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Plugged versus Unplugged Activities within Problem-based Learning for Computational Thinking Skills: A Meta-Analytic Review

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Abstract

Integrating technology into 21st-century education brings considerable advantages, particularly through "plugged" activities within problem-based learning (PBL) frameworks in enhancing computational thinking (CT) skills. The impact of plugged activities, however, in PBL on CT skills development has shown inconsistency. Additionally, theplugged activities are compared to unplugged activities within PBL for optimizing CT skills. This study addresses this question by contrasting between the impact of plugged and unplugged activities integrated into PBL toward the student skills. A meta-analytic review was performed on 17 documents published in the period of 2011 - 2023, which produced 31 units of effect size in g and included data from 1,376 students. Using the Q Cochrane and Z tests, the data were analyzed to determine these effects. Findings of this review presented that, descriptively, plugged activities in PBL ($g = 0.818$; $p < 0.05$) had a stronger impact toward the enhancement of the skills than unplugged activities ($g = 0.649$; $p < 0.05$). Statistically, sufficient evidence indicated that plugged activities within PBL are more effective than unplugged activities for improving students' CT skills. Therefore, educators, including teachers and lecturers, may consider using plugged activities as part of a PBL framework in promoting the development of the student skills

Keywords: meta-analysis, plugged activity, problem-based learning, unplugged activity, computational thinking

1. Introduction

In the 21st-century, the rapid advancement of technology has transformed every aspect of life, making computational thinking (CT) as one of the most fundamental thinking processes for students. CT involves problem-solving methods, for example, decomposition, abstraction, pattern recognition, and algorithm (Grover & Pea, 2018; Wing, 2006), which are critical in navigating today's increasingly complex digital world. As societies continue to rely on technology, the ability to think computationally equips students with the skills necessary to adapt and innovate to sophisticated systems (Hunsaker, 2020). Educational institutions are progressively integrating CT skills into their curricula to better prepare them for the careers' demand (Sung et al., 2023). Developing the skills early fosters problem-solving, creativity, and logical thinking, essential not only in technology-related fields but across various domains (Helsa et al., 2023). The increasing interconnectivity of systems and data across industries highlights the urgent need for students to be proficient in CT to effectively address future challenges. Thus, promoting computational thinking in educational settings is crucial to cultivating a workforce capable of driving technological innovation.

Despite its importance, many students face challenges in acquiring CT skills in traditional educational environments. These difficulties often stem from limited exposure to computational concepts, such as algorithms, logic, and abstraction, in early education (Chen & Huang, 2017). Additionally, many students struggle to apply theoretical knowledge to practical problems, which hinders the development of their CT abilities. Conventional teaching methods, which tend to focus on rote learning, may not provide sufficient opportunities for them to engage in critical thinking and problem-solving that are essential for the skills (Suparman et al., 2022; Suparman & Juandi, 2022a). Furthermore, many educators are not adequately trained in teaching CT, which exacerbates the problem by preventing effective implementation in the classroom (Scherer et al., 2020). This gap between students' needs and the resources available to teach CT creates a significant barrier to their development. Without proper intervention, students may remain ill-prepared for the technological demands of the future workforce.

One potential solution to address students' low CT skills is the use of plugged activities, that involve programming exercises and digital tools (Ye et al., 2023). Plugged activities provide students with interactive platforms to practice CT concepts in real time, enabling them to explore algorithms, coding, and data analysis in a hands-on manner (Kuo & Hsu, 2020). These activities offer immediate feedback, allowing students to study their mistakes and refine their problem-solving approaches. Additionally, plugged activities often include engaging visualizations and simulations, which help students understand abstract concepts more concretely (Angraini et al., 2023). By using computers and software, students can test different problem-solving strategies and witness the outcomes of their decisions, which fosters students' understanding toward CT skills (Leonard et al., 2016). In addition, the flexibility of plugged activities allows for differentiated instruction, enabling teachers to adjust the complexity based on students' individual learning needs (Lee & Wong, 2021; Sharma et al., 2019). As a result, plugged activities offer a dynamic and engaging environment for students to improve their CT skills.

Meanwhile, unplugged activities propose an alternative approach by fostering the skills without the use of digital devices. These activities focus on teaching CT concepts through problem-solving activities, such as games, real-world simulations, and puzzles (Tsarava et al., 2017). Unplugged activities offer students a more accessible way to understand computational concepts, as they encourage critical thinking and logical reasoning without the distractions or technical challenges of using a computer (Li et al., 2022). These exercises often involve physical movement or group interaction, which can enhance engagement and make learning more enjoyable for students. Additionally, unplugged activities are highly adaptable, requiring minimal resources and can be used in various educational contexts, making them suitable for classrooms with limited access to technology (Wahyudin et al., 2021). The activities create students with an opportunity to enhance the essential skills in an approachable and tangible manner (del Olmo-Muñoz et al., 2020; Tonbuloğlu & Tonbuloğlu, 2019). By engaging unplugged activities, students can construct a strong foundation in the CT skills before transitioning to more complex digital tasks.

