Computational Thinking through Cooperative Games in Elementary

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Abstract. *This study explores an unplugged approach to teaching computational thinking (CT) by integrating cooperative games into physical education. Addressing gaps in interdisciplinarity between CT and Physical Education and replicability, the intervention introduced sequencing and single repetition steps to fourth- and fifth-grade students in a Brazilian public school. Led by a trained teacher, the study used semi-structured field notes, teacher remarks, and assessments to evaluate engagement and learning. Results showed that embodied activities fostered collaboration and CT understanding, though challenges like group coordination and distractions affected outcomes. The study presents a replicable model for interdisciplinary CT learning in resource-limited settings.*

1. Introduction

The growing demand for computational thinking (CT) skills has led many countries to integrate computer science into early education. In Brazil, digital inequality limits access to technology, making unplugged computing a key approach to teaching CT through physical activities. This method aligns with Henri Wallon's framework that emphasizes the interwoven nature of affective, motor, and cognitive dimensions in child development [Van der Veer 1996]. Cooperative games, widely used in physical education, naturally support these principles.

The unplugged computing literature has presented various dynamic and creative contributions. Regarding physical activities, some studies have focused on creating engaging debugging experiences in physical computing [Zeng 2024]. Others challenged students to analyze gymnastics routines to simulate algorithm creation [Chen and Jacques 2024]. However, this literature neither connected CT and Physical Education in an interdisciplinary way nor used cooperative games.

Considering these limitations, this exploratory study elaborated and evaluated an unplugged intervention that incorporates computational thinking, sequencing, and single repetition principles into the physical education curriculum using cooperative games. A trained teacher conducted the intervention with two fourth-grade and two fifth-grade classes in a public school. We analyzed students' engagement and learning outcomes using qualitative and quantitative data from researcher observations, an assessment, and teacher remarks. Thus, this work proposes the following research question:

Can cooperative game learning activities, integrated into the physical education curriculum and facilitated by a trained teacher, enhance children's understanding of sequence and single repetition steps?

This work is organized as follows: In Section 2, we outline related works. We discuss the school context and the pedagogical framework in Section 3 while presenting our method in Section 4. We present and discuss the learning activities' results in Sections 5 and 6, respectively. In Sections 7, we examine threats to the validity of these results while concluding this work in Section 8.

2. Related Works

This study focuses on research exploring unplugged approaches for teaching CT in early elementary education, particularly those incorporating body movement. For a broader discussion of unplugged computational thinking approaches, see [Grebogy et al. 2024].

Many studies have combined physical activities with CT in fully unplugged approaches, using structured dance to teach sequencing to children aged 7 to 9 [Fairlie 2023]. Other investigations have focused on creating engaging debugging experiences in physical computing [Zeng 2024], examining gestures used by students acting as algorithm debuggers [Litts et al. 2019], or exploring the physical enactment of algorithmic instructions [Manches et al. 2020]. However, these studies do not foster interdisciplinary connections between CT and physical education.

Other parts of the literature have explored the interdisciplinary. Some studies have described interventions that analyze data from wearable microcontrollers during physical activities to develop problem-solving skills [Jeong et al. 2022]. However, they often require technical training, limiting accessibility for teachers. In a more accessible approach, specific works challenged undergraduate students to analyze gymnastics routines to simulate algorithm creation [Chen and Jacques 2024]. Other studies presented activities (e.g., imitation, repetition, algorithm building) based on physical exercises [Magalhães 2021] or examined the engagement potential of embodied computation acting as machines [Munasinghe et al. 2023].

Our work differs from previous studies in some aspects, including target age groups, teacher involvement, and CT topics addressed. Specifically, we developed an unplugged intervention focused on sequencing and repetition concepts. It was designed for seamless integration into the fourth and fifth-grade physical education curriculum, ensuring accessibility for teachers.

3. Background

3.1. School Context and Challenges

We conducted this study at a public elementary school in São Paulo, Brazil, serving approximately 215 children in the early years of education. The school has twelve teachers, none with specific training in computational thinking. Moreover, it faces significant technological barriers, including limited access to computers and digital resources.

