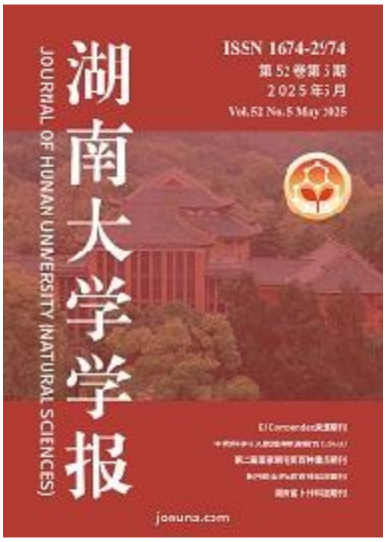

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Plugged Versus Unplugged Activities in Mathematics Learning to Promote Computational Thinking Skills: A Systematic Review and Qualitative Meta-Synthesis

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Abstract: Although many empirical studies have explored how plugged (technology-based) and unplugged (non-digital) activities foster students' computational-thinking (CT) skills in mathematics classrooms, their qualitative findings have never been brought together in a systematic synthesis. To address this gap, we conducted a systematic review coupled with a qualitative meta-synthesis. A comprehensive search of the Scopus database retrieved 14 peer-reviewed articles and conference papers published between 2004 and 2023 that reported qualitative evidence on the topic. Guided by grounded-theory procedures—open, axial and selective coding—implemented in NVivo 14, we analysed the data. The synthesis shows that mathematics lessons enriched with plugged activities—particularly educational robotics, augmented-reality applications and virtual mathematics laboratories—enabled learners to demonstrate the full spectrum of CT components: decomposition, pattern recognition, abstraction, algorithm design and evaluation. By contrast, lessons relying solely on unplugged activities fostered only limited aspects of CT. These results indicate that technology-enhanced (plugged) learning experiences are more effective than unplugged tasks for cultivating computational thinking in mathematics. We therefore recommend that mathematics educators systematically integrate suitable educational technologies to strengthen students' CT skills and suggest that future research examine how specific design features of plugged activities contribute to different CT components.

Keywords: Computational thinking; Mathematics learning; Plugged activities; Qualitative meta-synthesis; Systematic review; Unplugged activities.

数学学习中插电与非插电活动对促进计算思维能力的作用：系统综述与定性元综合

摘要：迄今为止，许多实证研究已经探讨了插电与非插电活动在提升学生数学教育中的计算思维（CT）能力方面的作用。然而，尽管这些研究的个别发现提供了有价值的见解，但仍缺乏对这些定性实证研究结果进行综合的系统性综述。因此，本研究采用系统综述结合定性元综合的方法，探讨并分析将插电与非插电活动整合到数学学习中以促进学生计算思维能力的作用。通过使用 Scopus 数据库进行全面检索，共筛选出 2004 至 2023 年间发布的 14 篇符合条件的文献（如期刊文章和会议论文），涉及定性研究结果。为进行定性元综合分析，研究采用了来自扎根理论的编码范式，包括开放编码、主轴编码和选择性编码，并借助 Nvivo 14.0 软件进行支持。研究结果表明，在融合了机器人技术、增强现实和数学实验室的插电数学学习中，学生能够掌握计算思维各组成部分的大部分技能，包括分解、模式识别、抽象、算法和评估。相比之下，参与非插电数学学习的学生仅能掌握计算思维部分技能的一小部分。这表明，与非插电活动相比，将插电活动整合进数学学习在促进学生计算思维能力方面具有更有效的作用。因此，数学教师或讲师可在教学中应用包含教育技术的插电活动，以提升学生的计算思维能力。

关键词：计算思维；数学学习；插电活动；定性元综合；系统综述；非插电活动

1. Introduction

Computational thinking (CT) has emerged as one of the fundamental skills students need to develop to effectively solve mathematical problems in today's educational landscape. This skill encompasses a set of cognitive processes such as pattern recognition, algorithmic thinking, decomposition, and abstraction, which empowers students to break down complex problems and devise logical solutions [1], [2]. Educational institutions worldwide recognize the transformative potential of computational thinking, particularly in mathematics, where problem solving forms the backbone of the discipline. By fostering computational thinking, students can develop a more structured and analytical approach to mathematics, equipping them with the skills necessary to thrive in a rapidly evolving technological world [3]. Thus, integrating computational thinking into mathematics education is critical for ensuring students' preparedness for both academic and real-world challenges.

Despite their importance, many students exhibit low levels of computational thinking skills in mathematics, which hinders their ability to solve problems effectively [4]–[8]. This issue is prevalent across various educational settings, with studies highlighting the persistent challenges of fostering these skills. Researchers attribute this problem to several factors, including traditional teaching methods that prioritize rote memorization over critical thinking, lack of teacher preparedness in incorporating computational thinking into lessons, and limited access to innovative teaching tools [9], [10]. Other contributing factors include curriculum designs that do not adequately emphasize problem-solving skills and students' varying levels of motivation and prior knowledge [11], [12]. For instance, scholars such as Wing [1] and Brennan and Resnick [13] have underscored the disconnection between existing pedagogical strategies and the demands of computational thinking in mathematics. Addressing these barriers is essential for improving students' ability to approach mathematical problems with computational efficiency and confidence.

Plugged activities, which involve the use of educational technologies, offer a promising solution for enhancing students' computational thinking skills in mathematics learning. Tools such as coding platforms, interactive simulations, and digital games create immersive learning experiences that foster engagement and skill development [14]–[16]. For instance, educational technologies such as Scratch, GeoGebra, and Python have been shown to help students apply computational thinking concepts in problem-solving scenarios [17]–[19]. These technologies not only provide interactive environments for exploring mathematical concepts but also enable students to visualize problems and experiment with solutions [20], [21]. Researchers have demonstrated that plugged activities can enhance students' skills in recognizing patterns, developing algorithms, and understanding abstract mathematical principles [22], [23]. Educators can bridge the gap between traditional instruction and modern computational thinking approaches by leveraging the potential of plugged activities.