To optimize the enhancement of the skills, combining problem-based learning (PBL) with both plugged and unplugged activities presents a powerful solution. PBL immerses students in real-world problems requiring them to use CT concepts, encouraging collaboration, inquiry, and critical thinking (Juandi et al., 2022; Suparman et al., 2022). Integrating plugged activities within PBL allows students to use digital tools to model and test solutions to complex problems, enhancing their understanding through trial and error (Fuadi et al., 2021; Suyanto et al., 2023). Simultaneously, the activities can be conducted to explain core concepts and encourage teamwork, giving students a chance to develop their skills without relying on technology (Chen et al., 2023). This blended approach leverages the strengths of both methods, providing students with a comprehensive learning experience that fosters both practical and theoretical understanding of CT. Moreover, PBL promotes the enhancement of some soft skills, such as collaboration and communication, that are vital for the workforce success (Gao et al., 2019; Karatas & Baki, 2013). Combining problem-based learning with plugged and unplugged activities creates a rich educational environment that maximizes students' CT skills.

To date empirical studies investigating the integration of plugged and unplugged activities into PBL environment have relatively massively been conducted to optimize CT skills in educational settings. Several studies found that plugged activities integrated to PBL classroom have significant positive effect on the student skills (Azizah et al., 2024; Gao et al., 2019; Handayani et al., 2023; Kwon et al., 2021; Manullang & Simanjuntak, 2023), whereas few studies revealed that plugged activities in PBL environment do not significantly optimize the student skills (Bai et al., 2021; Banic & Gamboa, 2019). Similarly, several studies also found that unplugged activities collaborated to PBL environment has significant positive effect on students' CT skills (Asrianti & Rakhmawati, 2024; Chikkamath et al., 2024; Dewi et al., 2024; Nurasiah et al., 2023; Pratiwi & Akbar, 2022; Urankar et al., 2024), but other studies showed that unplugged activities in PBL classroom do not significantly optimize students' CT skills (Moreno-Palma et al., 2024; Santi et al., 2024; Swaminathan et al., 2024; Torgal et al., 2024). From the reports of these studies, it can be stated that both plugged and unplugged activities integrated into PBL classroom have an inconsistent impact toward the optimization of the student skills. Moreover, whether plugged activities are more effective than unplugged activities collaborated with PBL environment in optimizing students' CT skills. These gaps require a comprehensive systematic review, which provides the clear conclusions related to the estimation and comparison of the effect of plugged and unplugged activities integrated into PBL classroom on students' CT skills.

1.1.Computational Thinking

CT is often described as one of the most fundamental thinking processes for problem-solving activities. Wing (2006), who brought widespread attention to the concept, defined the skills as a thought process that involves formulating problems and solutions in ways that a computer could execute. She emphasized that it is not just programming but a way of thinking that can be applied across multiple domains, equipping individuals with the tools to approach complex problems methodically. Brennan and Resnick (2012) further describe CT as an approach to problem-solving that involves abstraction, decomposition, and generalization, which are integral for understanding and designing systems. Grover and Pea (2018) also highlight that CT involves cognitive processes such as pattern recognition and algorithmic thinking, which enhance critical and analytical skills. Additionally, Kafai and Proctor (2021) expand CT meaning, which early as cognitive CT to be situated CT and critical CT. Various scholars agree that CT is interdisciplinary, crossing boundaries beyond computer science, making it relevant in a variety of fields, including education, business, and engineering. Thus, CT is framed as a universal cognitive skill that empowers individuals to handle complexity in a structured and effective way.

Several experts have identified specific components that serve as indicators for measuring CT skills. According to Brennan and Resnick (2012), CT can be broken down into three main dimensions: computational concepts, computational practices, and computational perspectives. These include core skills such as decomposition (breaking a problem into smaller parts), pattern recognition (identifying similarities), and algorithmic thinking (creating a sequence of steps). Wing (2006) also emphasizes abstraction and evaluation as key components, which allow individuals to filter out unnecessary details and refine their problem-solving approaches. Additionally, Grover and Pea (2018) propose that debugging (the iterative process of identifying and fixing errors) and generalization (applying solutions to different contexts) are critical skills in CT. Asbell-Clarke et al. (2021) also have used these components to develop assessment frameworks that help evaluate students' computational thinking abilities. These indicators collectively help educators and researchers to better understand and cultivate computational thinking in learners across diverse educational contexts.

1.2.Plugged and Unplugged Activities

Plugged activities refer to educational tasks or exercises that require the use of digital devices or technology, typically involving computers, tablets, or programmable robots (Rose et al., 2020; Sáez López et al., 2021; Talan, 2021). In the context of the skills, these activities often focus on coding, simulations, and interactive problem-solving, helping learners apply CT concepts in a digital environment (Moreno-León et al., 2021; Yang et al., 2022). For example, platforms like Scratch, Code.org, and robotics kits like LEGO Mindstorms are widely used in classrooms to teach students how to code, solve puzzles, and develop logical reasoning. These digital tools provide an engaging and hands-on approach to learning, enabling students to directly implement and visualize their solutions (Relkin et al., 2021). One of the key advantages of plugged activities is that they allow for immediate feedback; students can see the results of their algorithms in real-time, which supports iterative problem-solving and debugging (Zhang et al., 2023). Moreover, plugged activities can accommodate complex problems that require sophisticated computation, giving students exposure to advanced CT concepts like automation and parallel processing (Noh & Lee, 2020). This integration of technology also fosters a familiarity with digital tools, preparing students for real-world applications of CT in technology-driven careers.