The school follows the São Paulo Curriculum (SPC), an educational framework aligned with Brazil's BNCC, which emphasizes critical thinking, interdisciplinarity, and socio-emotional skills as foundational [SEDUC-SP 2019]. Regarding the Physical Education curriculum, the SPC emphasizes movement exploration and body awareness through gymnastics, dance, and traditional games. This flexibility creates opportunities to design interventions that promote interdisciplinary collaboration between physical education, CT, and other subjects.

3.2. Pedagogical Rationale

The analytical skills developed through computational thinking (CT) enhance learning across various disciplines, showcasing its versatile application [Wing and Stanzione 2016]. Acknowledging this interconnectedness, we have integrated CT into the Physical Education curriculum outlined in the SPC.

To achieve this integration, we adopted a cooperative games approach. Cooperative games emphasize collaborative problem-solving and inclusive participation by eliminating competition, hierarchical structures, and exclusionary mechanics [Dyson and Casey 2016]. This approach aligns with socio-emotional learning principles and Henri Wallon's framework that states that the interconnectedness of emotions and physical activities enables children to connect to abstract concepts, making learning more meaningful [Van der Veer 1996].

4. Method

4.1. Teacher Preparation for Cooperative Game Intervention

The preparation focused on equipping the teacher with CT knowledge to ensure the effective execution of activities. This process began with an introductory meeting involving the teacher, the school's pedagogical coordinator, and the principal, where we presented our intervention's objectives and the Informed Consent Form (ICF) signed by the teacher, confirming her voluntary participation. A second meeting gathered details about the school context, student profiles, and the teacher's planning.

Three training sessions followed based on the second intervention content. The first, a three-hour session, introduced key CT concepts using practical examples and interdisciplinary connections. The second and third sessions, each lasting 45 minutes, included simulations of our cooperative game activities, where the teacher practiced them with other teachers acting as students. These sessions emphasized her role as a facilitator, guiding students rather than providing direct answers. The teacher received detailed materials, including examples of salutations and samples of instruction cards. Despite initial uncertainty about CT, the educator gained confidence and enthusiasm after the training.

4.2. Pedagogical Intervention Design

We designed the intervention considering the school's context (Section 3.1) and the preparation (Section 4.1). The "Robot Arena" activity focuses on a few rules and collaboration, building a foundation for sequencing and repetition (Table 1). The "Cosmic Salute" encourages students to explore and express these concepts more creatively (Table 2).

The "Robot Arena" activity starts with a *warm-up moment* using slow diaphragmatic breathing to promote mindfulness and relaxation by activating the parasympathetic nervous system. This process helps students shift their attention to the class. The teacher should maintain a calm tone and a peaceful environment to support cognitive readiness.

Grade (SPC Competency):	4^{th} grade ($EF04EF01$) · 5^{th} grade ($EF05EF04$)
Material:	Chalk or Adhesive Tape (e.g., Crepe Tape), nine 10cm X 10cm cardboard instruction cards containing a physical movement, a mime, or a simple exercise with the respective number of repetitions in the following format: "perform *x* for *n* times" or "do *x*".
Location:	Athletic court or other outdoor area suitable for movement.
Preparations:	At the location chosen for the activity, the teacher should lay out three (or more) non-linear, independent trails with right-angled curves over 10 steps long, as exemplified in supplementary materials. The teacher also must distribute three instruction cards to each team.
Minimum duration:	45 minutes
Moments (Estimated Time):	Warm-up (5 min.) → Orientation (10 min.) → Execution (20 min.) → Sharing (10 min.)

Table 1. "Robot Arena" Intervention

In the *orientation moment*, the teacher explains the rules of the robot game. Students form a line, with the first student acting as the blindfolded "robot" and moving one step at a time based on commands from the "programmers" behind them. Incorrect moves send the robot to the end of the line, and the next student becomes the robot. When robots land on instruction cards along the trail, they must perform the "programmers" indicated actions, such as "jump on one leg three times." Every time a robot reaches the finish line, the next student in the line assumes this role.

During the *execution moment*, the teacher divides students into groups (up to seven members) and assigns each to a track. The blindfolded "robot" begins at the starting point, while the "programmers" place instruction cards along the track. Once everything is set, the game starts with "programmers" giving commands step by step, pausing to interpret the instruction cards when robots land on them. This process continues until all students have taken both roles. If challenges emerge, the teacher encourages everyone to reflect on the situation.