By contrast, unplugged activities—those that do not rely on educational technology—also play a crucial role in cultivating computational thinking skills in mathematics. These activities involve hands-on, collaborative problem-solving tasks, such as puzzles, logic games, and paper-based exercises that encourage students to think critically and systematically [24]. Unplugged activities are particularly beneficial for fostering teamwork and communication skills, as students often work together to tackle complex problems [25]. Research has shown that such activities help students internalize computational thinking principles in a tangible and accessible manner [26]–[28]. For example, tasks involving physical manipulatives or structured group discussions can effectively illustrate concepts, such as decomposition and abstraction. By integrating unplugged activities into mathematics lessons, educators can provide diverse opportunities for students to practice computational thinking in a variety of contexts.

Numerous empirical studies have examined the role of both plugged and unplugged activities in enhancing computational thinking skills in mathematics education. These studies, conducted using both quantitative and qualitative approaches, have explored the effects of such activities on students' problem-solving abilities, engagement levels, and overall performance [10], [29]–[32]. However, although the individual findings of these studies provide valuable insights, there remains a lack of comprehensive and systematic reviews that synthesize their collective contributions. In particular, comprehensive systematic reviews using qualitative meta-synthesis to holistically analyze the role of plugged and unplugged activities in mathematics education regarding the issue of computational thinking skills are extremely rare. This gap in research underscores the need for a broader understanding of how these approaches, both plugged and unplugged, can be effectively integrated into mathematics learning to enhance computational thinking skills.

Meta-synthesis offers a powerful framework for systematically reviewing and interpreting the existing qualitative empirical studies. This approach enables researchers to identify patterns, themes, and insights across multiple studies, thereby providing a deeper understanding of complex phenomena [33]. Despite its potential, no qualitative meta-synthesis has systematically reviewed empirical research on plugged and unplugged activities in mathematics education to enhance computational thinking skills. To date, so far there are many systematic reviews have highlighted the effect of plugged activities in educational settings to promote students' computational thinking skills [17], [21], [34]–[36]. Additionally, a number of meta-analytic reviews have systematically highlighted the effect of unplugged activities in educational settings to enhance students' computational thinking skills [26], [37]–[40]. Consequently, this systematic review addresses this novel idea by offering a comprehensive analysis of existing empirical studies regarding the role of plugged and unplugged activities in educational settings of mathematics in promoting students' computational thinking skills through a qualitative meta-synthesis approach. The present systematic review aims to qualitatively explore and analyze the role of plugged and unplugged activities in the educational setting of mathematics to enhance students' computational thinking skills using a meta-synthesis approach. By synthesizing insights from previous empirical studies, this systematic review seeks to contribute to the existing body of knowledge by offering a comprehensive understanding of how this meta-synthesis approach can be effectively utilized. The findings of this review are expected to inform educators, curriculum designers, and policymakers on the best practices for integrating computational thinking skills into mathematics education, ultimately paving the way for more effective teaching and learning strategies. To achieve the purpose of this systematic review, the following research questions were asked: (1) To what extent does the achievement of students' computational thinking skills in the educational settings of mathematics integrated with plugged activities? (2) To what extent is the achievement of students' computational thinking skills in the educational settings of mathematics integrated into unplugged activities?

2. Method

2.1. Research Design

This study employed a systematic literature review (SLR) combined with a qualitative meta-synthesis to explore and analyze the role of plugged and unplugged activities in mathematics learning to promote students' computational thinking skills. SLR is a methodical approach for identifying, evaluating, and synthesizing research on a specific topic [41], whereas meta-synthesis involves the synthesis of qualitative findings from multiple studies to generate comprehensive insights [42]. The strength of qualitative meta-synthesis lies in its ability to integrate diverse qualitative data, identify themes, and provide a deeper understanding of complex phenomena [3]. This systematic review followed a structured process comprising seven steps: (1) defining the research problem to establish a clear focus for the study, (2) deciding inclusion criteria to delimit the scope of the review, (3) conducting a comprehensive literature search to gather relevant studies, (4) selecting documents that met the inclusion criteria, (5) extracting data from the selected documents, (6) analyzing the data to identify patterns and themes, and (7) interpreting the findings and creating a detailed report [43], [44]. These steps ensured a rigorous and transparent approach to reviewing empirical studies, allowing for a nuanced understanding of how plugged and unplugged activities affect students’ computational thinking skills in mathematics.

2.2. Inclusion Criteria

To limit the scope of the defined problems, this systematic review employed specific inclusion criteria to ensure the relevance and quality of the selected documents. First, the title of the document contained the keywords "Computational Thinking" and "Mathematics" Mathematics’ to focus on the intersection of these fields. Second, the text of the document had to be written in English to facilitate consistent analysis and interpretation. Third, the document type was limited to articles or conference papers sourced from reputable journals or conference proceedings, to ensure academic rigor. Fourth, the review included documents published between 2004 and 2023, reflecting the period in which computational thinking gained prominence as an educational focus. Fifth, the participants described in the documents had to be Asian, American, African, European, or Australian students from different educational levels, including pre-school, primary school, secondary school, or higher education. Finally, the documents were required to provide information regarding students' computational thinking skills, including the core components of decomposition, pattern recognition, abstraction, algorithms, and evaluation. These criteria ensured that the review included studies that directly addressed the research problem and offered a diverse global perspective on the topic.

2.3. Comprehensive Search

A comprehensive search for relevant documents was conducted using the Scopus database, which is a highly reputable source of academic literature. Scopus is widely recognized as one of the most comprehensive and reliable research databases, offering access to peer-reviewed journals, conference proceedings, and high-quality scholarly content across multiple disciplines [45].

The database’s advanced search functionality and extensive indexing make it the preferred choice for systematic reviews, providing a robust platform for identifying relevant studies. In this review, two combinational keywords, including "Computational Thinking" and "Mathematics," were used to retrieve documents that explicitly addressed the research focus. Boolean operators, such as “AND” and “OR” were employed to ensure precision and inclusivity in the search results.