Unplugged activities, by contrast, involve teaching the concepts without the use of digital devices (Chen et al., 2023). These activities rely on physical or mental exercises that convey key CT concepts through kinesthetic learning, role-playing, or the use of tangible objects. For example, games like "Sorting Networks" where students physically arrange themselves based on certain rules, or "Algorithm Relay Races," where students act out steps of an algorithm, help them understand decomposition, sequencing, and algorithmic thinking (Li et al., 2022). The primary advantage of the activities is their accessibility, as they do not require technological resources, making them feasible in classrooms with limited digital infrastructure. Furthermore, unplugged methods emphasize the cognitive aspects of CT, permitting students to focus on the logic and structure of problems without being distracted by the technical intricacies of software or hardware. These activities also foster collaboration and communication, as many unplugged exercises are group-based and encourage discussion about problem-solving strategies (Tonbuloğlu & Tonbuloğlu, 2019; Tsarava et al., 2017). By detaching CT from technology, unplugged activities demonstrate that the skills is fundamentally a way of thinking rather than a skill limited to computer use.

1.3.Problem-Based Learning

PBL is an instructional approach, which places students in the active role of problem-solvers, using complex, real-world problems (Suparman et al., 2021). Barrows and Tamblyn (1981), who pioneered PBL in medical education, define it as a learner-centered method in which they perform in solving problems, thereby acquiring new knowledge through active engagement. The problems presented are often open-ended, requiring students to not only find solutions but also explore multiple perspectives and disciplines. Hmelo-Silver (2004) highlights that PBL fosters self-directed learning, collaboration, and critical thinking, making it an alternative way to enhance the skills. Characteristics of PBL include student autonomy, collaborative learning, and inquiry-based exploration, where they identify what they know, what they need to learn, and how to apply knowledge in practical contexts. Instructors in PBL serve as facilitators rather than knowledge dispensers, guiding students as they navigate the problem-solving process(Suparman et al., 2022; Suparman & Juandi, 2022a). This approach promotes deeper learning as students must synthesize information and apply it to authentic situations, aligning well with the development of CT.

The PBL process typically follows a structured sequence of phases that help learners tackle complex problems in an educational setting. The first phase involves presenting a real-world problem requiring the investigation (Du et al., 2013). In the second phase, students brainstorm ideas, identify what they already know, and what they need to learn, often by conducting independent research (Yew & Goh, 2016). During the third phase, students work collaboratively to develop solutions, using critical thinking and reasoning to address the problem's core challenges. The final phase involves presenting their solutions, reflecting toward the learning process, and receiving feedback (Nargundkar et al., 2014). These phases align closely with CT skills, particularly in decomposition (breaking down problems), algorithmic thinking (planning a solution), and iterative testing (debugging and refining). The strengths of PBL for developing CT include fostering creativity, critical thinking, and collaboration—core aspects of the skills (Banic & Gamboa, 2019; Gao et al., 2019; Kwon et al., 2021). Grover and Pea (2013) suggest that PBL encourages the application of CT concepts to real-world problems, making the learning process relevant and practical. By integrating PBL into CT education, students not only learn technical skills but also develop higher-order thinking abilities essential for problem-solving in various fields.

1.4.Relevant Meta-Analytic Reviews

To date meta-analytic reviews which study the impact of plugged or unplugged activities toward the skills have widely been carried out in the educational settings, particularly in computer science. Several meta-analytic reviews found that plugged activities, such as educational robots and programming education have significant positive effect on the student skills (Alonso-García et al., 2024; Fidai et al., 2020; Helsa et al., 2023; Hong, 2024; Lai & Wong, 2022; Lee & Wong, 2021; Scherer et al., 2020; Sun et al., 2021; Sun & Zhou, 2023; Wang & Xie, 2024; Xu et al., 2023). Similarly, other meta-analytic reviews revealed that unplugged activities also have significant positive impact in optimizing students' CT skills (Chen et al., 2023; Chen et al., 2023; Cheng et al., 2023; Hu, 2024; Lei et al., 2020; Li et al., 2022; Li & Oon, 2024; Lu et al., 2023; Ma et al., 2023; Merino-Armero et al., 2021; Montuori et al., 2024; Sun et al., 2024; Sun et al., 2023; Ye et al., 2022; Zhang et al., 2024; Zhang et al., 2024). This recent meta-analytic review, however, investigates the effect of plugged and unplugged activities integrated into PBL classroom in optimizing the student skills.

1.5.Present Study

The present meta-analytic review estimates, examines, and compares the effect of plugged and unplugged activities integrated into PBL classroom to optimize the student skills. The review is expected to provide clear conclusion regarding the estimated effect size of both plugged activities and unplugged activities in the PBL environment on the student skills. Moreover, precise information related to what is plugged activities better than unplugged activities in PBL classroom to optimize students' CT skills, can be decided to suggest educational policies for the educators, such as teachers or lecturers to select the best activities in optimizing students' CT skills. The following research questions are directed to operate the aim of this meta-analytic review, such as:

1. What is the effect size of plugged activities integrated into PBL classroom on students' CT skills?
2. Do plugged activities collaborated in PBL classroom have significant positive effect toward the student skills?
3. What is the effect size of unplugged activities integrated into PBL classroom toward the student skills?
4. Do unplugged activities collaborated in PBL classroom have significant positive effect toward the student skills?
5. Is there any significant difference of CT skills in PBL classroom between students who follow plugged activities and students who follow unplugged activities?