In the *sharing moment*, the teacher guides students' reflections with questions such as "$Q1$ - How did the robot feel?", "$Q2$ - What happens if a command is changed?", "$Q3$ - What happens if the robot receives no command?" By addressing students' answers, the teacher can connect the activity to how robots, computers, and cell phones execute commands. For instance, in response to question $Q3$, the teacher might explain, "This could be a mistake in the sequence, just like when a cellular app crashes or game characters do not move correctly."

Grade (SPC Competency):	4^{th} grade ($EF04EF07$) · 5^{th} grade ($EF05EF07$)
Material:	One sheet of A4 paper and one self-adhesive notepad per group.
Location:	Athletic court or other outdoor area suitable for movement.
Minimum duration:	45 minutes
Moments (Estimated Time):	Warm-up (5 min.) → Orientation (5 min.) → Exploration (15 min.) → Execution (20 min.) → Sharing (10 min.)

Table 2. "Cosmic Greeting" Intervention

The "Cosmic Greeting" *warm-up moment* employs the same method as the previous activity to help students concentrate on the class. Next, during the *orientation moment*, the teacher captures the students' attention by performing a random dance of 10 to 15 steps, including at least one repeated movement. To engage the students further, the teacher asks questions such as, "What did I just do? Was it a dance?" and "Did you notice the movements? Does a dance follow a sequence of steps, similar to guiding a robot?"

Once the students share their responses, the educator explains that the dance represents an Earthling greeting to aliens. The teacher then challenges students to recall and repeat the movements. If necessary, the greeting is performed again for clarity. To deepen students' understanding, the teacher asks "Did you notice any part of my greeting that repeats? How do you know it is the same?". After gathering the children's perceptions on these questions, the teacher introduces the learning activity. Working in groups of up to seven, students will create and perform a short dance representing their greeting to the inhabitants of other planets.

In the *exploration moment*, the teacher guides each group in creating a cooperative greeting for other planets, emphasizing time limits, a minimum of ten movements, and ensuring everyone's contribution. To help explore and visualize the greeting steps, the teacher provides self-adhesive notes to each group to write and arrange their greeting steps on paper.

During the *execution moment*, each group presents its greeting. Before the first presentation begins, the teacher instructs the students to observe their colleagues' movements and patterns. Once all the presentations are completed, the teacher concludes the session with a collective appreciation, highlighting the learning outcomes.

In the *sharing moment*, the teacher captures students' reflections with questions such as: "$Q4$ - Can you recall the steps followed by the group from the planet 'a'?", "$Q5$ - What happens if a step in your greeting is changed?", "$Q6$ - How did you recognize the teacher's or your classmates' greeting?". Students' responses allow the teacher to connect the "Cosmic Greeting" and "Robot Arena" learnings. For example, in response to $Q5$, the teacher might explain, "The steps in the greeting are like robot instructions; changing the order leads to a different outcome, just like in Robot Arena." Similarly, for $Q6$, the teacher could highlight, "Just as you recognized unique moves in greetings, in Robot Arena, we understand a robot's actions by watching its steps. A wrong sequence can lead to mistakes, just like a misstep in a greeting."

4.3. Data Collection Framework

We employed an ethical, non-intrusive approach to assess student engagement, collaboration, and learning outcomes. Our data collection approach combined qualitative and quantitative data from three sources: the *teacher's remarks*, an *assessment activity*, and the *researcher's field notes*. The use of images and video was not permitted.

The teacher's remarks were brief post-class observations on students' behavior and classroom dynamics. One week after the intervention, the assessment activity asked students to visually map a path through a forest (Qb) and describe how to plant a tree (Qa), assessing their retention of sequence and repetition steps. The researcher's field notes documented classroom events using a semistructured observation method. This method combines structured tracking of pre-established events with unstructured notes on unexpected behaviors and emotional responses [Cohen et al. 2002].