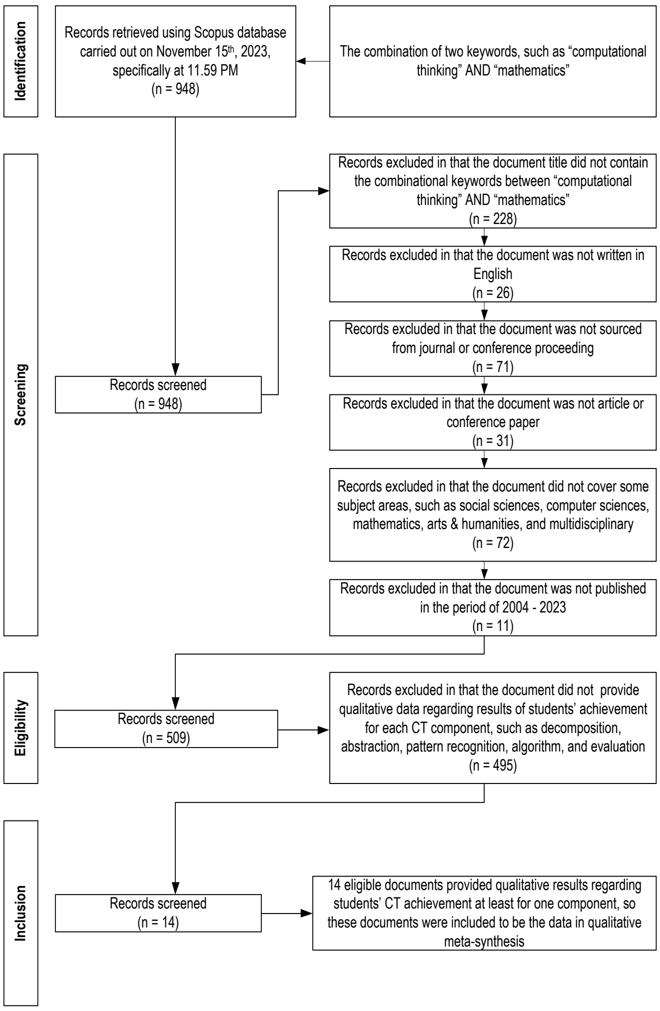

Figure 1. Systematic document-selection process (authors’ elaboration)

The database’s advanced search functionality and extensive indexing make it the preferred choice for systematic reviews, providing a robust platform for identifying relevant studies. In this review, two combinational keywords, including "Computational Thinking" and "Mathematics," were used to retrieve documents that explicitly addressed the research focus. Boolean operators, such as “AND” and “OR” were employed to ensure precision and inclusivity in the search results. The search process included filtering options to align with the inclusion criteria, such as the document type, publication period, and language. Additionally, Scopus facilitates the identification of high-impact studies through citation analysis and relevance ranking, further ensuring the quality of the selected documents [46]. This systematic search process yielded a comprehensive set of documents, forming the foundation for rigorous and insightful qualitative meta-synthesis.

2.4. Document Selection

The document selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which ensures a systematic and transparent approach to literature reviews. The process involves four main stages: (1) identification, (2) screening, (3) eligibility, and (4) inclusion [47], [48], as shown in Figure 1. During the identification phase, 948 records were retrieved from the Scopus database on November 15th, 2023, using the combined keywords "Computational Thinking" and "Mathematics." Finally, in the inclusion phase, 14 documents were selected as they provided qualitative results regarding students' achievement in computational thinking skills for at least one component. These documents formed the basis for qualitative meta-synthesis, offering rich insights into the role of plugged and unplugged activities in mathematics learning to promote students' computational thinking skills. This structured process ensured the selection of high-quality relevant studies for this research.

2.5. Data Extraction

Fourteen eligible documents were selected for qualitative meta-synthesis and were coded into a structured sheet. The coding sheet included categories, such as authors, educational level, participant country, activity, and qualitative results (see Appendix 1). These 14 documents were chosen for their qualitative findings related to the achievement of students' computational thinking skills in five components, including decomposition, pattern recognition, abstraction, algorithm, and evaluation. Table 1 provides a summary of the educational level, country participants, number of participants, and computational thinking (CT) components covered in these studies.

Table 1. The existence of CT component of qualitative documents

Authors	Participatory Country	Educational Level	N	CT Component				
				C1	C2	C3	C4	C5
Fry et al. (2023)	Australia	Primary School	4	✓	✓	✓	✓	✓
Budiyanto et al. (2022)	Indonesia	College/University	8	✓	✓	✓	✓	✓
Leonard et al. (2023)	USA	Primary School	22	X	✓	X	✓	✓
Aminah et al. (2022)	Indonesia	College/University	21	✓	✓	X	✓	X
Hanid et al. (2022)	Malaysia	Secondary School	31	✓	✓	X	✓	✓
Cui & Ng (2021)	Hong Kong	Primary School	8	X	✓	X	X	X
Rich et al. (2020)	USA	College/University	1	✓	✓	✓	X	X
Dian (2020)	Indonesia	College/University	4	✓	✓	✓	X	X
Guimaraes et al. (2020)	Brazil	Primary School	2	✓	✓	✓	✓	X
Masfingatin & Maharani (2019)	Indonesia	College/University	3	✓	✓	X	✓	✓
Maharani et al. (2019)	Indonesia	College/University	3	✓	✓	X	✓	✓
Ehsan et al. (2018)	USA	Primary School	2	✓	✓	✓	✓	X
Pei et al. (2018)	USA	Secondary School	16	✓	X	✓	X	X
Shumway et al. (2021)	USA	Pre-School	36	✓	X	X	X	X

Note: C1: decomposition, C2: abstraction, C3: pattern recognition, C4: algorithm, C5: evaluation, N: research subject, ✓: Exist, X: not exist

The reliability and validity of the included data were ensured to ensure robust findings [63]. Two experts in qualitative meta-synthesis verified the accuracy of the data. After re-coding and reviewing the coding sheet, inter-coder consistency was assessed for a qualitative meta-synthesis. Cohen's kappa test was used to measure the level of agreement between two experts [64]. According to McHugh [64], the kappa value can be expressed as follows:

$$\kappa = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)}$$

$\Pr(a)$ represents the observed agreement and $\Pr(e)$ reflects the expected agreement by chance. The Kappa values were categorized with following the criteria, such as: 0.00–0.20 (None), 0.21–0.39 (Minimal), 0.40–0.59 (Weak), 0.60–0.79 (Moderate), 0.80–0.90 (Strong), and 0.91–1.00 (Almost Perfect) [64].