2. Methods

2.1. Research Design and Inclusion Criteria

The study used a systematic review, using a meta-analytic review to estimate, examine, and compare the effects of plugged and unplugged activities integrated into a PBL environment on students' CT skills. The meta-analysis involved quantitative techniques, focusing on the effect size as a unit of measurement (Ariani et al., 2024; Suparman et al., 2024b, 2024a). To narrow the scope, specific inclusion criteria were set. The first criterion was that the document title had to contain the keywords: "problem-based learning" AND "computational thinking" AND "plugged activities" OR "unplugged activities." The second was that the document needed to be an English-language article sourced from a journal. Third, the publication date must fall between 2011 and 2023. Fourth, the population studied in the document had to be students from Asia (e.g., Indonesia, Malaysia, Taiwan, South Korea), America (e.g., Mexico, United States of America), Europe (e.g., Spain, United Kingdom, Estonia, Netherlands, Russia), or Africa (e.g., Nigeria) at the elementary, middle school, or college/university. Fifth, the study must investigate plugged and unplugged activities within a PBL context. Sixth, the comparison group in the study should involve traditional teaching methods. Seventh, the document must report CT skills as an outcome. Eighth, the research design had to be quasi-experimental. Lastly, the document must provide enough statistical data to compute the effect size.

2.2. Literature Search and Document Selection

The literature search was conducted using Google Scholar and Scopus, focusing on documents that explored CT skills and the integration of plugged and unplugged activities into the PBL environment. The search employed combinations of keywords such as “problem-based learning,” “computational thinking,” “plugged activities,” and “unplugged activities” to refine results. An initial search on January 1st – June 30th, 2024, identified 158 relevant documents published between 2001 and 2024. A systematic selection process was then applied, which involved four steps: (1) identification, (2) screening, (3) eligibility, and (4) inclusion (Juandi & Suparman, 2024; Putra et al., 2024; Suparman & Juandi, 2022a). The details of this process are summarized in Figure 1.

2.3. Data Coding

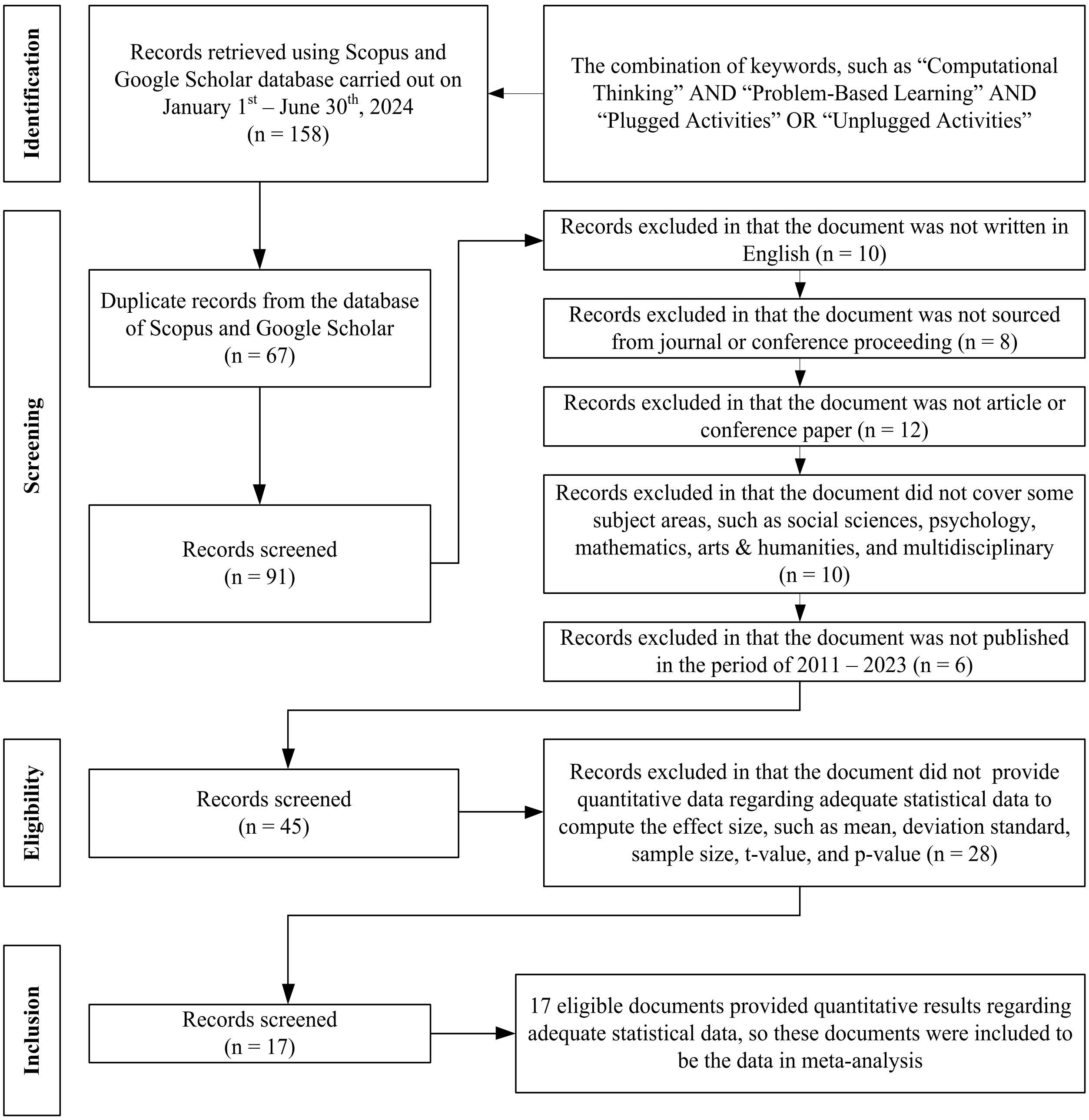
From the selected documents, seventeen documents were deemed suitable for inclusion in this meta-analytic review. Data from these documents were extracted into a coding sheet, which included information such as the authors, quantitative findings, and publication details like the journal name, email, and DOI or URL link. In total, the 17 documents produced 31 effect size units and involved 1,376 students across various educational levels and countries. Two experts in meta-analytic reviews ensured the data's credibility and validity. They re-coded and verified the data, and consistency among coders was assessed using Cohen's Kappa test. This test was used to evaluate agreement levels between the two coders for both the meta-analysis and qualitative meta-synthesis parts (McHugh, 2012).