We conducted observation sessions during a 45-minute class involving two fourth- and two fifth-grade classes, with the lead researcher acting as a detached observer to minimize interference. For the structured approach, we used a table sheet with a 5-minute division and predefined markers (Table 3) to track engagement patterns, participation, and application of learned concepts. For unstructured observations, we wrote down un-

Code	Behaviour	Evidence
AT	Exhibit attentiveness	Demonstrates more concentrated behavior and sustained focus on the teacher's or fellows presentation
PA	Participation	Engagement in discussions with colleagues or the teacher, either focusing on aspects of the learning activity or inspired by it
CL	Collaboration	Demonstrates active participation with group members, adapts effectively to group work, and cooperates willingly with the teacher as a volunteer
CO	Comprehension	Performs the sequence fluidly, avoiding unnecessary pauses or confusion. Show comprehension by predicting the next step in a recurring pattern
RP	Pattern Recognition	Verbal comments, repetition of body movements, and gestures related to pattern recognition
$D1$	Algorithmic Challenge	Demonstrates gestures of confusion, expressions of frustration, hesitant movements, or prolonged gazes toward colleagues or teachers throughout the intervention
$D2$	Disengagement	Exhibits distraction by engaging in side conversations or playing with friends, resulting in reduced participation in the learning activity
$D3$	Collaboration and Communication Difficulties	Exhibits isolation, centralization, and interpersonal conflicts
$D4$	Activity Misunderstanding	Repeatedly asking the teacher or a classmate questions or engaging in procrastination

Table 3. Strucutured Observations Codes

expected events (e.g., inventing commands, expressing movements) and indicated transitions between the intervention's moments in a notebook. After each class, we conducted an expanded observational analysis. Notably, we used the transition annotations to adjust the 5-minute intervals, enabling a more precise depiction of the temporal structure of the intervention moments in Figure 1.

We planned the learning activities to be used sequentially by fourth- and fifth-grade classes, starting with the "Robot Arena". However, due to time constraints, the "Robot Arena" took place in two fourth-grade classes: one with 22 students (12 girls and 10 boys) and the other with 19 students (9 girls and 10 boys). The "Cosmic Salutation" was carried out in two fifth-grade classes, which included 20 students (11 girls and 9 boys) in one class and 16 students (8 girls and 8 boys) in the other.

4.4. Data Analysis Procedures

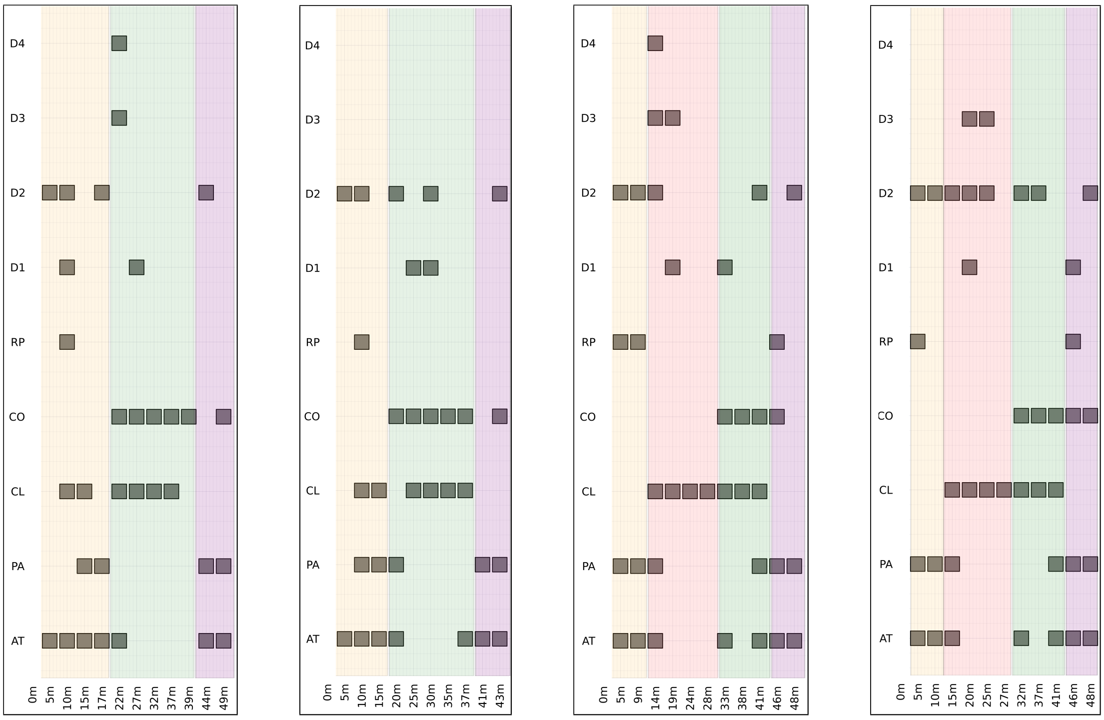
We conducted the data analysis in three stages. First, we organized and digitized the data (field notes, teacher remarks, and assessment results) for processing in a qualitative tool. Second, we refined unstructured observations and applied thematic coding [Saldaña 2013] to identify participation and engagement patterns. Moreover, we used pattern coding [Saldaña 2013] to analyze students' evaluation responses into categories such as successes and errors (e.g., omissions, reversed order). Finally, we created visualizations using the Julia programming language to highlight events over time and support triangulation by integrating teacher comments and student responses.