Table 2. The results of Cohen's Kappa test

Coding Item	Kappa Value	Agreement Level	Significance Value
Authors	0.832	Strong	0.017
Educational Level	0.849	Strong	0.017
Participatory Country	0.875	Strong	0.011
Activity	0.812	Strong	0.018
Decomposition	0.788	Moderate	0.022
Abstraction	0.714	Moderate	0.028
Pattern Recognition	0.794	Moderate	0.021
Algorithm	0.725	Moderate	0.027
Evaluation	0.754	Moderate	0.024

As shown in Table 2, the agreement levels for all coding items ranged from moderate to strong. Furthermore, the significance values for all coding items were below 0.05, indicating statistically significant agreement among coders [65], [66]. These findings confirmed the reliability and credibility of the data used in the qualitative meta-synthesis, ensuring its suitability for further analysis.

2.6. Data Analysis

The coding paradigm from grounded theory was applied to analyze the data for qualitative meta-synthesis. According to Corbin and Strauss [67], this paradigm consists of three phases: open, axial, and selective coding. Qureshi and Unlu [68] provided further insight, explaining that open coding involves breaking down data into smaller segments to conceptualize and categorize phenomena through detailed analysis. This process identifies core ideas in each segment and develops codes to represent them. Axial coding, on the other hand, examines the relationships between concepts and categories established during the open coding phase. Finally, selective coding integrates these categories into a cohesive theory by elaborating and linking them based on the relationships identified in axial coding. The coding paradigm outlined by Creswell [69] was adapted to fit the data used in this qualitative meta-synthesis (Figure 2). From Figure 2, the grounded theory coding paradigm generated several conjectures regarding students' computational thinking achievements across five key components: algorithm, abstraction, decomposition, evaluation, and pattern recognition. These conjectures have evolved into substantive theories concerning the extent of students' computational thinking achievements in mathematics learning integrated into plugged and unplugged activities over the past two decades. Qualitative meta-synthesis analysis was conducted using Nvivo v.14 software.

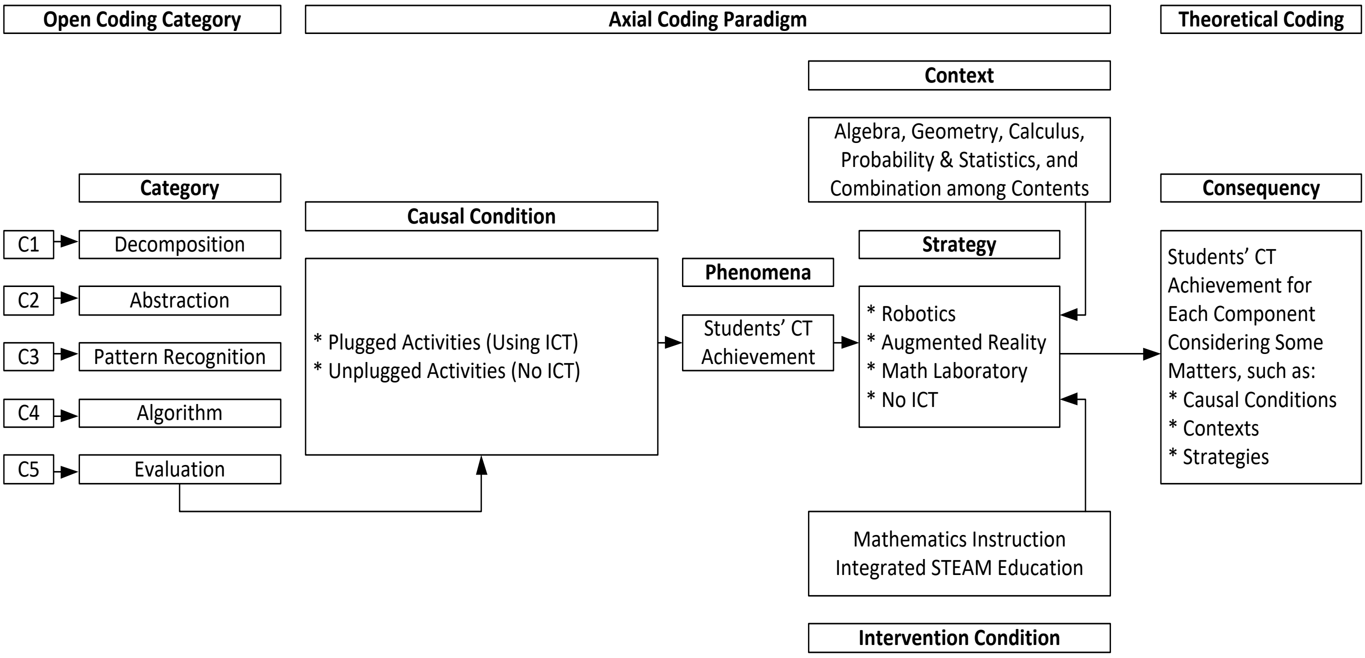

Figure 2. Coding paradigm for the achievement of students' CT skills across components (developed by authors)

