



Integrating Unplugged Coding into Elementary Physical Education

An Embodied Computational Thinking Approach

¹ Hendra Puspita

Affiliations:

¹SD Negeri Kamijoro, Purworejo, Indonesia

*Correspondence: hendrapuspita30@gmail.com

ABSTRACT

The integration of computational thinking (CT) into primary education has expanded rapidly, yet its application in non-STEM domains remains limited. This study investigates how unplugged coding can be embedded within elementary physical education (PE) through an embodied learning approach. Using a qualitative case study design, data were collected through an in-depth interview with a PE teacher who implemented unplugged coding after completing a four-month professional training program. Findings reveal that CT principles—particularly sequencing and algorithmic thinking—can be effectively translated into movement-based instruction. The teacher operationalized coding as structured movement sequences, supported by visual mapping, collaborative learning, and field-based practice. Students demonstrated increased engagement, improved conceptual understanding of motor sequences, and heightened motivation. The study contributes to interdisciplinary pedagogy by proposing an “embodied computational thinking” model that integrates cognitive and kinesthetic learning. The findings have implications for curriculum innovation, teacher professional development, and equitable access to CT education without reliance on digital technologies.

Keywords

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Introduction

Computational thinking (CT) has been widely recognized as a foundational competency for the 21st century, extending beyond computer science into general education [1], [2]. CT encompasses a set of cognitive processes, including decomposition, pattern recognition, abstraction, and algorithmic thinking, which enable individuals to solve problems systematically [3]. While CT integration has been extensively explored in STEM disciplines, its application in non-STEM contexts, particularly physical education (PE), remains underdeveloped.

Recent educational discourse emphasizes the need for interdisciplinary approaches that bridge cognitive and physical domains of learning [4], [5]. Physical education, traditionally centered on motor skills and physical fitness, offers untapped potential for integrating higher-order thinking skills. Emerging perspectives in embodied cognition suggest that learning is deeply rooted in bodily experiences, where cognition is shaped through physical interaction with the environment [6]. This perspective provides a theoretical basis for embedding CT into movement-based activities.

One promising approach is unplugged coding, which introduces computational concepts without digital devices. Unplugged activities emphasize tangible, interactive experiences, making them particularly suitable for elementary education [7]. By focusing on fundamental principles such as sequencing and logical ordering, unplugged coding enables learners to grasp computational concepts in accessible ways.

Despite its potential, research on unplugged coding has largely focused on classroom-based subjects such as mathematics and science [8], [9]. There is limited empirical evidence on how unplugged coding can be integrated into PE, where learning is inherently kinesthetic.

This study addresses this gap by examining an instructional innovation in which unplugged coding is embedded into elementary PE. Specifically, it explores how a teacher conceptualizes coding as movement sequencing and how this approach influences student engagement and learning.

The study is guided by the following research questions:

1. How can computational thinking be operationalized in physical education through unplugged coding?
2. What pedagogical strategies support the integration of coding into movement-based learning?
3. How does this approach influence student engagement and understanding?

By situating the study at the intersection of CT, embodied cognition, and constructivist pedagogy, this research contributes to expanding the scope of interdisciplinary education.

Theoretical Framework

A. Computational Thinking as a Cross-Disciplinary Competence

Computational thinking (CT) has progressively evolved from a domain-specific concept rooted in computer science into a universal problem-solving framework applicable across multiple disciplines [1], [10]. Rather than being limited to programming, CT is now understood as a set of cognitive processes, including decomposition, pattern recognition, abstraction, and algorithmic thinking, which support structured reasoning and decision-making [3]. Contemporary educational frameworks position CT as a foundational literacy comparable to reading and numeracy, emphasizing its relevance in diverse learning contexts such as science, mathematics, social studies, and even the arts. This shift reflects a broader pedagogical movement toward integrating higher-order thinking skills across the curriculum. In primary education, CT provides opportunities to develop logical reasoning through age-appropriate and contextually meaningful activities. As a result, CT is increasingly framed not as a technical skill set, but as a transferable cognitive competence that can enrich interdisciplinary learning experiences and prepare students for complex, real-world problem solving.

