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The utilization of computer-assisted mathematics education integrated into project-based learning to optimize Indonesian students' mathematics achievement: A systematic review and meta-analysis

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ABSTRACT

In the last six years, computer-assisted mathematics education (CAME) in project-based learning (PBL) has been conducted in a relatively large part of the learning environment. However, using CAME in the PBL has an inconsistent effect on Indonesian students' mathematics achievement. A meta-analytic review was used to estimate and examine the effectiveness of CAME integrated into PBL on students' mathematics achievement across class capacity, educational level, mathematics content, and computer technology. 13 empirical studies published during 2019 – 2024, generating 17 units of effect size and involving 1,313 students were included to this review as the data. Some analyses were applied to analyze the data, including sensitivity, publication bias, Z test, and Q Cochrane test using Comprehensive Meta-Analysis (CMA) software. Results showed that utilizing CAME in the PBL environment had a significant positive, strong effect ($g = 1.018$; $p < 0.01$) on the mathematics achievement of Indonesian students. Additionally, several factors, such as educational level, mathematics content, and computer technology, significantly differentiated students' mathematics achievement in the PBL environment but vice versa for class capacity. This meta-analytic review implies that using CAME integrated into PBL can be one of the effective interventions to optimize students' mathematics achievement.

Keywords: computer-assisted mathematics education, Indonesia, mathematics achievement, meta-analysis, project-based learning

INTRODUCTION

The sophisticated and fast development of science and technology in the 21st century requires individuals, especially students in educational contexts, to adapt to emerging challenges, such as difficulties and problems. The challenges related to emerging technologies in the educational sector necessitate programming skills, which are fundamental in computer science (Ehsan et al., 2018). The demands for educators in mathematics with programming skills constrain them to have computational thinking (CT), a central topic to be discussed in educational technology in numerous countries (Fry et al., 2023; Sung et al., 2023). According to Molina-Ayuso et al. (2022), CT is an integrated and comprehensive skill that promotes students in solving complex problems in many scientific fields, including mathematics. Consequently, CT skills must be essential in educational settings and must be developed and enhanced in the learning environment.

CT skills are incredibly related to mathematics as a primary language of science and technology in that the activities to think mathematically require it. Some empirical studies found that CT skills were positively related to mathematics achievement, indicating that the higher the students' CT skills, the more optimal it is for students' mathematics achievement, and vice versa (Aminah et al., 2023; Angraini et al., 2023; Kaup et al., 2023). This reveals that mathematics achievement is crucial for students to get high CT skills. Several empirical studies, however, found that students' mathematics achievement at every educational level has not been optimal (Adams et al., 2023; Hollenstein et al., 2024; Siller & Ahmad, 2024). Some empirical studies also found that Indonesian students still had low mathematics achievement (Azid et al., 2022; Juniati & Budayasa, 2020; Kadir, 2023). Consequently, effective interventions in the mathematics learning environment are highly required to optimize the mathematics achievement of Indonesian students.

Project-based learning (PBL) can be a potential intervention that can optimize the mathematics achievement of Indonesian students. PBL refers to a learning model widely implemented in advanced educational institutions. It is defined as a learning model organizing students in the classroom to work on projects in a group atmosphere to solve a real-world problem to prepare themselves for real life (Kokotsaki et al., 2016; Tascı, 2015). According to Kokotsaki et al. (2016), PBL aims to get new knowledge and skills in learning and construct students to be more active in solving intricate project problems. Additionally, Tascı (2015) revealed that PBL has some advantages, such as solving real problems through project activity, being more active in learning, being more independent in solving the project, being motivated to compete in producing a good product, and having responsibility for the projects. Moreover, several empirical studies found that the intervention of PBL can enhance students' achievement, interest, motivation, creativity, and attention in mathematics learning (Lou et al., 2017; Putra et al., 2024; Siew et al., 2015; Suparman et al., 2024).

In today's technology-driven world, computer-assisted mathematics education (CAME) has emerged as a powerful tool to enhance the teaching and learning of this crucial subject. By leveraging the capabilities of digital platforms (e.g., Moodle, Google Classroom, Edmodo, Schoology, and Zoom) and interactive software (e.g., GeoGebra, CABRI 3D, Geometer's Sketchpad, and Maple), educators can create dynamic and engaging learning experiences that help students develop a deeper understanding of mathematical concepts (Jaya & Suparman, 2021; Suparman et al., 2024). From virtual manipulatives and simulations to personalized learning algorithms and real-time feedback, CAME offers many opportunities to make mathematics more accessible, intuitive, and engaging for students of all ages and skill levels. By seamlessly integrating technology into the classroom, mathematics teachers can create a more collaborative and project-based learning environment, fostering critical and creative thinking, problem-solving, and reasoning in mathematics (Suparman et al., 2022; Susiyanti et al., 2022; Yunita et al., 2022). Consequently, the utilization of CAME integrated into the PBL environment is hypothesized as an alternative intervention to optimize the mathematics achievement of Indonesian students.