3. Results

This analysis aims to explore the extent of students' computational thinking achievements over the past two decades. The investigation considered students' computational thinking achievements from the perspective of the utilization of educational technology in mathematics learning, including plugged and unplugged activities. To facilitate this analysis, a coding paradigm was applied, which incorporated three phases: open coding, axial coding, and selective (or theoretical) coding [67]. Students' computational thinking achievements in the educational setting of mathematics were evaluated by analyzing their components as defined by Wing [1] and Grover and Pea [2], including algorithm, abstraction, decomposition, evaluation, and pattern recognition. These components were further broken down into specific indicators, as outlined by Ehsan et al. [60]. For decomposition, the indicators included (1) breaking down data, processes, and problems into smaller parts and (2) organizing these components to solve a problem. Additionally, for abstraction, the indicators were (1) identifying the structure or main ideas and (2) utilizing these structures or main ideas. Pattern recognition was assessed by (1) identifying a given pattern, (2) completing missing patterns, (3) representing patterns differently, and (4) creating original patterns. Algorithmic thinking was measured using the following indicators: (1) following a series of ordered steps, (2) identifying step sequences, (3) applying ordered instructions, and (4) creating ordered instructions. Lastly, evaluation was conducted through (1) adapting chosen solutions to relevant problems, (2) implementing solutions for similar problems, and (3) assessing the effectiveness of these solutions. First, of 14 qualitative empirical studies, six documents reported qualitative findings regarding the achievement of students' computational thinking skills using plugged activities, robotics, augmented reality, and mathematics laboratories in mathematics learning [50], [51], [53], [54], [57], [62]. Figure 2 outlines the framework for achieving students' CT skills using plugged activities in mathematics learning. It centered on five key computational thinking components, including abstraction, algorithms, decomposition, evaluation, and pattern recognition, which collectively develop students' problem-solving skills. In particular, abstraction involves identifying the structure of concepts or main ideas, and utilizing these structures to address complex problems. This component fosters critical thinking by helping students to focus on the most relevant aspects of a problem. In addition, the algorithm emphasizes the application of a sequence of ordered steps. It included some skills, such as applying instructions, following a logical progression, identifying the sequence of steps required to achieve a solution, and promoting systematic thinking. Subsequently, decomposition was crucial for breaking down problems into smaller, manageable parts and managing these components to devise effective solutions. This helps students handle complexity by isolating and addressing individual elements of a larger problem. The evaluation involved adapting the chosen solutions to relevant problems and implementing these solutions effectively. This ensured that students critically assessed their methods, refined their approaches, and validated their outcomes. Finally, pattern recognition focuses on identifying and completing patterns, representing patterns in different ways, and creating original patterns. These skills encourage students to discern connections and to develop strategies based on recurring trends.

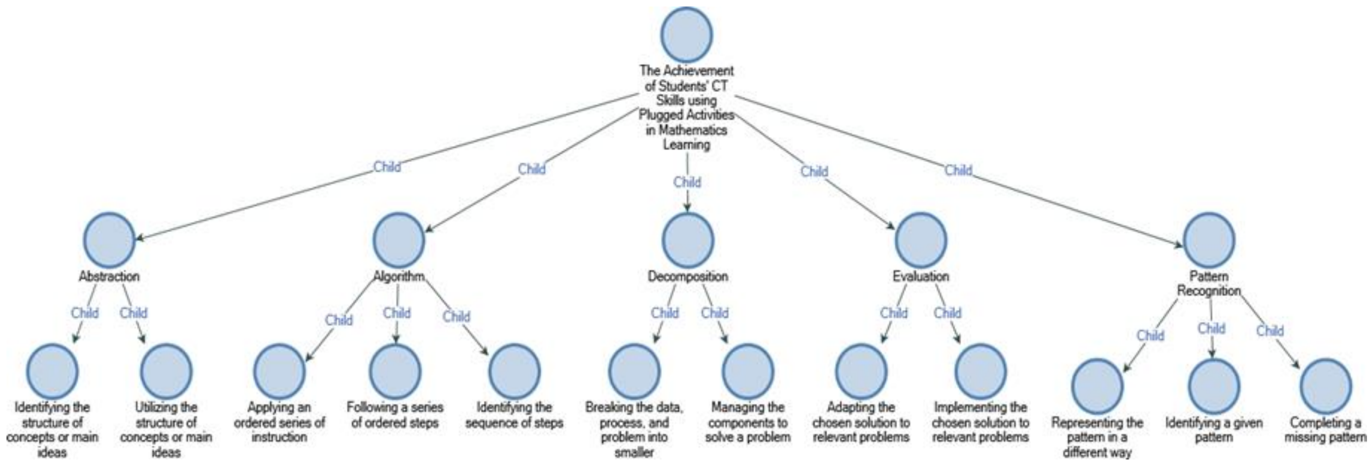

Figure 3. Students' CT skills in mathematics learning with plugged activities (developed by authors)

Plugged activities in mathematics integrated educational technologies such as robotics, augmented reality, and mathematics laboratories to facilitate the practical application of these computational thinking components. This approach enhanced engagement, allowing students to experiment and learn through hands-on experience. In addition, the hierarchical structure in Figure 2 demonstrates how each computational thinking component was broken down into sub-skills, ensuring detailed and comprehensive development of computational thinking. For example, abstraction and pattern recognition address higher-order thinking, whereas algorithms and decomposition provide structured problem-solving strategies. Figure 3 represents a detailed roadmap for educators to design mathematics learning integrated with plugged activities that promote computational thinking skills. It emphasizes the importance of combining theory with practice to ensure a balanced and effective approach to developing computational thinking. Through this model, plugged activities in mathematics learning emerge as a powerful tool to foster creativity, resilience, and a lifelong passion for problem solving, laying a strong foundation for student success.

