Outdoor Mathematics Learning Activities Based on Unplugged Coding Enhance Self-Regulated Learning: A Systematic Review

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Abstract.

Technological advancements in the 21st century require the mastery of computational thinking from an early age. However, mathematics learning is often perceived as monotonous, leading to low levels of student self-regulation. This study aims to systematically review the effectiveness of developing outdoor mathematics activities based on unplugged coding in enhancing self-regulation. The method used was a Systematic Literature Review (SLR) following the PRISMA protocol, analyzing 35 research articles (2006–2026). The results indicate that unplugged coding activities are as effective as computer-based methods in training algorithmic logic. Outdoor learning has been shown to increase motivation and reduce boredom, while self-regulation strategies emerge as the primary predictor of success in solving mathematical problems. The study's conclusion emphasizes that the integration of these three components—outdoor mathematics, unplugged coding, and Self-Regulated Learning—creates an interactive and self-directed learning environment that specifically contributes to enhancing students' learning autonomy.

Keywords: *Unplugged Coding, Computational Thinking, Self-Regulated Learning, Outdoor Learning and Mathematics Education.*

I. INTRODUCTION

In the era of 21st-century digital transformation, proficiency in computational thinking (CT) has been recognized as an essential competency on par with reading, writing, and arithmetic skills (Wing, 2006). CT is not merely the activity of programming devices, but rather a cognitive process of solving complex problems through decomposition, pattern recognition, abstraction, and algorithmic thinking (Selby & Woollard, 2013; Delal & Oner, 2020). However, the integration of CT into the curriculum is often hindered by limitations in technological infrastructure, particularly in areas with minimal digital access (Chen et al., 2023). Additionally, a major challenge in current mathematics education is the dominance of conventional methods that tend to be monotonous and focus solely on memorizing formulas, as well as rigid learning approaches that lead to student burnout and low motivation (Junaedy et al., 2024; Sumandya & Wikanta, 2023).

As a pedagogical solution, unplugged coding has emerged as an effective method for introducing computer science logic concepts without reliance on computer devices (Bell et al., 2009; Salsabila & Aminudin, 2026). Through physical activities, card games, or the manipulation of concrete objects, students can understand algorithmic instructions more intuitively (Rahmawati & Agustin, 2024). This approach is highly relevant for students at the concrete operational stage, who require hands-on experience to grasp abstract concepts (Piaget, 1977; Salsabila & Aminudin, 2026). Research demonstrates that unplugged methods are just as effective as computer-based (plugged) methods in enhancing CT skills, while also being more inclusive and cost-effective for educational institutions (Chen et al., 2023; Setiawan & Ringo, 2024; Kirçali & Özdener, 2022).

In an effort to maximize student engagement, unplugged coding activities can be integrated with outdoor learning. Moving the learning environment to the outdoors has been shown to refresh the atmosphere, reduce mental stress, and allow the brain to work more freely (Mann et al., 2022; Junaedy et al., 2024). The natural environment serves as a tangible learning medium, allowing students to bridge mathematical theory with real-world applications (Crismono, 2017). These out-of-

class activities significantly contribute to enhancing mathematical critical thinking skills because students are compelled to interact directly with physical objects and solve problems within a broader social context (Crismono, 2017; Mann et al., 2022).

A crucial aspect determining the success of this method's integration is Self-Regulated Learning (SRL). SRL is a proactive process in which students independently manage their cognition, motivation, and behavior to achieve learning goals (Zimmerman, 2002; Pintrich, 2000). Students with high self-regulation are not only more organized in their learning but also possess greater "perseverance" and self-confidence when facing complex mathematical problems (Ituga & Alman, 2023; Harahap, 2023). SRL ability serves as a primary predictor of students' academic success and problem-solving skills from elementary through secondary school levels (Ituga & Alman, 2023; Mahrufah & Rijanto, 2024).

The primary reason for conducting this literature review is that, although the potential of each component—namely outdoor mathematics, unplugged coding, and self-regulation—has been extensively studied separately, there remains a significant gap in the literature regarding how the integration of these three can be systematically designed. There are few reviews that specifically map the impact of integrating computer-free, code-based outdoor physical activities on stimulating the phases of self-regulation in elementary school students.

This study aims to conduct a systematic literature review to summarize effective development strategies, identify implementation challenges, and map the combined impact of these three elements on students' learning autonomy (Khalaf & Zin, 2018; Ahn & Kang, 2018). The results of this review are expected to provide a strategic framework for educators in designing innovative, adaptive, and student-centered mathematics learning environments to enhance learning by incorporating Self-Regulated Learning (SRL).

II. METHOD

This study is a systematic literature review (SLR) aimed at summarizing strategies for developing outdoor mathematics learning activities (Khalaf & Zin, 2018; Martins & Gorschek, 2016). This method employs structured analysis and evidence-based categorization of previously generated evidence (Ahn & Kang, 2018). The review process is strictly limited to the inclusion criteria (Martins & Gorschek, 2016).