Table 1.
Cohen’s Kappa Test Results

Coding Item	Kappa Value	Agreement Level	Significance Value
Mean of Experiment Group	0.931	Almost Perfect	0.009
Std. Dev. of Experiment Group	0.917	Almost Perfect	0.009
Sample Size of Experiment Group	0.921	Almost Perfect	0.009
Mean of Control Group	0.911	Almost Perfect	0.009
Std. Dev. of Control Group	0.926	Almost Perfect	0.009
Sample Size of Control Group	0.935	Almost Perfect	0.009
T-value	0.814	Strong	0.007

As shown in Table 1, the agreement level for each coding item ranged from strong to almost perfect, with a significant value below 0.05, indicating a high level of consistency among the coders (Susiyanti et al., 2022; Yunita et al., 2022). This confirms that the data included in this meta-analytic review were both credible and valid, making them suitable for further analysis.

Figure 1
The Process of Document Selection using PRISMA Approach



2.4. Data Analysis

For the meta-analytic review, the random effects model was chosen as the preferred approach to estimate effect sizes, examine publication bias, conduct sensitivity analysis, and apply both the Z test and the Q Cochrane test. This model was selected because it accommodates empirical studies with varying characteristics, including country, educational level, instruments, intervention duration, learning environment, math content, and class size (Suparman & Juandi, 2022a, 2022b). Hedges' equation was employed to calculate effect sizes, especially for studies with smaller sample sizes (Borenstein, 2019). The equation is as follows:

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

The Z test was used to assess the significance of integrating plugged and unplugged activities into PBL environments for optimizing CT skills among students. Additionally, the Q Cochrane test was applied to analyze the comparison between plugged activities and unplugged activities integrated into a PBL environment on students' CT skills. To analyze the data, Comprehensive Meta-Analysis (CMA) software v.4 was used.

3. Result and Discussion

3.1. Publication Bias and Sensitivity Analysis

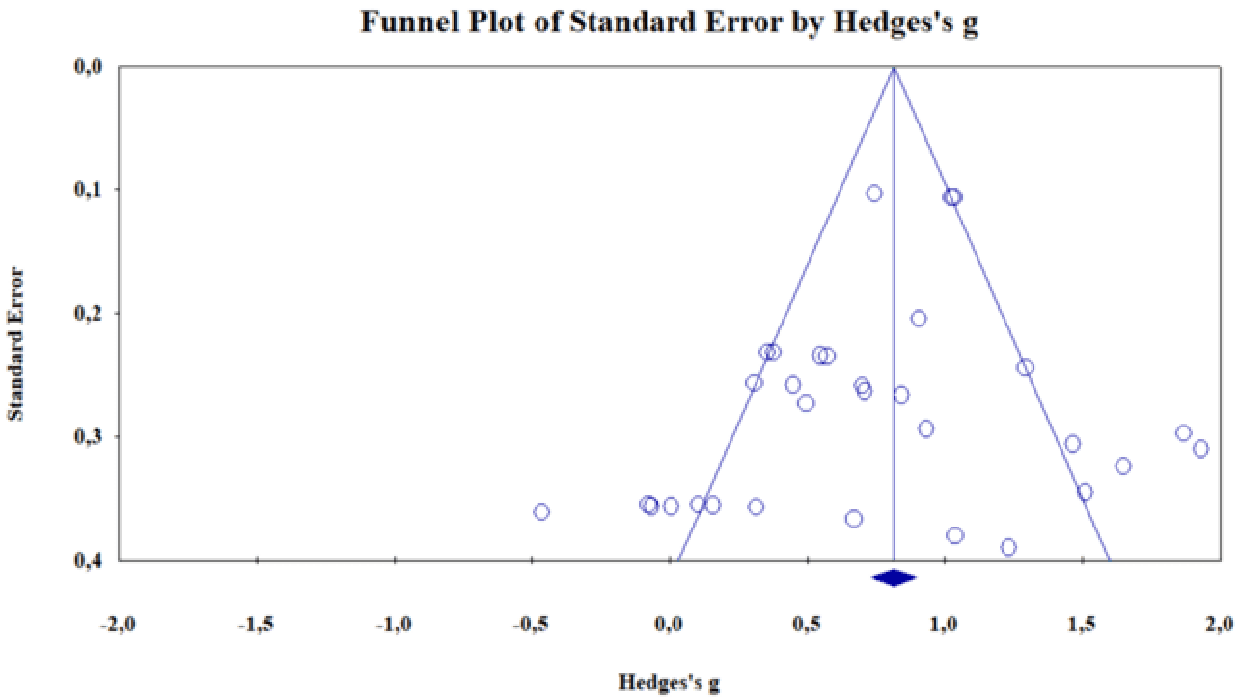
To assess the possibility of publication bias, a funnel plot was used to display the display the distribution of effect size data (see Figure 2). Figure 2 shows a symmetrical distribution of effect size data in the funnel plot. To confirm this symmetry, a trim-and-fill test was conducted (see Table 2).