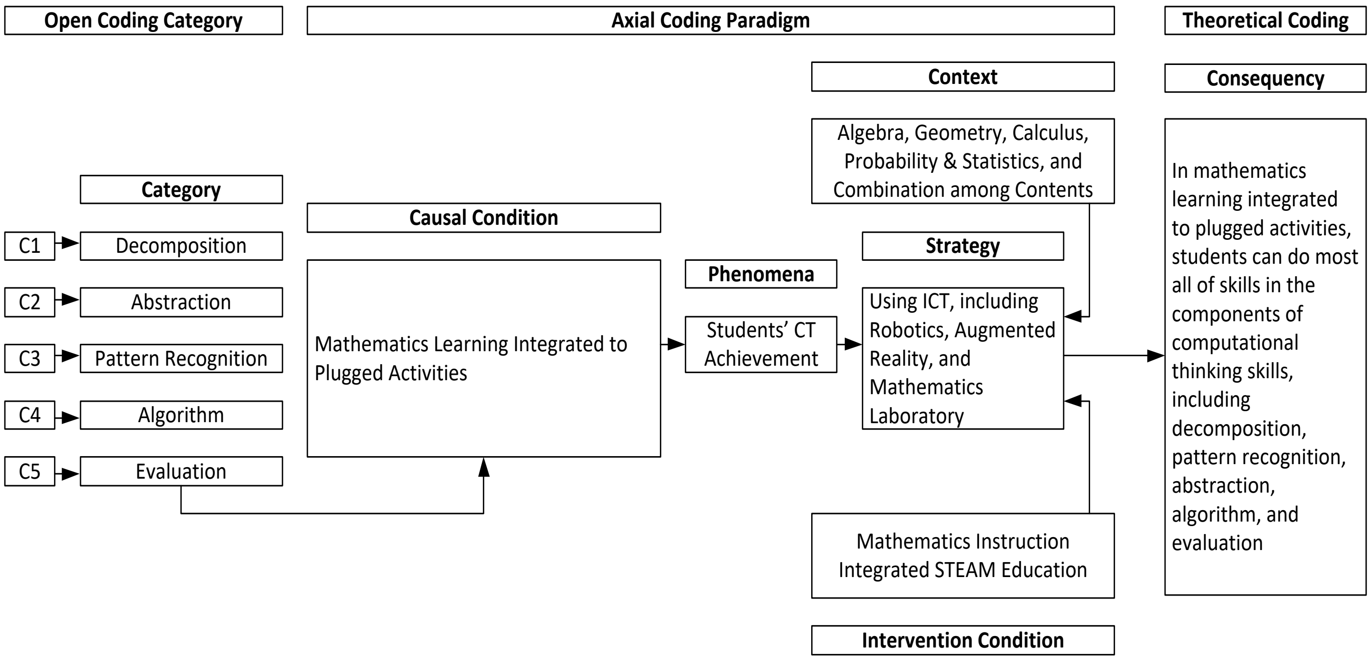

Figure 4. The conjectures of students' CT skills in mathematics learning with plugged activities (developed by authors)

Second, of 14 qualitative empirical studies, eight documents reported qualitative findings regarding the achievement of students' computational thinking skills using unplugged activities in mathematics learning [49], [52], [55], [56], [58]–[61]. Figure 4 illustrates the achievement of students' computational thinking skills using unplugged activities in mathematics learning. It identified five components of computational thinking skills — abstraction, algorithm, decomposition, evaluation, and pattern recognition — each of which was crucial for developing students' logical reasoning and problem-solving skills. In particular, abstraction is represented as a process involving two specific skills: identifying the structure of concepts or main ideas and utilizing those structures to simplify and solve complex problems. This skill encourages students to focus on essential elements while ignoring irrelevant details. Subsequently, the algorithm emphasized a procedural approach to problem-solving. It includes identifying the sequence of steps and following an ordered series of steps to achieve a solution, enabling students to develop structured and efficient problem-solving methods. Additionally, decomposition involves breaking down data, processes, or problems into smaller parts and managing these components to effectively address the larger problem. This approach fosters clarity and helps students to tackle complex challenges systematically. Moreover, the evaluation involved adapting a chosen solution to fit the relevant problems and implementing the solution effectively. This component encourages reflective thinking, ensuring that students critically assess and refine their own strategies. Finally, pattern recognition focuses on identifying the given patterns and completing the missing patterns. These skills help students develop the ability to identify trends and relationships that are vital for making predictions and generalizations in mathematics.

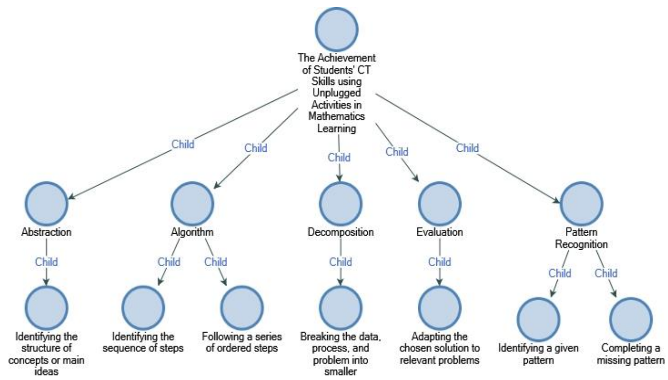

Figure 5. Students' CT skills in mathematics learning with unplugged activities (developed by authors)

The use of unplugged activities highlighted the focus on teaching computational thinking without the use of digital tools, relying instead on physical or conceptual exercises. This approach ensured that students understood the fundamental concepts before transitioning to technology-based methods. The hierarchical structure in Figure 4 demonstrates the breakdown of each computational thinking component into smaller actionable sub-skills. This enables educators to design targeted activities that progressively and effectively build these skills. Ultimately, Figure 5 underscores the importance of unplugged activities as powerful tools for teaching computational thinking. By focusing on the core skills, it ensured that students were well prepared to tackle increasingly complex challenges in mathematics and beyond. This structured approach not only enhances students' computational thinking skills, but also nurtures a lifelong passion for learning, ensuring their readiness for future academic and professional endeavors.