The inclusion criteria defined in this study are: (a) research articles focusing on mathematics, unplugged coding, and self-regulation, (b) research subjects at the K-12 education level (early childhood through secondary), and (c) research articles published between 2016 and 2026

The literature was searched online using the Google Scholar, Scopus, ERIC, and SINTA databases. Primary keywords included "unplugged coding," "mathematics," "outdoor learning," and "self-regulated learning." Screening followed the PRISMA protocol to ensure transparency and minimize reporting bias (Adin Selçuk, 2019; Moher et al., 2009). From the search results, 35 relevant articles were selected for in-depth review.

The data analysis technique in this systematic review focused on the data extraction phase, which is crucial for transforming information from scientific journals into new, structured data (Mathes et al., 2017; Munn et al., 2014). The screening process was conducted rigorously and meticulously to ensure only valid data was included, thereby preventing the loss of important information and ensuring optimal and satisfactory results (Mathes et al., 2017; Schmidt et al., 2021). All data relevant to the research objectives are summarized into a systematic extraction table, which includes key parameters such as the researcher's name and year of publication, study design, research location, sample characteristics and size, instruments used, and the final conclusions of the findings (Mathes et al., 2017; Dewi et al., 2022; Popenoe et al., 2021)

Data were synthesized in a structured manner using a narrative method to provide a comprehensive and in-depth overview of the topic under study (Mathes et al., 2017). This narrative synthesis approach was conducted by grouping findings with similar characteristics based on measured variables, specifically designed to address the research objectives regarding the effectiveness of integrating learning methods (Thomas & Harden, 2008). Through this process, the researcher conducts a comparative analysis to identify similarities and differences among various studies, which then serves as a strong foundation for drawing sophisticated and reliable research conclusions (Munn et al., 2014; Onwuegbuzie et al., 2012; Mann et al., 2022).

To ensure credibility (internal validity), researchers accurately interpret authentic data to ensure that the review's findings possess reliable research attributes (Miles et al., 2014). The methodological quality of each primary study is evaluated using standard assessment instruments, such as the Joanna Briggs Institute (JBI) checklist for qualitative research or the CCEERC (Child Care and Early Education Research Connections) tool for quantitative research, which assess the appropriateness of statistical techniques and adherence to ethical standards (Mann et al., 2022). To minimize the risk of bias and ensure transparency in reporting, this study adopted the PRISMA protocol and involved discussions among investigators to reach consensus at each stage of the literature screening (Adin Selçuk, 2019; Ahn & Kang, 2018; Martins & Gorschek, 2016). As a final step, the analysis results were discussed in depth by comparing them with previous expert findings and relating them to the social cognition theoretical framework to strengthen the validity of the findings (Ahn & Kang, 2018; Harahap, 2023)

III. RESULTS

The literature review yielded a total of 35 papers. The author reviewed these papers in greater detail and confirmed whether they addressed the integration of outdoor mathematics activities (outdoor learning), the use of unplugged coding as a medium for stimulating computational thinking, and mechanisms for enhancing self-regulated learning in students. The author then categorized them based on the established inclusion criteria. Finally, 35 relevant papers were selected based on the most dominant estimated categories (see Table 2). The analyzed papers were published within a very recent timeframe to capture the latest pedagogical innovation trends. The papers discussed were published in 2016 (1 paper), 2017 (4 papers), 2018 (3 papers), 2019 (5 papers), 2020 (7 papers), 2021 (4 papers), 2022 (5 papers), 2023 (2 papers), 2024 (4 papers), and 2026 (1 paper)

Table 1. Summary of Research Areas and Literature Distribution

No	*Research Area*	Year of Publication	Number of Articles	Temuan Penting
1	*The Effectiveness of Unplugged Coding in Mathematics*	2017-2026	18	Screen-free activities effectively develop computational thinking and a concrete understanding of number concepts Coding requires planning and cognitive control, which fosters students' independent learning
2	*Mechanisms for Enhancing Self-Regulated Learning (SRL)*	2017 – 2024	9	SRL Boosts motivation, reduces boredom, and strengthens mathematical critical thinking.

