could be prevented of any finding in the primary study (Bernard et al., 2014). This meta-analysis study analyzed publication bias by *Funnel plot* and *Egger test*. *The funnel plot* represented the spread of the effect size for each primary study, whether it was spread symmetrically around the vertical line or not. If the distribution was symmetric, then this meta-analysis study did not get publication bias (Retnawati et al., 2018). But if the *Funnel plot* was complex to interpret the symmetry, then the *Egger test was* used to examine whether the spread of the effect size symmetry or not. In the *Egger test*, if the *p-value*> 0,05, then the spread of the effect size in the *Funnel plot* was confirmed to be symmetrical, so it could conclude that there was no publication bias in the meta-analysis study. Furthermore, *fail-safe N* was also used to estimate the number of studies with insignificant results (unpublished data) needed, so that the effect size's average became not statistically significant. A meta-analysis study did not get publication bias if the result of *fail-safe N* more than $5k + 10$, where k represented the number of studies.

RESULTS AND DISCUSSION

Results

The ten effect sizes in the meta-analysis ranged from 0,97 to 4,33, with 100% of studies having a positive effect size. This describes that all studies report the effect of PBL on students' mathematics

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reasoning ability better than the control group. This is because PBL presents problems in a learning context requiring reasoning ability or always relating mathematics concepts to daily life. In addition, mathematics reasoning ability procedurally will work if students attempt to understand the problem, connect and representation between related mathematics concepts, and generalize. The analysis result showed that 9 of 10 studies had an effect size of more than one, indicating a powerful effect of PBL on reasoning ability. The sample number in the meta-analysis ranged from 48 to 97 students (a combination of the samples of experimental and control classes). Figure 1 shows the effect sizes of all studies. The primary analysis result showed that there was a significant effect of the implementation of PBL on students' mathematics reasoning ability (g_{RE} = 2,062; 95% CI [1,436; 2,689]; p < 0,001). The *summary effect* was 2,062; if compared with Cohen's classification (Table 1) that value was in the very strong category. Therefore, it can be concluded that there is a very strong effect of the implementation of PBL on students' mathematics reasoning ability.

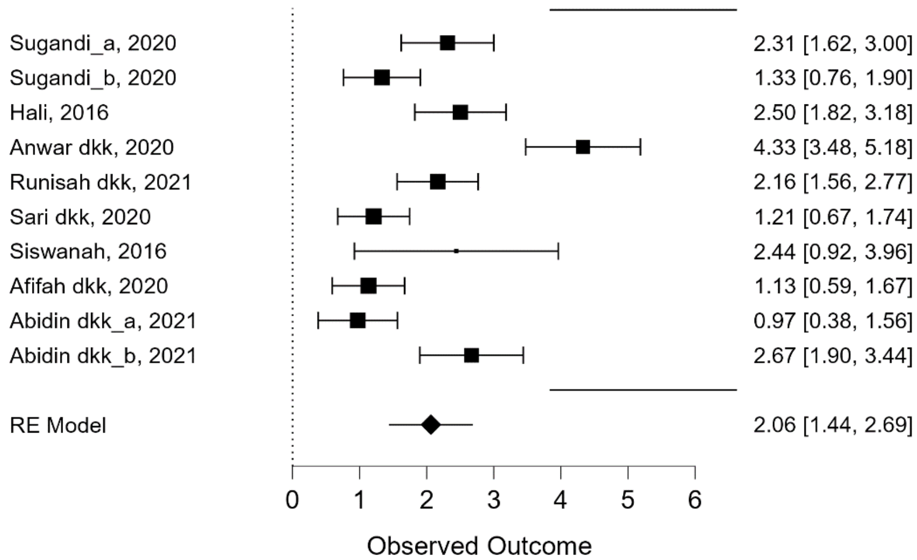

Figure 1. Forest Plot for Effect Sizes

The ten studies in the meta-analysis confirmed that the heterogeneity test showed there was a significant difference variance of effect sizes (Q = 67,474; p < 0,001). This indicates the potential to analyze moderator variables to reveal the source of variance between effect sizes. The following is a variable moderator analysis in this meta-analysis study.

Table 2. Variable Moderator Analysis Results

Variables	n	g_{RE}	95% CI	Q	df	Q_w	Q_b
Overall	10	2,062*	[1,436; 2,689]	67,474*	9		
Publication year					1	62,014	5,460**
2014-2017	2	2,490*	[1,864; 3,116]	0,005	1		
2018-2021	8	1,981*	[1,227; 2,736]	62,009	7		
Educational level					1	65,825	1,649
SD-SMP	6	2,048*	[1,041; 3,054]	57,357	5		
SMA-University	4	2,071*	[1,439; 2,703]	8,468	3		
Sampling technique					1	58,442	9,032*
Non Random	4	2,520*	[1,260; 3,779]	37,622	3		
Random	6	1,721*	[1,120; 2,323]	20,820	5		
Sample size					1	65,393	2,081
≤ 30	4	1,792*	[1,013; 2,571]	16,737	3		
> 30	6	2,256*	[1,308; 3,205]	48,656	5		
Publication source					1	66,901	0,573
Journals	6	1,904*	[1,398; 2,411]	16,492	5		
Proceedings	4	2,268**	[0,762; 3,775]	50,409	3		

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Note. *$p < 0{,}001$; **$p < 0{,}05$; n = number of studies; CI = Confidence Interval; Qw = *Q within*; Qb = *Q intermediate*.