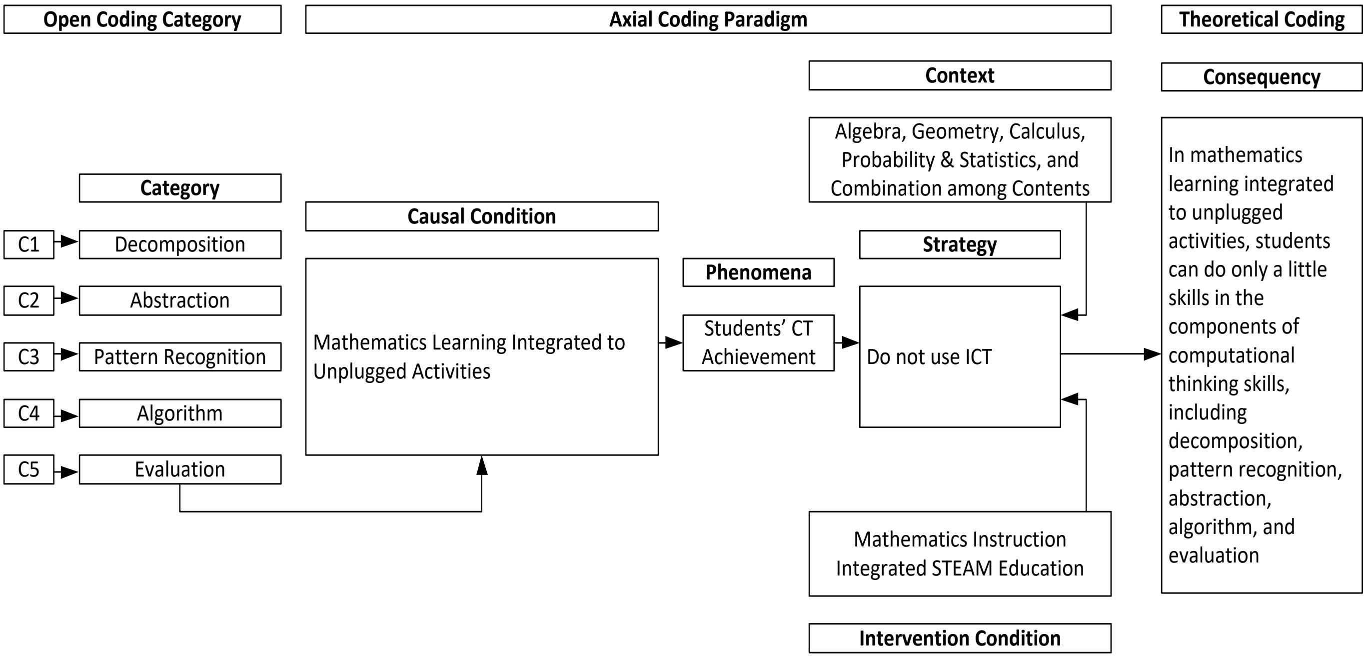

Figure 6. The conjectures of students' CT skills in mathematics learning with unplugged activities (developed by authors)

4. Discussion

Mathematics learning integrated with plugged activities provides an engaging and interactive platform for developing students' computational thinking skills. Plugged activities involve the use of technology and digital tools, which expose students to problem-solving scenarios that reflect real-world computational challenges [70]. These activities promote logical reasoning by allowing students to manipulate variables, explore patterns, and analyze relationships through simulations and coding platforms [5]. The integration of mathematics ensures a structured learning process, as mathematical principles provide the foundation for CT concepts, such as abstraction, decomposition, and algorithms. By leveraging technology, students are encouraged to test, modify, and optimize their solutions, which closely aligns with the development of CT. Plugged activities also foster self-directed learning, where students actively explore mathematical problems and learn through trial and error [71]. Moreover, feedback mechanisms in plugged environments provide students with immediate insights into their problem-solving approaches, helping them refine their thought processes [72]. As digital tools replicate real-world scenarios, students develop the ability to generalize their problem-solving strategies, which is a key CT skill. The combination of technology and mathematics creates a synergistic learning environment that simultaneously nurtures analytical and computational skills [73]. Thus, mathematics learning with plugged activities lays the groundwork for building essential CT competencies in an accessible and engaging manner.

Plugged activities in mathematics learning are essential for developing core computational thinking skills such as decomposition, pattern recognition, abstraction, algorithm design, and evaluation. Decomposition helps students to break complex problems into smaller parts, a process supported by digital tools that allows them to visualize and manage interconnected elements [73]. Coding platforms and modeling software allow learners to isolate variables and test components individually, reinforcing logical sequencing and critical analysis [12], [47]. These tools also enhance pattern recognition by enabling students to identify trends in data through interactive simulations and graphing software, thereby deepening their predictive reasoning and analytical skills [11], [32]. Abstraction is another key skill developed through plugged activities, as students learn to filter out irrelevant information and focus on essential problem components using technology-based modeling tools and coding tasks [23], [42]. Mathematics provides a structured framework for abstraction, helping students simplify and generalize problems. Similarly, algorithmic thinking is fostered as students use digital platforms to build, test, and refine step-by-step procedures, aligned naturally with mathematics' emphasis on logical sequences [22], [25]. These experiences support structured problem-solving while encouraging experimentation and creativity. Evaluation skills are strengthened as students receive real-time feedback from coding tools, prompting them to analyze solution effectiveness and optimize their approaches [73]. The process becomes more engaging through simulations and interactive elements with real-world implications. Overall, integrating plugged activities into mathematics education equips students with essential computational thinking tools for solving complex problems across domains.

Mathematics learning integrated with unplugged activities fosters the development of students' computational thinking skills in a hands-on, engaging manner, without the need for technology. Unplugged activities often involve collaborative games, puzzles, or kinesthetic exercises that mirror computational concepts in tangible real-world contexts. These activities help students build logical reasoning by breaking problems into smaller parts, identifying patterns, and applying structured problem-solving approaches [74]. Mathematics provides a logical and systematic foundation that is further enriched by the creative and exploratory nature of unplugged activities. Without distractions or limitations of digital tools, students can focus solely on understanding fundamental concepts and processes. Unplugged activities also encourage teamwork and communication as students often work together to solve challenges and explain their thought processes and strategies. These experiences develop key computational skills such as critical thinking, adaptability, and creativity, which are transferable to both academic and real-world applications [32]. The tactile and interactive nature of unplugged activities makes abstract CT concepts more concrete and accessible to students. By integrating mathematics into unplugged exercises, educators can seamlessly connect theoretical concepts with practical applications and enhance their understanding [26]. As a result, unplugged activities serve as an effective and inclusive way to nurture students' computational thinking skills in mathematics.