From 2019 to 2024, the development of empirical studies regarding mathematics achievement and CAME integrated into PBL has gradually increased in Indonesia. Lots of empirical studies found that the utilization of CAME in the PBL environment had significant positive effect in optimizing students' mathematics achievement (Destini et al., 2023; Kosmani et al., 2023; Lusiana, 2023; Mulyani & Arif, 2021; Prabaningrum & Waluya, 2020; Suherman et al., 2020; Surmilasari et al., 2022; Tilari et al., 2024). According to Sudianto et al. (2019), however, integrating CAME into the PBL environment did not significantly affect the optimization of students' mathematics achievement. Moreover, a few empirical studies found that using CAME integrated into the PBL environment hurt the optimization mathematics achievement of Indonesian students (Angreanisita et al., 2021; Ferdiani, 2022; Khodijah et al., 2023). This indicates that using CAME integrated into the PBL environment had an inconsistent effect on optimizing Indonesian students' mathematics achievement.

Furthermore, of many empirical studies conducted in Indonesia, some studies found that the use of CAME integrated to the PBL environment had moderate effect (Kholid et al., 2022; Lusiana, 2023; Prabaningrum & Waluya, 2020; Surmilasari et al., 2022), and strong effect on the optimization of students' mathematics achievement (Destini et al., 2023; Kosmani et al., 2023; Mulyani & Arif, 2021; Suherman et al., 2020; Tilari et al., 2024). Nevertheless, Sudianto et al. (2019) revealed that using CAME in the PBL environment weakly affected students' mathematics achievement optimization. Moreover, a few empirical studies found that the use of CAME integrated into the PBL environment hurt optimizing the mathematics achievement of Indonesian students (Angreanisita et al., 2021; Ferdiani, 2022; Khodijah et al., 2023). This shows that using CAME integrated into the PBL environment had a heterogeneous effect on optimizing Indonesian students' mathematics achievement. This indicates that the mathematics achievement of Indonesian students who learn in the PBL environment using CAME is various, and they have low, moderate, or high mathematics achievement.

The inconsistent and heterogeneous effect of CAME integrated into the PBL environment significantly requires a systematic review to provide a clear and precise conclusion. A meta-analytic review, a series of quantitative methods estimating and examining the relationship strength of two variables or more of several relevant empirical studies using a unit of effect size (Ariani et al., 2024; Fuad et al., 2023; Putri et al., 2024), can be a precise way to provide transparent information related to the role of CAME in the PBL environment for mathematics achievement of Indonesian students. To date, some meta-analytic reviews have studied PBL and academic achievement whereby the intervention of PBL had positive modest effect to positive moderate effect on the optimization of students' academic achievement (Chen & Yang, 2019; Goyal et al., 2022; Santhosh et al., 2023; Zhang & Ma, 2023). Particularly in mathematics education, a meta-analytic review of twelve empirical studies conducted by Yunita et al. (2022) found that PBL had a positive, strong effect on achieving mathematical problem-solving skills. Additionally, a meta-analytic review of ten empirical studies by Susiyanti et al. (2022) reported that PBL had a moderate positive effect on achieving mathematical critical thinking skills. These reviews show that the PBL environment is one of the effective interventions to optimize the mathematics achievement of Indonesian students. In contrast, the present meta-analytic review studies the utilization of CAME integrated into the PBL environment to optimize the mathematics achievement of Indonesian students.

Hence, this meta-analytic review aims to estimate and examine the effectiveness of CAME integrated into the PBL environment on optimizing Indonesian students' mathematics achievement across class capacity, educational level, mathematics content, and computer technology. The moderating factors (e.g., class capacity, educational level, mathematics content, and computer technology) must be investigated. These can potentially differentiate Indonesian students' mathematics achievement in the PBL environment using CAME. This review is expected to provide a clear and precise conclusion regarding the role of CAME integrated into the PBL environment to optimize the mathematics achievement of Indonesian students. The following research questions are directed to meet the purpose of this meta-analytic review, namely:

RQ1 What is the overall effect size of CAME integrated into PBL toward Indonesian students' mathematics achievement?

RQ2 What does the utilization of CAME integrated into PBL have significant positive effect toward Indonesian students' mathematics achievement?

RQ3 How do moderating factors (e.g., educational level, mathematics content, class capacity, and computer technology) vary the effect of CAME integrated into PBL toward Indonesian students' mathematics achievement?