B. Embodied Cognition in Learning

Embodied cognition theory posits that knowledge is constructed through the dynamic interaction between the body and the environment, challenging traditional views that separate mind and body in the learning process [6]. From this perspective, cognition is not solely an internal mental activity but is deeply influenced by physical experiences and sensory engagement. In the context of physical education (PE), this framework suggests that cognitive processes such as sequencing, coordination, and decision-making can be meaningfully embedded within movement-based activities. For example, learning a sequence of motor actions requires students to engage in planning, prediction, and adaptation, all of which are core components of cognitive processing. Empirical studies have shown that physical activity can enhance executive functions, memory, and attention, reinforcing the connection between movement and cognition [11]. Therefore, integrating computational thinking into PE through embodied activities provides a powerful approach to unify physical and cognitive development in a holistic learning environment.

C. Constructivist and Experiential Learning

Constructivist learning theory emphasizes that knowledge is actively constructed by learners through interaction with their environment and through social engagement with others [12]. Rather than passively receiving information, students build understanding by connecting new experiences with prior knowledge. This perspective is closely aligned with experiential learning

theory, which highlights the importance of learning through direct experience, reflection, and application [13]. In the context of this study, instructional strategies such as group collaboration, visual mapping, and physical practice reflect these theoretical principles. Students first engage in conceptual tasks, such as organizing movement sequences, before applying their understanding through physical execution. This progression mirrors experiential learning cycles, where abstract conceptualization is followed by active experimentation. Additionally, collaborative activities promote social interaction, enabling learners to negotiate meaning and refine their understanding collectively. Such approaches not only enhance cognitive engagement but also support deeper, more meaningful learning outcomes in interdisciplinary educational settings.

D. Unplugged Coding as Inclusive Pedagogy

Unplugged coding represents an inclusive pedagogical approach that enables the integration of computational thinking without reliance on digital technologies [7]. By focusing on core computational concepts such as sequencing, logic, and problem-solving, unplugged activities make coding accessible to a broader range of learners, particularly in contexts with limited technological infrastructure [14]. This approach is especially relevant in elementary education, where hands-on and interactive learning experiences are essential for conceptual understanding. Unplugged coding also supports equity in education by reducing the digital divide and allowing all students to participate regardless of access to devices or internet connectivity. Furthermore, it provides teachers with flexibility to embed computational thinking into various subjects, including physical education, without requiring advanced technical skills. As a result, unplugged coding not only democratizes access to computational learning but also fosters creativity and innovation in teaching practices, making it a valuable strategy for interdisciplinary and inclusive education.

Methods

A. Research Design

This study employs a qualitative case study design to examine an instructional innovation in depth within its natural setting. A case study approach is particularly suitable for investigating complex educational practices, as it allows for a holistic understanding of processes, interactions, and contextual factors influencing implementation [15]. By focusing on a single case, the research captures detailed insights into how unplugged coding is conceptualized and applied in physical education. This design enables the exploration of both pedagogical strategies and participant experiences, providing rich, contextualized data that contribute to a nuanced understanding of interdisciplinary teaching practices.

Table 1. Learning Stages in the Embodied Computational Thinking Approach

Phase	Learning Activity	Pedagogical Basis	Student Role	Teacher Role
Conceptual Introduction	Explanation of movement sequences	Constructivism	Listen, observe	Provide explanation and examples
Representation	Matching images with numbered steps	Cognitive theory & abstraction	Analyze and match	Facilitate and guide
Collaboration	Group sequencing tasks	Social constructivism	Discuss and collaborate	Monitor group interaction
Individual Practice	Individual sequencing and reasoning	Experiential learning	Demonstrate understanding	Provide feedback
Embodied Practice	Performing movements in field	Embodied cognition	Execute movements	Observe and correct
Reflection	Reviewing correctness and process	Metacognition	Reflect on learning	Guide reflection

B. Participant and Context

The participant in this study is an elementary physical education teacher in Indonesia with formal academic training in physical education and a master's degree in education. The teacher is responsible for teaching all grade levels from Grades 1 to 6, providing a broad instructional context. The implementation of unplugged coding emerged after the teacher participated in a four-month professional development program organized by the local education authority. This training introduced computational thinking concepts and practical strategies for classroom integration. The school context reflects a typical public elementary setting, making the innovation relevant and transferable to similar educational environments.