Unplugged activities in mathematics learning effectively support the development of key computational thinking skills including decomposition, pattern recognition, abstraction, algorithm design, and evaluation. Through tasks such as puzzles, group problem solving, and role-playing games, students practice breaking complex problems into smaller, manageable parts, a core aspect of decomposition [1], [52]. These activities also provide opportunities to explore hands-on mathematical patterns using tools such as colored blocks or number games to identify sequences, trends, and relationships in an engaging way [1]. Without relying on technology, students gain deeper insight into patterns and improve their ability to generalize and predict [23]. Abstraction is similarly strengthened as students learn to filter out irrelevant details using tactile models, flowcharts, or budgeting simulations, helping them to focus on essential mathematical elements [1]. By simplifying problems into their core components, learners can build a foundation for modeling and generalization. Algorithmic thinking is reinforced through activities that involve following or creating step-by-step procedures such as logic games or sequencing tasks, allowing students to physically build and test algorithms [25], [27]. These unplugged methods make the logical structure of algorithms clear and accessible, particularly when paired with mathematics. Evaluation skills also grow as students critically assess different problem-solving strategies and test outcomes and refine their methods through collaborative activities such as peer reviews and route optimization tasks [2], [38]. These exercises promoted iterative and analytical thinking. Together, unplugged activities and mathematics provide a practical and inclusive way of teaching computational thinking without digital tools.

5. Conclusion, Implication, Limitation, and Suggestion

5.1. Conclusion

This systematic review, employing a qualitative meta-synthesis, provides a comprehensive exploration of the role of plugged and unplugged activities integrated into mathematics learning in promoting students' CT skills. The findings demonstrated that both types of activities offer unique and complementary contributions to the development of core CT components, including decomposition, pattern recognition, abstraction, algorithms, and evaluation. Plugged activities leverage technology to create dynamic, interactive learning environments, foster student engagement, and allow real-time feedback and iterative problem-solving. Conversely, unplugged activities focus on tangible, hands-on experiences that emphasize foundational CT principles without relying on digital tools, thus making them accessible across diverse educational settings. Together, these approaches bridge the gap between theoretical understanding and practical application, ensuring that students develop transferable problem-solving skills essential for the digital age. However, challenges, such as varying definitions of CT skills, inconsistent measurement frameworks, and limited geographic representation, highlight the need for further research and standardization. Despite these limitations, this review underscores the importance of integrating plugged and unplugged activities into mathematics learning to create a balanced, inclusive, and effective approach to CT skill development. It also emphasizes the role of educators in designing and implementing thoughtful context-specific instructional strategies that align with students' needs and resources. This review contributes to the growing body of literature on computational thinking in education and provides valuable insights for policymakers, curriculum developers, and educators. Ultimately, this lays a solid foundation for future research to refine and expand the integration of these activities, ensuring that CT skills are effectively cultivated across diverse educational landscapes.

5.2. Practical Implication for Educational Settings

The integration of plugged and unplugged activities into mathematics education has profound practical implications in future educational settings. Practically, this approach equips educators with a versatile toolkit to teach computational thinking skills, while ensuring accessibility for all students. Plugged activities such as coding applications or online math games provide educators with resources to make abstract concepts more relatable and interactive. Meanwhile, unplugged activities, such as role-playing games, puzzles, and physical manipulatives, ensure that computational thinking is accessible, even in low-resource settings without technological infrastructure. This dual approach encourages a balance between screen time and hands-on learning, addressing concerns about the overreliance on technology in education. It also fosters collaboration and communication among students, as unplugged activities often require teamwork and discussions to solve problems. Teachers can use unplugged activities to introduce computational concepts and then extend learning with plugged activities, creating a seamless progression from basic understanding to advanced applications. Additionally, this strategy promotes inclusivity, as unplugged activities are suitable for students with limited access to digital tools, whereas plugged activities can cater to advanced learners seeking additional challenges. The blended use of plugged and unplugged methods prepares students for real-world problem solving by connecting computational thinking with practical, everyday scenarios. As a result, future mathematics curricula that incorporate these strategies will produce learners who are not only adept at computational skills, but also adaptive and creative problem-solvers in diverse settings.

5.3. Limitations and Suggestions

This systematic review, which used qualitative meta-synthesis to examine how plugged and unplugged activities support students' computational thinking (CT) skills through mathematics, has several limitations. First, it only included studies published in English, possibly excluding relevant research owing to language and publication bias. Second, the review focused on qualitative data, which restricted its ability to quantitatively compare the effectiveness of different activity types. Third, inconsistencies in the definition and application of CT skills were defined and applied across studies have made it difficult to develop a unified analytical framework. Fourth, methodological and contextual differences, such as variations in student populations, teaching practices, and education systems, limit the generalizability of the findings. Fifth, the review primarily analyzed studies from specific regions, potentially missing insights from broader international contexts. Sixth, reliance on secondary data without primary data collection may have constrained the depth and reliability of the analyses. Seventh, little attention has been paid to the long-term impact of plugged and unplugged activities on retention and use of CT skills. Eighth, the absence of a standardized tool for evaluating CT in mathematics makes cross-study comparisons less reliable. Finally, the review did not sufficiently explore the role of teacher training and pedagogical readiness in effectively implementing these activities. Finally, by focusing only on mathematics, interdisciplinary opportunities that could strengthen CT skills development may have been overlooked.

Declarations

Author Contributions

All the authors contributed to the conception and design of the study. A.L.F: Conceptualization, collecting the data, document selection, data extraction, writing - original draft, data analysis, and interpretation; Y. S. K., E. N., and D. J.: review and editing.

Data Availability Statement

Data available in a publicly accessible repository that does not issue DOIs: Publicly available datasets were analyzed in this study. The data in this study can be found by contacting this email: ahmadlutfifauzi@upi.edu

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Institutional Review Board Statement

The authors did not involve humans as participants in this study, so the Institutional Review Board Statement is not applicable.

Informed Consent Statement

However, an informed consent statement was not applicable.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this manuscript.

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