METHOD

Research Design and Inclusion Criteria

A systematic review was performed to conduct the recent study. Moreover, this recent study involved a meta-analytic technique — a series of quantitative procedures employing the effect size (Fuad et al., 2023; Helsa et al., 2023), was applied to estimate and examine the effect of CAME integrated into the PBL environment in optimizing mathematics achievement of Indonesian students across class capacity, educational level, mathematics content, and computer technology. Some inclusion criteria were decided to restrict the breadth of stated problems. Firstly, every document title had to contain keywords: "project-based learning" AND "mathematics" AND "computer technology". Secondly, the document was an article that was written in English and Indonesia. Moreover, it was sourced from the journal. Thirdly, the document was published between 2019 and 2024. The period was selected since there were any educational reforms and technological changes as the effect of COVID-19 phenomena from the end of 2019 to the early of 2022. Fourthly, the population in the document was Indonesian students in the level of elementary school, junior high school, senior high school, or college/university. Fifthly, the intervention in the document was CAME integrated into the PBL environment. Sixthly, the comparator in the document was traditional mathematics instruction. Seventhly, the outcome in the document was mathematics achievement. Eighthly, the research design in the document was quasi-experimental research. Ninthly, the document reported adequate statistical data to calculate the effect size. The documents that did not meet the inclusion criteria were removed from the recent study in the step of document selection.

Literature Search and Document Selection

Google Scholar, as a search engine, was used to find documents regarding mathematics achievement and CAME integration into the PBL environment. Some combinational keywords, such as "project-based learning", "mathematics", and "computer technology" were applied to ease the search of documents. The initial search conducted on May 31st, 2024, precisely at 11.59 PM, found 158 documents published in the period of 2001 – 2024. To systematically select documents found in the initial search, four steps, such as:

(1) identification,

(2) screening,

(3) eligibility, and

(4) inclusion had to be passed through (Putra et al., 2024; Zainil et al., 2024).

The selection process for those documents is briefly and comprehensively explained in **Figure 1**.

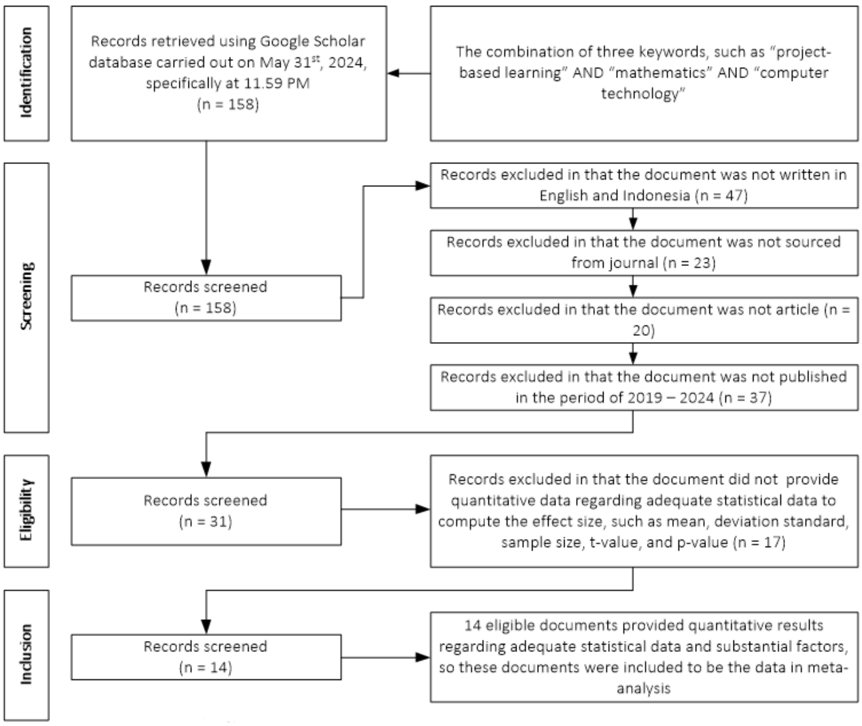

Figure 1. The systematic process of document selection (Source: Authors' own elaboration)

Table 1. The results of Cohen's Kappa test

Coding Item	Kappa value	Agreement level	Sig. value
Mean of Experiment Group	0.923	Almost perfect	0.009
Dev. Std. of Experiment Group	0.912	Almost perfect	0.009
Sample Size of Experiment Group	0.927	Almost perfect	0.009
Mean of Control Group	0.957	Almost perfect	0.008
Dev. Std. of Control Group	0.943	Almost perfect	0.008
Sample Size of Control Group	0.952	Almost perfect	0.008
T-value	0.962	Almost perfect	0.007
Class Capacity	0.822	Strong	0.018
Educational Level	0.845	Strong	0.017
Mathematics Content	0.889	Strong	0.011
Computer Technology	0.867	Strong	0.012