C. Data Collection

Data were collected through a semi-structured interview designed to capture in-depth information about the instructional innovation. The interview focused on several key aspects, including the design of learning activities, the process of implementing unplugged coding in physical education, student responses to the approach, and the assessment strategies used by the teacher. This flexible format allowed the researcher to explore emerging insights while maintaining alignment with the research objectives. The interview was recorded and transcribed to ensure accuracy and completeness, providing a rich source of qualitative data for analysis and interpretation.

D. Data Analysis

The collected data were analyzed using thematic analysis, a method that allows for the systematic identification and interpretation of patterns within qualitative data[16]. The analysis began with data familiarization, followed by coding significant statements related to the research

focus. These codes were then grouped into broader categories, resulting in four major themes: coding as movement sequencing, structured instructional design, student engagement and motivation, and authentic assessment practices [17]. This analytical approach enabled the researcher to organize complex data into meaningful constructs, facilitating a deeper understanding of how computational thinking is integrated into physical education.

Results and Discussion

A. Operationalizing Computational Thinking through Movement Sequencing

In this study, computational thinking is operationalized through the concept of movement sequencing, where coding is redefined as arranging actions in a logical order. This approach transforms abstract computational principles into concrete physical activities, aligning with algorithmic thinking processes [3]. For instance, in teaching the long jump, the movement is divided into sequential phases, including preparation, approach run, take-off, flight, and landing. Each phase represents a structured step in a movement algorithm. This model reflects embodied computational thinking, where students physically enact algorithms through movement. Such an approach demonstrates that computational thinking can be experienced kinesthetically, extending beyond traditional digital environments.

Table 2. Example of Movement Algorithm (Long Jump)

Step Number	Movement Phase	Description	Coding Representation
1	Preparation	Initial stance and focus	Start position
2	Approach Run	Running towards take-off board	Forward movement
3	Take-off	Jumping from board	Upward force
4	Flight	Body movement in air	Controlled motion
5	Landing	Landing on sand	Stable finish

B. Instructional Design: From Representation to Embodiment

The instructional design in this study follows a structured progression that bridges cognitive understanding and physical application. Initially, movement sequences are visually represented using numbered illustrations, forming a simplified algorithm that students can interpret. Students then engage in collaborative activities, working in groups to organize and discuss the correct sequence, which reflects principles of social constructivism [12]. Following this, cognitive verification occurs as students match visual representations with logical sequences, reinforcing conceptual understanding. Finally, students perform the movements in real contexts, translating their cognitive knowledge into physical action. This process reflects experiential learning cycles, where learners move from abstract conceptualization to active experimentation [13]. This integrated approach not only strengthens students' procedural understanding but also enhances engagement, cooperation, and kinesthetic learning experiences during the instructional process.

Table 3. Unplugged Coding Integration Process in Physical Education

Stage	Instructional Activity	Computational Thinking Element	Description	Learning Outcome
1	Movement Decomposition	Decomposition	Teacher breaks down physical movements (e.g., long jump) into smaller steps	Students understand components of a movement
2	Sequence Structuring	Algorithmic Thinking	Steps are ordered numerically (e.g., 1-5)	Students recognize logical order
3	Visual Mapping	Abstraction	Movements are represented through drawings and symbols	Students connect abstract representations with real actions
4	Group Arrangement	Pattern Recognition	Students collaboratively arrange sequences	Students identify patterns and correct errors
5	Verification	Debugging	Students check correctness of sequence	Students refine logical thinking
6	Physical Execution	Algorithm Implementation	Students perform movements based on sequences	Students apply cognitive understanding to physical practice

C. Student Engagement and Motivation

The integration of unplugged coding into physical education significantly enhances student engagement and motivation. The novelty of combining coding concepts with physical activity creates a stimulating learning environment that captures students' interest. Visual aids and collaborative tasks encourage active participation, making the learning process more dynamic and interactive. This increased engagement aligns with self-determination theory, which emphasizes the importance of autonomy, competence, and social interaction in fostering motivation [18]. Group-based activities promote a sense of relatedness among students, while successfully completing sequencing tasks strengthens their sense of competence. As a result, students become more enthusiastic and actively involved in both cognitive and physical aspects of learning.