5. Results

Figure 1 presents the structured observations collected over time for all classes. Each scatter plot indicates a time division on the x-axis, with observation markers on the y-axis, as described in Section 4.3. The colored areas highlight the duration of each intervention moment (Tables 1 and 2), starting with pastel blue for "warm-Up" and concluding with pastel purple for "sharing". We discuss the results below for each intervention moment to facilitate the examination of engagement and learning dynamics.

In the "Robot Arena" activity (*4-T1* and *4-T2* in Figure 1), the teacher skipped the *warm-up* and began directly with the *orientation moment* (denoted as yellow). She introduced the activity's goal by demonstrating the game's rules with volunteers (CL), emphasizing sequencing and repetition for clarity (RP). We observed that this hands-on approach engaged and sparked children's interest through questions and active participation with the instruction cards ($AT, PA, D1$), creating a positive atmosphere for the activity.

After the explanations, the teacher started the *execution moment* (green area), dividing the students into three teams, each assigned to a trail on the school court. Within the first ten minutes, the teams organized themselves and planned their strategies (CL). One group in *4-T1* initially attempted to manually guide their robot to the endpoint, bypassing the use of commands ($D4$). Notably, neighboring teams quickly intervened to help correct the deviation and reinforce the intended process (CL). Additionally, in *4-T1*, one student tried to control all the robots ($D3$), limiting the participation of others. The teacher promptly intervened, restoring the collaborative nature of the game.



(a) $4-T1$ **(b)** $4-T2$ **(c)** $5-T1$ **(d)** $5-T2$

Figure 1. Behaviour and moments transition during learning activities

During the *sharing moment* (denoted as purple), the teacher gathered the students in a semi-circle for a reflective discussion, guided by our proposed questions (Section 4.2). Many children spontaneously shared their perceptions and feelings (PA), offering valuable insights into their engagement. For example, a unanimous response of "he does not move!" to $Q4$ showcased their practical understanding of the consequences of the absence of commands (CO). The teacher, in her remarks, underlined that this lesson was notably more participative than usual, emphasizing the effectiveness of the activity.

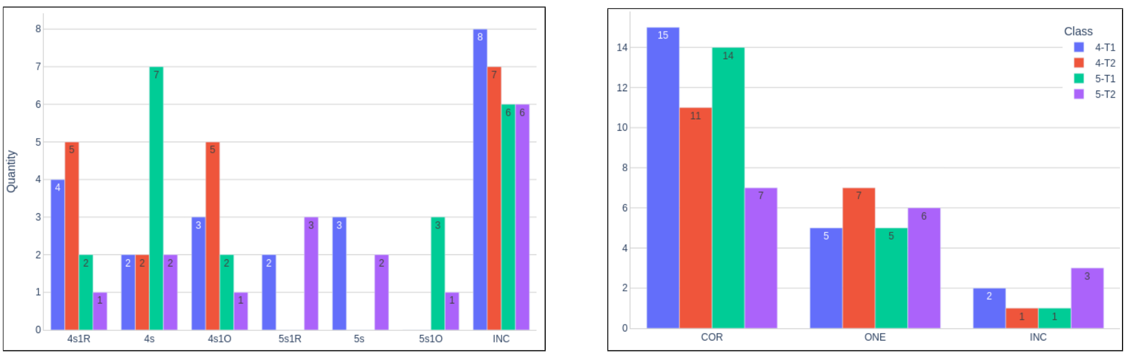
Shifting to the "Cosmic Greeting" activity (*5-T1* and *5-T2* in Figure 1), the teacher skipped (again) the *warm-up* and moved directly into the *orientation moment* (denoted as yellow). She captured the class's attention with twelve disconnected body movements (that provoked joy among students), followed by the activity explanation. The teacher repeated their greeting and encouraged them to identify patterns in her salutation, turning the demonstration into an engaging and playful challenge.