Data Extraction

13 eligible documents included in the data in the meta-analysis were extracted from the coding sheet. It consisted of code, author, quantitative results, moderating factors, document type, journal or proceeding name, email, and DOI or URL link. Moreover, 13 included documents generated 17 units of effect size and 1,313 students in every educational level. The credibility and validity of the data used in the research have been required to provide qualified reports (Cohen et al., 2018). Two experts in meta-analytic review were involved to verify and justify the data. After they re-coded and checked the data in the coding sheet, the coding consistency among coders for the meta-analysis part and qualitative meta-synthesis part was performed. Cohen's Kappa test was applied to describe and analyze the coding consistency among coders in that there were only two experts involved for each part (McHugh, 2012).

From **Table 1**, it can be stated that the agreement level for each coding item was from moderate to almost perfect. Moreover, the significant value for every coding item was less than 0.05, which means that each part significantly agrees with the extracted data (Suparman & Juandi, 2022a, 2022b). Consequently, this provides strong evidence that the data included in the meta-analysis was credible and valid, and then the data is able to be analyzed.

In detail, the moderating factors (e.g., educational level, mathematics content, class capacity, and computer technology) were operationalized by a number of categorical variables. For instance, the factor of educational level consisted of elementary school (7 – 12 years old), junior high school (13 – 15 years old), senior high school (16 – 18 years old), and university (19 years old and more). Additionally, the factor of mathematics content consisted of algebra, geometry, measurement, number and operation, statistics, and trigonometry. Meanwhile, class capacity consisted of small class ($n < 31$ students) and large class ($n \geqslant 31$ students). On the other hand, the factor of computer technology consisted of audio-visual, digital game, e-worksheet, GeoGebra, google classroom, Moodle, and zoom platform.

Data Analysis

To do this meta-analytic review, the random effect model was applied as a preference to make decisions, such as estimated effect size, analysis of publication bias, sensitivity analysis, Z test, and Q Cochrane test. It was selected as an estimation model in that it was able to cover the collection of empirical studies that had heterogeneous characteristics, such as country, educational level, instruments, intervention duration, learning environment, mathematics content, and class capacity (Fuad et al., 2022; Juandi et al., 2023; Sulistiawati et al., 2023; Suyanto et al., 2023). Hedges' equation was applied to calculate the effect size in which this formula accommodated quantitative empirical research, which had a relatively small sample size (Borenstein, 2019). In the literature, Pigott (2012) stated that Hedges' equation was written as follows:

$$g = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{(n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}}} \times \left(1 - \frac{3}{4df - 1}\right) \tag{1}$$

Furthermore, the Z test was applied to examine the significance of CAME integrated into the PBL environment in optimizing the mathematics achievement of Indonesian students. Additionally, the Q Cochran's test was used to analyze four moderating factors (e.g., mathematics content, educational level, computer technology, and class capacity) in differentiating Indonesian students' mathematics achievement utilizing CAME integrated into the PBL environment.

RESULTS

This meta-analytic review explained some parts, such as sensitivity analysis and publication bias, estimated effect size, and subgroup analysis. Each of these meta-analysis parts was explained in the following subsections.