Moderator analysis results

The publication years' variable is divided into two categories: studies published in 2014-2017 and 2018-2021. Table 2 shows that the effect sizes' average of two categories was found to be statistically difference significant (Q_b = 5,460; p = 0,019). This indicated that publication year affected the effectiveness of PBL on students' mathematics reasoning ability compared to the traditional learning model. Of these two categories analyzed, using PBL was more effective in the studies published in 2014-2017 (g = 2,490; p < 0,001) when compared to the studies published in 2018-2021 (g = 1,981; p < 0,001).

The educational levels variable is divided into the SD-SMP level and SMA-Universities level. Table 2 shows that the effect sizes' average of the two categories did not explain a statistically significant difference (Q_b = 1,649; p = 0,199). Although the effect sizes' average of SMA-Universities' level (g = 2,071; p < 0,001) was higher than SD-SMP's level (g = 2,048; p < 0,001), the difference was not significant. This indicated that the educational level did not affect the effectiveness of PBL on students' mathematics reasoning ability compared to the traditional learning model.

The sampling techniques' variables divided to be two categories: *non-random sampling* and *random sampling*. Table 2 shows that the effect sizes' average of two categories was found to be statistically difference significant (Q_b = 9,032; p = 0,000). This indicated that the sampling technique affected the effectiveness of PBL on students' mathematics reasoning ability compared to the traditional learning model. Of these two categories analyzed, using PBL was more effective in the studies with *non-random sampling* (g = 2,520; p < 0,001) when compared to *random sampling* (g = 1,721; p < 0,001).

The sample sizes' variable divided to be two categories, namely studies with the sample size ≤ 30 and > 30. Table 2 shows that the effect sizes' average of the two categories did not explain a significant statistical difference (Q_b = 2,081; p = 0,149). Although the effect sizes' average of studies with a sample size > 30 (g = 2,256; p < 0,001) is higher than ≤ 30 (g = 1,792; p < 0,001), the difference was not significant. This indicated that the sample size did not affect the effectiveness of PBL on students' mathematics reasoning ability compared to the traditional learning model.

The publication sources' variable is divided into two categories: studies from journals and proceedings. Table 2 shows that the effect sizes' average of the two categories did not explain a significant statistical difference (Q_b = 0,573; p = 0,449). However, the effect sizes' average of studies sourced from proceedings (g = 2,268; p = 0,003) *was* higher than journals (g = 1,904; p < 0,001), and the difference was not significant. This indicated that the publication source did not affect the effectiveness of PBL on students' mathematics reasoning ability compared to the traditional learning model.

Publication bias

For checking publication bias, we used several methods, namely the *Funnel plot* and *Egger test*. Figure 2 shows the overall effect size studies from *Funnel plot* analysis. Whether the spread of the effect size in *Funnel plot* symmetry or not is examined using the *Egger test*. The *Egger test's* result was z = 1,649 and p = 0,099, which confirmed that the spread of the effect size is symmetrical. These results indicated that there was no publication bias in this meta-analysis study.

Furthermore, in this study, the *fail-safe N* was 1191 (α = 0,05; p < 0,001). The number of studies (k) was ten so the value of 5k + 10 = 5(10) + 10 was 60. Because the fail-safe N was 1191 and higher than the value of 5k + 10, it could be concluded that there was no publication bias in this meta-analysis study.

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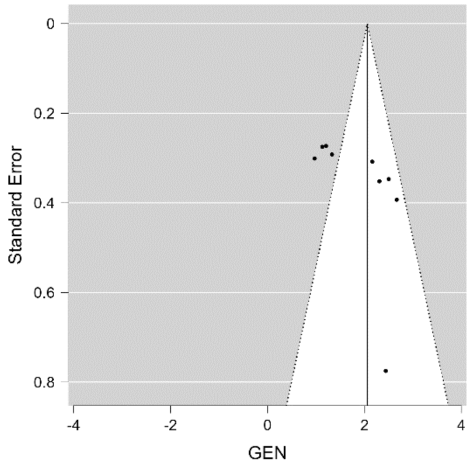