3	*The Impact of Outdoor Learning*	2017 – 2024	8	Outdoor learning environments serve as pedagogical laboratories that reduce cognitive load, boost intrinsic motivation, and sharpen mathematical critical thinking skills
	Total		35	

DISCUSSION

The Effectiveness of Unplugged Coding in Mathematics

Unplugged coding activities have been recognized as a highly effective pedagogical method for introducing the concept of computational thinking (CT) without relying on digital devices (Wing, 2006; Bell et al., 2009; Chen et al., 2023). CT itself is an essential cognitive process involving decomposition, pattern recognition, abstraction, and algorithmic thinking to solve complex problems (Selby & Woollard, 2013; Zapata-Cáceres et al., 2024). In the context of mathematics, the use of manipulative media such as cards, board games, and physical activities has been shown to facilitate the concrete understanding of number concepts, search algorithms, and geometry (Romero et al., 2017; Tonbuloğlu & Tonbuloğlu, 2019). This approach is particularly crucial for students at the concrete operational stage, where manipulating physical objects helps them bridge abstract mathematical logic with real-world experiences (Piaget, 1977; Salsabila & Aminudin, 2026). A meta-analysis of various studies indicates that unplugged activities have a very large positive effect (Hedges's g = 1.028) in promoting CT skills at the K-12 level (Chen et al., 2023). Furthermore, this method offers an inclusive, low-cost solution for schools with limited technological infrastructure, without compromising instructional effectiveness compared to computer-based (plugged) methods (Delal & Oner, 2020; Setiawan & Ringo, 2024)

This self-regulation is crucial because superior SRL capabilities have been shown to enhance cognitive resilience, "grit," and students' self-confidence in tackling the complexity of abstract mathematical problems. Thus, the triadic integration of outdoor mathematics, unplugged coding, and stimulation of self-regulation phases can empower students to effectively monitor their own learning progress.

The Impact of Outdoor Learning

The implementation of nature-specific outdoor learning (NSLOtC) provides significant holistic benefits for students' academic development and emotional well-being (Mann et al., 2022). Moving the learning space to the outdoors can reduce the mental stress and boredom often experienced in conventional classrooms, thereby making "brain work more relaxed" and improving student focus (Cintami, 2018; Junaedy et al., 2024). The outdoor environment serves as a real-world laboratory that allows students to conduct direct observations, which automatically boosts intrinsic motivation and active engagement in the learning process (Junaedy et al., 2024; Ryan & Deci, 2000). In mathematics, direct interaction with the physical environment helps students bridge the gap between textbook theories and real-world applications, ultimately contributing to improved scores in mathematical critical thinking skills (Crismono, 2017; Thomas & Munge, 2017). Outdoor learning has also been shown to increase students' sense of ownership over their own learning and to develop social and collaborative skills through authentic group challenges (Mann et al., 2022; Miller et al., 2021)

Mechanisms for Enhancing Self-Regulated Learning (SRL)

Self-Regulated Learning (SRL) is a proactive process in which students independently manage their cognition, motivation, and behavior to achieve predetermined learning goals (Zimmerman, 2002; Harahap, 2023). The SRL mechanism involves a cycle that includes phases of

strategic planning, performance monitoring, and self-reflection on the results achieved (Panadero, 2017; Lasmanawati, 2021). Coding activities, even when conducted unplugged, strongly support the development of SRL because they require students to engage in systematic instructional planning, exercise cognitive control while constructing logical reasoning, and perform self-evaluation (debugging) when encountering errors in problem-solving steps (Ahn et al., 2021; Romero et al., 2017). This self-regulation ability serves as a primary predictor of students' success in tackling complex mathematical problems, where students with high SRL tend to be more persistent, confident, and possess more effective problem-solving strategies (Ituga & Alman, 2023; Mahrufah & Rijanto, 2024). In addition to internal factors, teacher support and encouragement in creating a conducive learning environment also play a crucial role in stimulating students' use of self-directed learning strategies (Šimić Šašić & Atlaga, 2024; Damayanti et al., 2024). Thus, the integration of outdoor mathematics activities based on coding creates an ecosystem that is both challenging and systematically supports students' cognitive autonomy (Khalaf & Zin, 2018; Harahap, 2023).

This study confirms that unplugged coding activities are not merely computer-free methods, but rather powerful cognitive tools for facilitating computational thinking indicators, particularly in the aspects of decomposition, pattern recognition, and the development of simple algorithms through concrete manipulative experiences. The use of an outdoor environment plays a crucial role in reducing the boredom and mental stress that often accompany conventional mathematics learning, while simultaneously enhancing students' intrinsic motivation and critical thinking skills through direct interaction with the field environment.

IV. CONCLUSION

Based on the systematic literature review conducted, it can be concluded that the research objective of formulating strategies for developing mathematics activities has been achieved. The integration of outdoor mathematics (outdoor learning) and unplugged coding has proven to be significantly effective in creating a learning ecosystem capable of holistically stimulating students' Self-Regulated Learning.

Furthermore, the mechanism for enhancing self-regulation occurs when students are actively engaged in coding challenges that require strategic planning, cognitive control, self-monitoring, and evaluation of results to arrive at a parsimonious (efficient) solution. Students with high levels of learning autonomy have been shown to possess greater "resilience" and self-confidence when facing complex mathematical problems.

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