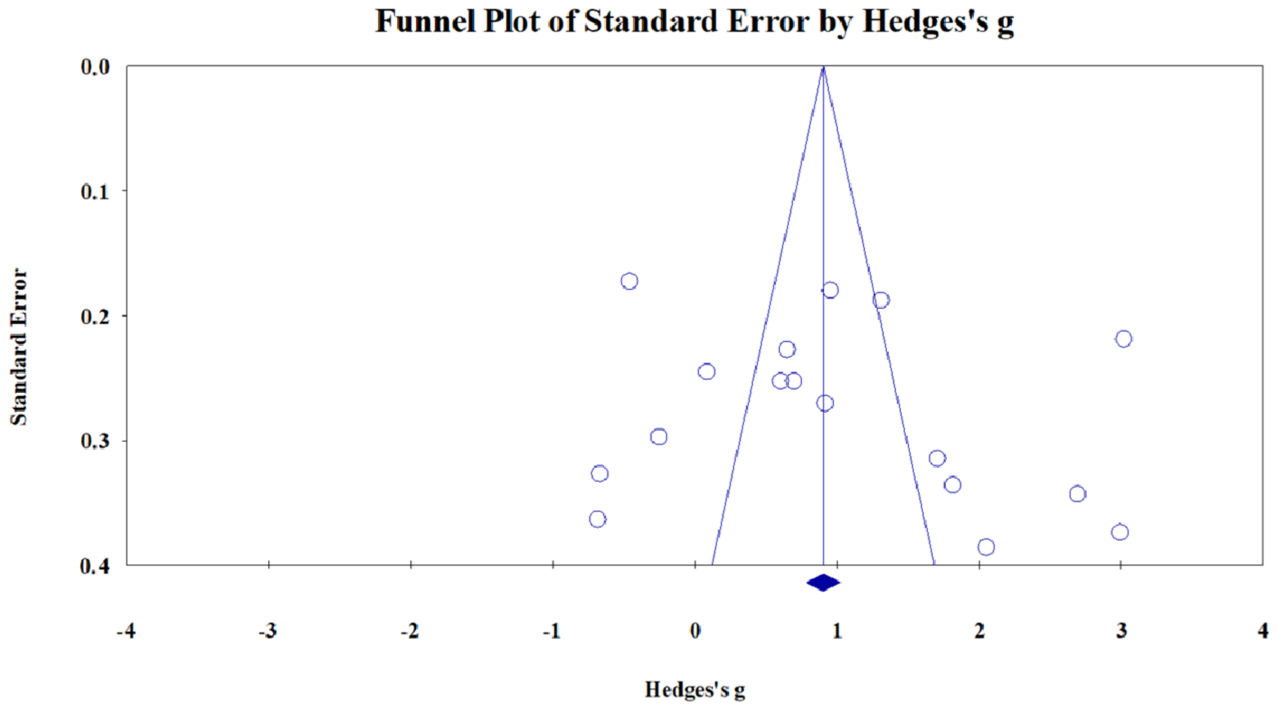

Figure 2. The distribution of effect size data in the funnel plot (Source: Authors' own elaboration)

Table 2. The results of fill and trim test

	Studies trimmed	Effect size in g	Lower limit	Upper limit	Q-value
Observed Values		1.018	0.476	1.559	313.617
Adjusted Values	0	1.018	0.476	1.559	313.617

Sensitivity Analysis and Publication Bias

To verify phenomena of publication bias indication, it can be carried out by observing the distribution of effect size data in the funnel plot (see **Figure 2**).

From **Figure 2**, it can be stated that there was symmetrical distribution of effect size data in the funnel plot. To justify the symmetry of the distribution, the test of trim and fill was conducted (see **Table 2**).

Table 2 shows that there was no effect size data that had to be excluded in the distribution both from right side and from left side. This justifies that there was symmetrical distribution of effect size data in the funnel plot. Consequently, this interprets that there is no phenomenon of publication bias of the collection of effect size data (Tawaldi et al., 2023).

To verify the sensitive phenomenon of effect size data, sensitivity analysis was performed by observing the existence of outliers in the interval between highest and lowest effect size. The results showed that the lowest effect size in g was 0.885 and the highest effect size in g was 1.120. On the other hand, the estimated point in g of 17 effect size data was 1.018. As a consequence of these findings, the estimated point was in the interval between 0.885 and 1.120, and moreover, there was no data that could be outlier. This interprets that there are no phenomena which indicated sensitive data when there was a change of data quantity in the collection of effect size (Suparman & Juandi, 2022b).

Estimated Effect Size

13 eligible documents included in this meta-analytic review generated 17 units of effect size in g and involved 1,313 students. The unit of effect size was heterogeneous in the perspective of direction, significance, and strength (see **Table 3**).

From **Table 3**, the estimated point of 17 units of effect size data in g was 1.018 whereby it can be interpreted that the use of CAME integrated to PBL environment has positive strong effect on mathematics achievement of Indonesian students. Furthermore, the significance value of the Z test was less than 0.05 in which this shows that the intervention of PBL environment promoted by CAME significantly affected in optimizing mathematics achievement of Indonesian students. This means that the utilization of CAME integrated to PBL environment is effective for the mathematics achievement of Indonesian students.

Subgroup Analysis

The Q Cochrane test was applied to test some moderating factors (e.g., educational level, mathematics content, class capacity, and computer technology) predicted in differentiating mathematics achievement of Indonesian students in the PBL environment utilizing CAME (see **Table 4**).