Table 2.
The Results of Trim-and-Fill Test

	Studies Trimmed	Effect Size in g	Lower Limit	Upper Limit	Q-value
Observed Values		0.747	0.580	0.914	112.238
Adjusted Values	0	0.747	0.580	0.914	112.238

Table 2 indicates that no effect size data required exclusion from either side of the distribution, affirming a symmetrical pattern in the funnel plot. This lack of asymmetry suggests there is no evidence of publication bias in the collected effect size data (Tawaldi et al., 2023).

Figure 2
The Distribution of Effect Size Data



To further examine the stability of the effect size data, sensitivity analysis was performed by identifying any potential outliers within the range between the highest and lowest effect sizes. Results indicated that the lowest effect size (g) was 0.713, while the highest was 0.781, with an estimated mean effect size of 0.747 across 31 data points. As the estimated value falls within the interval of 0.713 to 0.781, no data points were classified as outliers. This suggests there are no sensitivity issues in the data when adjusting the quantity of effect size data (Juandi et al., 2023).

3.2. Estimated Effect Size and Heterogeneity Analysis

This meta-analytic review included 17 relevant studies, yielding 31 effect size units in *g* and involving a total of 1,376 students. The effect sizes varied in terms of direction, significance, and magnitude (see Table 3).

Table 3.
The Results of Effect Size Calculation

Authors	Effect Size (g) [95% CI]	P-value
Kwon et al. (2021a)	1.025 [0.817, 1.233]	0.000
Kwon et al. (2021b)	0.745 [0.543, 0.947]	0.000
Kwon et al. (2021c)	1.034 [0.826, 1.242]	0.000
Gao et al. (2019)	1.293 [0.815, 1.771]	0.000
Banic & Gamboa (2019a)	1.233 [0.469, 1.997]	0.002
Banic & Gamboa (2019b)	1.038 [0.292, 1.784]	0.006
Banic & Gamboa (2019c)	0.672 [-0.046, 1.390]	0.067
Banic & Gamboa (2019d)	-0.463 [-1.171, 0.244]	0.200
Banic & Gamboa (2019e)	0.007 [-0.691, 0.704]	0.985
Banic & Gamboa (2019f)	-0.065 [-0.763, 0.633]	0.855
Bai et al. (2021a)	0.844 [0.322, 1.366]	0.002
Bai et al. (2021b)	1.934 [1.326, 2.541]	0.000
Bai et al. (2021c)	0.309 [-0.194, 0.811]	0.228
Bai et al. (2021d)	0.451 [-0.055, 0.957]	0.081
Bai et al. (2021e)	0.711 [0.195, 1.226]	0.007
Manullang & Simanjuntak (2023)	1.651 [1.016, 2.285]	0.000
Handayani et al. (2023)	0.933 [0.358, 1.509]	0.001
Azizah et al. (2024)	0.905 [0.504, 1.306]	0.000
Plugged Activities	0.818 [0.617, 1.019]	0.000
Moreno-Palma et al. (2024a)	0.316 [-0.383, 1.015]	0.376
Moreno-Palma et al. (2024b)	0.105 [-0.590, 0.800]	0.768
Moreno-Palma et al. (2024c)	0.158 [-0.537, 0.854]	0.655
Moreno-Palma et al. (2024d)	-0.077 [-0.772, 0.618]	0.829
Torgal et al. (2024)	0.378 [-0.077, 0.833]	0.104
Swaminathan et al. (2024)	0.357 [-0.098, 0.811]	0.124
Chikkamath et al. (2024)	0.574 [0.113, 1.034]	0.015
Urankar et al. (2024)	0.548 [0.089, 1.008]	0.019
Dewi et al. (2024)	1.511 [0.836, 2.187]	0.000
Asrianti & Rakhmawati (2024)	1.465 [0.865, 2.065]	0.000
Pratiwi & Akbar (2022)	1.869 [1.286, 2.451]	0.000
Santi et al. (2024)	0.497 [-0.037, 1.031]	0.068
Nurasiah et al. (2023)	0.701 [0.194, 1.208]	0.007
Unplugged Activities	0.649 [0.355; 0.944]	0.000

Table 3 shows an estimated effect size of 0.818 in *g* for plugged activities, interpreting that plugged activities integrated into a PBL environment has a moderate positive impact on students' CT skills. With a Z-test, p-value below 0.05, the integration of plugged activities into a PBL framework significantly optimizes CT skills among these students. Similarly, the estimated effect size of 0.649 in *g*, suggesting that unplugged activities integrated into a PBL environment has also a moderate positive impact on students' CT skills. Moreover, with a Z-test, p-value below 0.05, the integration of unplugged activities into a PBL framework significantly optimizes students' CT skills. This indicates that both plugged activities and unplugged activities integrated into a PBL setting is effective in optimizing CT skills among students.

To examine the difference of the estimated effect size between plugged activities and unplugged activities integrated into a PBL environment on CT skills among students, a Q Cochrane test was conducted (see Table 4).