D. Learning Outcomes: Understanding over Performance

The findings indicate a shift in learning outcomes from purely physical performance toward conceptual understanding of movement. Instead of emphasizing technical mastery, the instructional approach prioritizes students' ability to comprehend and organize movement sequences logically. Students are evaluated based on their capacity to correctly order actions and demonstrate an understanding of the underlying structure of movement. This reflects a process-oriented approach to learning, where understanding takes precedence over perfection. Such an approach aligns with formative assessment principles, which focus on continuous learning and improvement rather than final performance outcomes [19]. Consequently, students develop both cognitive and physical competencies in an integrated manner.

E. Authentic Assessment and Pedagogical Alignment

Assessment in this study is conducted through observational rubrics that capture students' performance in real learning contexts. This approach reflects authentic assessment practices, where learners demonstrate competencies through meaningful tasks rather than standardized tests [20]. The criteria include sequencing accuracy, participation, and the ability to apply movement logically. This form of assessment aligns closely with the instructional approach, ensuring coherence between teaching, learning, and evaluation. Furthermore, integrating computational thinking into physical education supports broader curriculum goals related to 21st-century skills, including critical thinking, problem-solving, and collaboration [21]. This alignment strengthens the pedagogical relevance of the innovation.

Table 4. Assessment Rubric for Unplugged Coding in Physical Education

Criteria	Indicator	Level 1 (Low)	Level 2 (Moderate)	Level 3 (Good)	Level 4 (Excellent)
Sequencing Accuracy	Ability to order movements correctly	Incorrect sequence	Partially correct	Mostly correct	Fully correct
Conceptual Understanding	Understanding of movement logic	No understanding	Limited understanding	Clear understanding	Deep understanding
Time Efficiency	Speed in completing task	Very slow	Slow	Adequate	Efficient
Collaboration	Participation in group work	Passive	Limited participation	Active	Highly collaborative
Physical Application	Ability to perform sequence	Unable to perform	Performs partially	Performs adequately	Performs fluently
Engagement	Motivation and participation	Disengaged	Slightly engaged	Engaged	Highly enthusiastic

F. Implications for Interdisciplinary Education

The findings of this study highlight significant implications for interdisciplinary education by demonstrating how computational thinking can be integrated into non-STEM subjects such as physical education. By simplifying coding as sequencing, the approach makes abstract concepts accessible to young learners [14]. The use of embodied learning strategies allows students to experience computational processes through physical activity, creating a more holistic learning experience. Additionally, the reliance on unplugged methods ensures that the approach remains feasible in low-resource contexts. This study proposes a shift from technology-centered coding toward concept-centered computational thinking, expanding opportunities for integration across disciplines and promoting more inclusive and innovative educational practices [22]. Furthermore, the findings suggest that integrating computational thinking into physical

education can foster creativity, problem-solving skills, and active participation, while simultaneously reducing students' anxiety toward learning coding-related concepts.

Conclusion

This study demonstrates that unplugged coding can be effectively integrated into elementary physical education through an embodied computational thinking approach that connects cognitive processes with physical activity. By redefining coding as movement sequencing, teachers are able to bridge abstract computational concepts with concrete motor skills, enabling students to experience algorithms through bodily movement. The findings indicate that computational thinking is not confined to computer science but is transferable across disciplines, including physical education. Moreover, the integration of sequencing tasks into movement-based learning supports the development of cognitive skills such as logical reasoning and problem-solving. The unplugged nature of the approach also enhances accessibility, allowing all students to participate regardless of technological resources, while increasing engagement through interactive and collaborative activities. Future research should investigate the scalability of this model, examine its impact on diverse student populations, and explore its alignment with broader curriculum frameworks and educational policies.

Conflict of Interest

The authors declare no conflict of interest.

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Authors



Hendra Puspita, S.Pd. M.Pd. is a physical education teacher at SD Negeri Kamijoro, Purworejo, Indonesia. He holds a Bachelor's degree in Physical Education, Health, and Recreation and a Master's degree in Education from Universitas Negeri Yogyakarta. He teaches Grades 1–6 and focuses on innovative, student-centered learning. His interests include physical education pedagogy, computational thinking, and interdisciplinary learning. (email: hendrapuspita30@gmail.com).