Table 3. The results of calculations of effect size

Document	Effect size in g unit	P-value
Kholid et al. (2022) – Part 1	1.310 [0.942; 1.679]	0.000
Kholid et al. (2022) – Part 2	-0.459 [-0.798; -0.121]	0.008
Kholid et al. (2022) – Part 3	0.955 [0.602; 1.308]	0.000
Kosmani et al. (2023)	1.816 [1.158; 2.474]	0.000
Destini et al. (2023)	1.707 [1.091; 2.324]	0.000
Sudianto et al. (2019)	0.085 [-0.395; 0.566]	0.728
Prabaningrum and Waluya (2020)	0.605 [0.110; 1.100]	0.017
Surmilasari et al. (2022)	0.697 [0.202; 1.193]	0.006
Suherman et al. (2020) – Part 1	2.994 [2.261; 3.726]	0.000
Suherman et al. (2020) – Part 2	0.917 [0.387; 1.447]	0.001
Suherman et al. (2020) – Part 3	3.020 [2.591; 3.449]	0.000
Tilari et al. (2024)	2.052 [1.296; 2.808]	0.000
Mulyani and Arif (2021)	2.694 [2.022; 3.367]	0.000
Khodijah et al. (2023)	-0.251 [-0.834; 0.332]	0.399
Ferdiani (2022)	-0.683 [-1.395; 0.028]	0.060
Lusiana (2023)	0.649 [0.204; 1.095]	0.004
Angreanisita et al. (2021)	-0.669 [-1.309; -0.028]	0.041
Estimated Effect Size	1.018 [0.476; 1.560]	0.000

Table 4. The results of Q Cochrane test

Substantial factor	Groups	Effect size in g unit	p-value
Education level	Elementary School	1.452	0.000
	Junior High School	1.625	
	Senior High School	-0.237	
	College/University	0.612	
Mathematics content	Algebra	1.190	0.000
	Geometry	1.228	
	Measurement	2.191	
	Numbers and Operations	0.697	
	Statistics	-0.683	
	Trigonometry	-0.261	
Class capacity	Large Class	1.052	0.902
	Small Class	0.979	
Computer technology	Audio-Visual	1.707	0.000
	Digital Games	0.236	
	E-Worksheet	-0.013	
	GeoGebra	1.410	
	Google Classroom	2.694	
	Moodle	-0.261	
	Zoom Platform	1.816	

From **Table 4**, it can be stated that some moderating factors (e.g., educational level, mathematics content, and computer technology) significantly differentiated Indonesian students' mathematics achievement in the PBL environment using CAME. Meanwhile, there have not been adequate evidence to state that class capacity significantly differentiated mathematics achievement of Indonesian students in the use of CAME integrated to the PBL environment.

DISCUSSION

The Effectiveness of CAME Integrated into PBL Environment for Students' Mathematics Achievement

This meta-analytic review finds that the estimated point of 17 units of effect size data in g was 1.018, whereby it can be interpreted that the use of CAME integrated into the PBL environment has a positive, strong effect on the mathematics achievement of Indonesian students. A meta-analytic review of twelve empirical studies conducted by Yunita et al. (2022) also found that PBL had a positive, strong effect on the achievement of mathematical problem-solving skills. Additionally, a meta-analytic review of ten empirical studies carried out by Susiyanti et al. (2022) reported that PBL had a moderate positive effect on the achievement of mathematical critical thinking skills. These reviews strengthen the idea that the utilization of CAME in the PBL environment has a positive effect on the mathematics achievement of Indonesian students. Furthermore, the present meta-analytic review also finds that the use of CAME integrated into the PBL environment significantly affected the mathematics achievement of Indonesian students. A few meta-analytic reviews also reported that PBL significantly affected Indonesian students' mathematics achievement, such as problem-solving and critical thinking (Susiyanti et al., 2022; Yunita et al., 2022). These meta-analytic reviews strengthen the fact that the PBL environment promoted by CAME significantly affected the mathematics achievement of Indonesian students. This means that the utilization of CAME integrated into the PBL environment is adequate to optimize the mathematics achievement of Indonesian students in the period of 2019 - 2024.

The incorporation of technology into the mathematics classroom has transformed the learning experience, unlocking a wealth of benefits for students. One of the key advantages is the ability to visualize complex mathematical concepts through dynamics simulations and interactive models, such as dynamic geometry software (DGS) and computer algebra system (CAS) (Jaya & Suparman, 2021). These visual aids help students develop a more intuitive understanding of abstract ideas, making it easier for them to grasp the underlying principles and apply them to problem-solving (Suparman et al., 2024). Furthermore, CAME fosters a more engaging and collaborative learning environment. This hands-on approach promotes a deeper level of engagement and retention of the subject matter. Additionally, the use of adaptive learning algorithms and personalized feedback mechanisms in CAME allows for tailored instruction that caters to the individual needs and learning styles of each student (Juandi et al., 2021). By continuously monitoring student progress and adjusting the content and pace accordingly, these technologies can help bridge gaps, identify areas of weakness, and provide targeted support, leading to improved learning outcomes.