Table 4.
The Results of Q Cochrane Test

Group	Effect Size (g) [95% CI]	Z Test		Q Cochrane Test		
		Z-value	P-value	Q-value	df	P-value
Plugged Activities	0.818 [0.617, 1.019]	7.965	0.000	2.853	1	0.036
Unplugged Activities	0.649 [0.355, 0.944]	4.318	0.000			

Table 4 shows that descriptively to optimize students' CT skills, the estimated effect size of plugged activities integrated into a PBL environment is higher than the estimated effect size of unplugged activities integrated into a PBL environment. With a Q Cochrane test, p-value below 0.05, there is a significant difference of the estimated effect size between plugged activities and unplugged activities integrated into a PBL framework on CT skills among students. This indicates that within a PBL environment, plugged activity is more effective to optimize students' CT skills than unplugged activity.

3.3. The Effect of Plugged and Unplugged Activities within a PBL Framework for CT Skills among Students

The integration of plugged activities within a PBL environment has a significant positive impact on students' CT skills, as evidenced by an estimated effect size of 0.818 (*g*) from the meta-analysis. The Z-test, yielding a p-value below 0.05, confirms that this effect is statistically significant, indicating that plugged activities in a PBL framework can meaningfully optimize CT skills. Plugged activities, which utilize technology-based tools such as programming software and simulations, offer an interactive platform that engages students in solving complex, real-world problems. Studies of meta-analytic review by Alonso-García et al. (2024), Hong (2024), and Wang & Xie (2024) demonstrate similar results, where plugged activities led to notable improvements in CT skills through immediate feedback and dynamic learning environments. The digital interactivity in plugged activities encourages students to practice logical reasoning, debugging, and iterative problem-solving, which are foundational to CT skills (Helsa et al., 2023). Comparatively, prior research has also highlighted that technology-based learning in PBL settings offers students immediate performance assessment, allowing them to refine their CT skills more effectively than traditional methods (Lai & Wong, 2022; L. Sun & Zhou, 2023; Xu et al., 2023). Overall, plugged activities integrated within PBL settings stand out as a method to effectively optimize students' CT skills through a blend of active, technology-mediated learning and problem-solving practices.

Unplugged activities within a PBL environment also exhibit a positive impact on CT skills, though with a slightly lower effect size of 0.649 (*g*) compared to plugged activities. The Z-test, with a p-value below 0.05, indicates a statistically significant improvement in CT skills from unplugged activities, confirming their efficacy in promoting computational thinking. These offline activities, which include role-playing, puzzles, and collaborative games, offer a tactile and group-based approach to problem-solving without relying on technology. Previous studies of meta-analytic review, such as those by Hu (2024), Z. Li & Oon (2024), and C. Sun et al. (2024), support these findings, showing that unplugged activities help students internalize computational concepts by engaging them in logical reasoning and sequence-based tasks. Unplugged activities particularly excel at developing fundamental CT skills by enabling students to practice decomposing problems and creating algorithms, skills that are critical to understanding computational logic (Merino-Armero et al., 2021). The lack of digital assistance in unplugged tasks encourages students to rely on cognitive strategies to solve problems, thereby strengthening their independent problem-solving skills (Lu et al., 2023). Compared to plugged activities, unplugged methods are often more accessible and can be implemented without technological resources, making them a valuable alternative for teaching CT skills (Y. P. Cheng et al., 2023; J. Ye et al., 2022). Hence, unplugged activities in PBL settings serve as an effective, inclusive approach to building foundational CT skills through collaborative, hands-on learning experiences.

When comparing the impact of plugged versus unplugged activities within a PBL environment, plugged activities show a higher estimated effect size ($g = 0.818$) than unplugged activities ($g = 0.649$), as revealed by the Q Cochrane test. This difference, statistically significant with a p-value below 0.05, suggests that plugged activities are more effective in optimizing CT skills among students. Studies by Fidai et al. (2020) and Scherer et al. (2020) highlight that technology-enabled tasks within plugged activities promote quicker skill acquisition due to real-time feedback and automated assessment, which may explain the observed higher effect size. Conversely, unplugged activities, while also beneficial, are typically less immediate in feedback, potentially making the learning curve slightly longer in CT skill development (Lei et al., 2020; L. Sun et al., 2023). However, both methods contribute positively to CT skills, with plugged activities often leading to quicker computational proficiency and unplugged activities strengthening students' foundational CT concepts and logical reasoning (Lee & Wong, 2021; Y. Zhang et al., 2024). This meta-analytic review supports the complementary nature of both approaches, as combining plugged and unplugged activities within a PBL environment can address diverse learning needs. Moreover, this meta-analytic finding thus indicates that while plugged activities may yield a slightly greater impact on CT skills, unplugged activities remain an effective and accessible tool in PBL settings.

Plugged activities offer several distinct advantages in optimizing students' CT skills within a PBL framework, particularly through the dynamic engagement that technology affords. The interactive nature of digital tools in plugged activities enables students to experiment, iterate, and immediately see the results of their problem-solving attempts, promoting iterative thinking (Hong, 2024). Drawing from Vygotsky's scaffolding theory, digital tools act as supportive aids that guide students through complex problem-solving processes, providing just-in-time assistance and reinforcement. Additionally, plugged activities allow for individualized learning, as students can proceed at their own pace and revisit tasks as needed, fostering a deeper understanding of CT concepts (Wang & Xie, 2024). This approach aligns with constructivist theories, suggesting that students learn effectively through active engagement and digital simulations that support trial and error. The immediate feedback loop available in technology-based tasks enhances motivation and encourages students to refine their CT skills continuously. Moreover, plugged activities bridge the gap between theoretical CT skills and practical application, making computational learning relevant and compelling for students (Lai & Wong, 2022). Thus, the strengths of plugged activities in PBL environments lie in their ability to offer scaffolded, individualized, and feedback-rich learning experiences that effectively build CT skills.