Figure 2. Funnel Plot of Effect Sizes

Discussion

The results of various research reported that PBL effectively enhances students' academic achievement at various levels of education. However, several other studies reported the opposite, finding that PBL was ineffective in enhancing students' academic achievement. This meta-analysis, which synthesizes 10 studies about the implementation of PBL in mathematics learning in Indonesia, provided another perspective, particularly on the effectiveness of PBL in students' mathematics reasoning ability. This meta-analysis study reveals that the implementation of PBL in Indonesia positively affects students' mathematics reasoning ability compared to the traditional learning model. This follows the opinion of NCTM (2000) opinion that mathematics reasoning occurs when students observe a pattern (especially in contextual problems), make generalizations and allegation linkages between mathematics concepts, examine the conjectures, build mathematics arguments, and validate a conclusion. The findings of this study are consistent and strengthen the results of the meta-analysis conducted by Susanti et al. (2020) and Paloloang et al. (2020). However, both studies are more focused on examining the effect of PBL on communication ability and mathematics literacy. The findings of this study are also consistent with the results of the meta-analysis conducted by Yunita et al. (2020). They found that PBL had a strong significant effect on creative thinking ability. Also, Suparman et al. (2021) found that PBL strongly affected students' mathematics problem-solving abilities.

The results of the overall moderator analysis show that publication year and sampling technique impact the effectiveness of PBL on students' mathematics reasoning ability. Based on the publication years' analysis, the studies published in 2014-2017 have a very strong effect size than studies in 2018-2021. Several studies in the second category (published in 2018-2021) are suspected of being conducted during COVID-19. In Indonesia, the learning system has changed from offline to online since the existence of COVID-19. It causes teachers to adapt quickly, especially in implementing learning models. The learning process that is already familiar with the student-centered concept then has to return to the teacher-centered concept. Therefore, when teachers try to implement PBL in the learning process during the COVID-19, students' mathematics reasoning ability is relatively unable to enhance significantly.

Based on the results of educational level, it can be seen that PBL is effective in enhancing mathematics reasoning ability at the SD, SMP, SMA, and University. This finding was also reported by Yunita et al. (2020), however slightly different from Paloloang et al. (2020), who found that PBL is more effective at the higher education level. Because there was only one study conducted at the university level, these findings can be used as an initial idea for further research involving more than one study at the university level. Comprehensive information will be obtained regarding the effectiveness of PBL based on educational level.

Based on the sampling technique results, non-random sampling groups have a more significant effect size than the *random sampling* groups. This shows that implementing PBL on non-random sampling is more effective than *random sampling*. This finding is consistent with Suparman et al. (2021), but different from the findings of Siddiq & Scherer (2019), which recommended that *random sampling* is more effective than *non-random sampling*.

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Based on the sample size results, PBL effectively enhances mathematics reasoning ability in the sample size ≤ 30 and > 30. This finding was also reported by Paloloang et al. (2020) and Yunita et al. (2020), however slightly different from the finding by Tamur, Juandi, dan Kusumah (2020), who found that the smaller sample size, PBL will be more effective in enhancing reasoning ability. Due to inconsistent results, further meta-analysis research needs to use more studies to reveal the impact of sample size on the effectiveness of the PBL model.

Based on the results of the publication source, PBL is reported to be effectively used to enhance mathematics reasoning ability in both studies from journals and proceedings. This finding answers the research of Paloloang et al. (2020) that not only do journals tend to report significant research, but proceedings also have that tendency. Thus, both studies from journals and proceedings can be used as references for implementing PBL in mathematics learning.

This meta-analysis study was limited to studies conducted in the Indonesian region. Other than that, the studies are only sourced from journals and proceedings, so the number of studies analyzed is relatively small compared to meta-analysis studies. Therefore, further meta-analysis studies are needed, involving the results of research from various countries and not limited to the studies published in journals and proceedings but also supplemented by another source (i.e., theses and dissertations). Hopefully, this will strengthen this meta-analysis study's findings and allow for even broader generalizations. Furthermore, the moderator variables were limited to five variables: publication year, educational level, sampling technique, sample size, and publication source.

Further research can reveal the impact of other moderator variables, such as the instrument types to examine reasoning ability and the country where the research is conducted. Analyzing the country's impact on the effect of PBL on reasoning ability is interesting to do so that possible to explore whether the effect of PBL is the same across countries. However, the challenge is that the studies must involve many studies spread across various countries.

CONCLUSION

This meta-analysis synthesized ten studies on the effectiveness of Problem-Based Learning (PBL) on students' mathematical reasoning ability. The findings of this meta-analysis study provide empirical evidence that there is a very strong effect of the implementation of PBL on students' mathematics reasoning ability compared to traditional learning models. These findings confirm that PBL can be used as an alternative learning model that can be applied at various educational levels to enhance students' mathematics reasoning ability. In addition, this meta-analysis study also reveals that the effectiveness of PBL on mathematics reasoning ability can also be influenced by the time of research implementation and the sampling technique. This needs to be a consideration and concern for researchers when using PBL as an intervention in the learning process. For further meta-analysis study, it is recommended to synthesize research on how learning media can facilitate students in enhancing learnings interest so that it will impact trained reasoning skills. In addition, further research should explore whether the problem-based learning media can explain the relation between PBL and students' mathematics reasoning ability. Therefore, future research must involve more primary studies to make the findings obtained more comprehensive.

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