One of the most powerful benefits of CAME is its ability to enhance students' problem-solving skills. By leveraging the interactive and dynamic nature of digital tools, educators can create learning experiences that challenge students to think critically, analyze information, and apply mathematical concepts to solve complex problems (Jaya & Suparman, 2021; Suparman et al., 2024). Using interactive simulations, virtual manipulatives, and gamified exercises, students are encouraged to experiment, explore, and discover patterns and relationships in mathematics. This hands-on approach not only deepens their understanding of the subject matter but also cultivates their ability to break down problems, devise strategies, and test potential solutions. The immediate feedback and guidance provided by these digital platforms help students learn from their mistakes, refine their problem-solving techniques, and develop a growth mindset that embraces challenges as opportunities for growth. Furthermore, the integration of technology into the mathematics classroom can expose students to a wider range of problem types and real-world scenarios, better preparing them to tackle the diverse challenges they may encounter in their academic and professional lives. By engaging with open-ended problems, simulations, and collaborative problem-solving activities, students develop critical thinking skills, flexibility, and the ability to adapt to novel situations, all of which are essential for success in the 21st century workforce.

The integration of technology into mathematics education has the remarkable potential to drive significant improvements in Indonesian students' mathematics achievement and overall academic performance. By leveraging the power of digital tools, interactive platforms, and adaptive learning algorithms, educators can create a learning environment that caters to the unique needs and learning styles of each student, ultimately leading to enhanced mastery of mathematical concepts and skills (Helsa et al., 2023). One of the keyways in which technology can boost mathematics achievement is through personalized and adaptive instruction. Digital learning platforms equipped with sophisticated algorithms can continuously monitor student progress, identify areas of weakness, and dynamically adjust the content and pace to provide targeted support and challenging opportunities for growth (Juandi et al., 2023). This tailored approach ensures that every learner receives the necessary scaffolding and enrichment to reach their full potential, resulting in measurable improvements in test scores and overall mathematical proficiency. Furthermore, the integration of visualization and simulation tools into the mathematics curriculum can have a profound impact on students' mathematical conceptual understanding and problem-solving abilities (Suparman et al., 2024). By bringing abstract concepts to life through interactive models, animations, and dynamic simulations, students can develop a more intuitive grasp of mathematical principles, leading to better retention and the ability to apply their knowledge to real-world scenarios. This enhanced engagement and deeper comprehension of the subject matter ultimately translate into higher achievement and better academic outcomes.

A Variety of Indonesian Students' Mathematics Achievements in the PBL Environment Using CAME

The present meta-analytic review has examined that some moderating factors (e.g., educational level, mathematics content, and computer technology) significantly differentiated Indonesian students' mathematics achievement in the PBL environment using CAME. Meanwhile, there has not been adequate evidence to state that class capacity significantly differentiated the mathematics achievement of Indonesian students in the use of CAME integrated into the PBL environment. Each substantial factor is explained in the following subsections.

Educational Level

There has been sufficient evidence to state that educational level significantly differentiated the mathematics achievement of Indonesian students in the PBL environment promoted by CAME. A few relevant meta-analytic reviews revealed that educational level differentiated students' mathematics achievement, such as problem-solving skills and critical thinking skills in the PBL environment (Susiyanti et al., 2022; Yunita et al., 2022). Inferentially, to optimize students' mathematics achievement, the effect of the use of CAME integrated into the PBL environment in junior high school was higher than the effect of it in other educational levels. As a consequence, it can be interpreted that the utilization of CAME integrated into the PBL environment is more effective in optimizing students' mathematics achievement in junior high school than at other educational levels.

Mathematics Content

A variety of mathematics contents significantly differentiated the mathematics achievement of Indonesian students who studied using the PBL promoted by CAME. Yunita et al. (2022), in a meta-analytic review, also found that there has been strong evidence that mathematics content differentiated students' mathematical problem-solving skills in the PBL environment. Inferentially, to optimize the mathematics achievement of Indonesian students, the effect of the CAME usage integrated into the PBL environment in measurement topics was significantly higher than the effect of the CAME usage integrated into the PBL environment in other topics (e.g., algebra, geometry, number & operations, statistics and trigonometry). Consequently, it can be interpreted that the utilization of CAME in the PBL environment to optimize Indonesian students' mathematics achievement is more effective in measurement topics than other mathematics contents.