Unplugged activities within a PBL framework support CT skill development by emphasizing fundamental computational principles through hands-on and collaborative experiences. This approach aligns well with Piaget's constructivist theory, where students develop understanding by engaging in physical activities that encourage active exploration of CT concepts (Hu, 2024). By focusing on offline problem-solving, unplugged activities foster deep cognitive engagement, allowing students to build a strong mental model of computational processes (Z. Li & Oon, 2024). Unlike plugged activities, unplugged methods encourage teamwork and interpersonal communication, as students often work in groups to solve puzzles or engage in algorithmic role-play (Ma et al., 2023). The accessibility of unplugged activities makes them inclusive, removing the barriers that might exist for students without access to technology, thus supporting equity in computational learning. This hands-on approach allows students to break down complex CT concepts into manageable parts, which is critical in developing foundational computational skills (C. Sun et al., 2024). Therefore, unplugged activities within PBL offer valuable strengths by providing an accessible, teamwork-based, and conceptually focused approach to learning CT skills.

3.4. Implications in Mathematics Education

The findings of this meta-analytic review have substantial implications for educational settings, especially in mathematics education where CT skills are increasingly essential. Plugged activities in a PBL framework can be utilized in mathematics to help students explore abstract mathematical concepts through interactive simulations, making these concepts more tangible and engaging. These activities align with differentiated instruction principles, addressing diverse learning styles and providing opportunities for students to practice mathematical reasoning in a hands-on, technology-supported environment. Unplugged activities, by comparison, allow for a grounded understanding of mathematical logic and sequence, helping students to build a foundation in CT that is directly applicable to mathematics. Teachers can integrate both activity types into math curricula to foster a comprehensive approach that includes both procedural and conceptual learning. Particularly, teacher may integrate unplugged activities such as algorithm role-play in early grade classrooms with limited access to technology, while plugged activities can be utilized in STEM clubs using Scratch or robotics for deeper engagement with CT. Studies suggest that using both plugged and unplugged activities can bridge the gap between theoretical math and real-life applications, enhancing student motivation and engagement. Implementing both approaches in mathematics can support students' understanding of complex topics such as algorithms, data structures, and geometric patterns. Furthermore, both methods encourage collaborative problem-solving and critical thinking, skills that are essential in advanced mathematics. The combined use of plugged and unplugged activities allows educators to cater to various learning preferences, creating a more inclusive classroom environment. Thus, the integration of these CT-oriented activities within a PBL framework offers a robust strategy for enhancing mathematical understanding and engagement among students.

3.5. Limitations and Suggestions

Despite its contributions, this meta-analytic review has several limitations that should be considered for future research. One major limitation is the variability in the implementation of PBL and the specific plugged and unplugged activities used across studies, which may affect the consistency of outcomes. Additionally, the analysis includes a relatively small sample size across 17 empirical studies, which may impact the generalizability of the results. Future meta-analytic reviews could expand the scope by including a broader range of studies, particularly from diverse educational and cultural contexts, to better understand the global applicability of these findings. The absence of long-term data on the lasting effects of plugged and unplugged activities in CT skill development is another limitation, longitudinal studies could provide more insight into the durability of these learning gains. Moreover, future research could explore the interaction between CT skills and other domains such as critical thinking and creativity, to better understand the broader cognitive benefits of these approaches. Researchers should also consider examining the role of teacher training in implementing PBL effectively, as educator readiness can significantly influence the outcomes of plugged and unplugged CT activities. There is also a need for studies focusing on the age-related efficacy of these methods, as younger students may respond differently than older students to plugged and unplugged activities. Furthermore, a more nuanced analysis of individual CT components, such as algorithmic thinking or debugging skills, could help educators tailor instructional strategies more effectively.

4. Conclusion

This meta-analytic review of 17 empirical studies, encompassing 31 effect size units and 1,376 students, reveals significant insights into the effect of plugged and unplugged activities on CT skills within a PBL framework. The findings demonstrate that both types of activities have a positive impact on CT skill development, with plugged activities showing a higher estimated effect size (g = 0.818) than unplugged activities (g = 0.649). This suggests that technology-based, or plugged, activities are slightly more effective at optimizing CT skills when integrated within a PBL environment. Plugged activities, characterized by interactive digital tools and immediate feedback mechanisms, appear to provide students with dynamic learning experiences that facilitate skill acquisition in CT more quickly and effectively than unplugged methods. In contrast, unplugged activities, which rely on hands-on and collaborative problem-solving without the use of technology, still make a valuable contribution to CT development by emphasizing foundational cognitive skills and logical reasoning.

The significance of these findings is reinforced by statistical analyses, including Z-tests showing p-values below 0.05 for both activity types, confirming the positive effect of each approach. Furthermore, the Q Cochrane test identifies a statistically significant difference between the effect sizes of plugged and unplugged activities, with a p-value below 0.05. This result underscores that within a PBL setting, plugged activities hold a distinct advantage over unplugged activities in optimizing CT skills, likely due to the adaptive and responsive nature of technology-driven tasks. Despite the observed difference, the moderate positive effects of both methods suggest that a balanced combination of plugged and unplugged activities might provide comprehensive support for CT skill development, catering to various aspects of computational understanding.

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