Class Capacity

There has not been adequate evidence to state that a variety of class capacities significantly differentiated the mathematics achievement of Indonesian students in the PBL environment promoted by CAME. A meta-analytic review conducted by Susiyanti et al. (2022) also found that the factor of class capacity does not differentiate students' mathematical critical thinking skills who studied in the PBL environment. These reviews provide strong evidence that class capacity does not differentiate the mathematics achievement of Indonesian students in the PBL environment supported by CAME. Descriptively, to optimize the mathematics achievement of Indonesian students, the effect of CAME usage integrated into the PBL environment in large class was higher than the effect of it in small class. Consequently, it can be interpreted that the utilization of CAME in the PBL environment to optimize students' mathematics achievement is more effective in large class than in small class.

Computer Technology

A variety of computer technologies significantly differentiated the mathematics achievement of Indonesian students who studied in the PBL environment supported by CAME. Helsa et al. (2023), in a meta-analytic review, also found that a variety of computer technologies significantly differentiated students' computational thinking in mathematics learning. Inferentially, to optimize students' mathematics achievement, the effect of Google classroom usage in the PBL environment was significantly higher than the effect of the PBL environment using other computer technologies (e.g., GeoGebra, Moodle, E-worksheet, Digital Games, Visual-Audio, and Zoom Platform). As a consequence, it can be interpreted that the implementation of PBL integrated with Google Classroom is more effective in optimizing the mathematics achievement of Indonesian students than using other computer technologies.

Implications for Mathematics Education

The present meta-analytic review provides some implications of CAME usage integrated into the PBL environment in future empirical studies. The use of CAME integrated into the PBL environment has a positive, strong effect on the optimization of Indonesian students' mathematics achievement. Moreover, the utilization of CAME in the PBL environment is significantly effective in optimizing the mathematics achievement of Indonesian students in the period of 2019 - 2024. Consequently, CAME can be utilized in the PBL environment to optimize the mathematics achievement of Indonesian students. Additionally, the utilization of CAME integrated into the PBL environment is more effective in optimizing students' mathematics achievement in junior high school than at other educational levels. Consequently, optimizing students' mathematics achievement using CAME integrated into the PBL environment should be implemented in junior high school. Subsequently, the utilization of CAME in the PBL environment to optimize Indonesian students' mathematics achievement is more effective in measurement topics than other mathematics contents. This implies that CAME usage integrated into the PBL environment should be performed in the measurement topic. In addition, the implementation of PBL integrated into Google Classroom is more effective in optimizing the mathematics achievement of Indonesian students than using other computer technologies. As a consequence, the implementation of the PBL environment should utilize Google Classroom to optimize the mathematics achievement of Indonesian students.

Limitations and Suggestions

This meta-analytic review has several limitations that should be acknowledged when interpreting its findings. First, the possibility of publication bias cannot be ruled out, as studies with statistically significant results are more likely to be published and thus included in the analysis. This bias may have led to an overestimation of the true effect sizes, potentially limiting the accuracy of the conclusions. Second, the included studies were predominantly conducted within specific cultural or contextual settings, which may restrict the generalizability of the findings to other populations or educational systems. Cultural norms, educational policies, and societal expectations can significantly influence the effectiveness of the interventions reviewed. Third, there was considerable variability in how the interventions were implemented across studies, including differences in duration, intensity, delivery methods, and fidelity of implementation. Such heterogeneity may have contributed to variations in reported outcomes and reduced the comparability of results. To address these limitations, future research should actively seek to include unpublished studies or gray literature to minimize publication bias and provide a more balanced evidence base. Researchers are encouraged to replicate similar interventions in diverse cultural and contextual settings to assess their applicability and robustness across populations. Standardizing intervention protocols, or at least clearly documenting implementation procedures, would help improve the comparability of future studies. Additionally, meta-analyses could benefit from subgroup analyses or meta-regression techniques to account for and better understand the sources of heterogeneity. Future studies should also investigate the longitudinal effects of these interventions, as the current evidence base is limited in capturing sustained impacts over time. Exploring effects on different demographic groups, such as varying age ranges, socioeconomic backgrounds, or learning abilities, would further enrich the evidence base. Mixed-method approaches could also be incorporated to complement quantitative findings with qualitative insights into implementation challenges and participant experiences. By addressing these gaps, future research can provide a more comprehensive and nuanced understanding of the effectiveness of the interventions reviewed.

CONCLUSION

The use of CAME integrated into the PBL environment has a positive strong effect on the optimization of Indonesian students' mathematics achievement. Moreover, the utilization of CAME in the PBL environment is significantly effective in optimizing the mathematics achievement of Indonesian students in the period of 2019 - 2024. Additionally, some moderating factors (e.g., educational level, mathematics content, and computer technology) significantly differentiate Indonesian students' mathematics achievement in the PBL environment using CAME. Meanwhile, there has not been adequate evidence to state that class capacity significantly differentiates the mathematics achievement of Indonesian students who learn in the PBL environment utilizing CAME.

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