Most students actively replicated the teacher's salute movements (RP), expressing them through body movements and verbal explanations in the correct sequence, while a few pupils stood passively. At the conclusion, the teacher clarified the activity's objective, which the children followed attentively (AT), demonstrating interest by asking questions (PA). We detected that the greeting activity was especially appealing to the girls, an observation corroborated by the teacher's remarks: "Today's activity, resembling a dance, was particularly appreciated by the girls."

During the *exploration moment* (denoted as red), the teacher divided the children into four groups, each forming a large circle. The first five minutes involved intensive team negotiations (CL) and teacher-student interactions to establish the greeting steps (PA, AT), though some students were dispersed ($D2$). Most teams engaged in active collaboration (CL), with members inventing or imitating each other's body movements. However, in each class, one team faced difficulties cooperating ($D3$), despite the teacher's efforts to facilitate engagement.

After completing the greetings, the teacher initiated the *execution moment* (denoted as green) by arranging the order of group presentations. Most groups performed approximately twenty movements each, with two groups ($5 - T1$) formed by girl members delivering a more intricate greeting. Although some minor imperfections were observed, attributed to limited training time, the students displayed a strong commitment to their roles (PA, CL) and effectively applied the sequencing and repetition steps concepts (CO). Nevertheless, groups that faced collaboration challenges produced less cohesive performances with some repetition step mistakes ($D1$).

During the *sharing moment* (denoted as purple), the teacher posed all the questions outlined in this study. Seated in a semi-circle, many children eagerly raised their hands to share their thoughts about the activity (PA), while others listened attentively (AT). Exemplifying these thoughts, when answering $Q4$, most children accurately recalled three or four steps from the groups highlighted by the teacher (RP). However, some in class $5 - T2$ reversed the sequence of the two groups ($D1$). For $Q6$, some students mentioned focusing carefully or "keeping everything in the head." In contrast, others admitted struggling with the task due to difficulty remembering all the steps.



(a) Qa **(b)** Qb

Figure 2. Categorization of Responses to the Assessment Activity

Turning our attention to the assessment activity, Figure 2 highlights a notable contrast between children's ability to express a sequence and repetition of steps visually (Qb) versus in written form (Qa). Nearly 90% of visual responses accurately depicted complete sequences ($Qb-COR$) or sequences with a single step omitted ($Qb-ONE$). In contrast, the remaining visual responses comprised paths with the wrong destination (Qb - INC). On the other hand, written responses showed a higher proportion of errors, with 35% classified as incomplete or completely wrong (Qa - INC). Nevertheless, written answers revealed a greater conceptual depth of the students: 24% included four or five sequential steps ($4s$ and $5s$), 22% incorporated a repetition step ($4s1R$ and $5s1R$) in their answer, while the remaining forgot one step ($4s1O$ and $5s1O$). These findings indicate that while visual representation aided comprehension, written responses provided deeper insights into the children's ability to apply concepts in a structured and nuanced manner.

6. Discussion

The results confirm that the intervention fostered active participation, joy, and cooperation among children, gradually engaging even those initially less focused. Aligned with Vygotsky's perspective [Vygotsky 2004], the cooperative game encouraged imaginative play and internalization of learned behaviors. Additionally, the games and intervention form promoted the development of social skills, particularly communication and collaboration, corroborating previous studies [Dyson and Casey 2016]. For instance, nearly all the children voluntarily shared their perceptions and feelings at the end of the learning activities, a recurring positive note in the teacher's report.

Regarding learning, our outcomes indicate that most children successfully demonstrated their understanding of repetition and sequencing concepts during the intervention and the assessment, integrating them fluidly into their actions and decisions. Although we observed some initial mistakes, they quickly adapted alone or with their colleagues' assistance, reinforcing the collaboration development. These findings underscore the potential of integrating computational thinking through embodied approaches [Litts et al. 2019, Manches et al. 2020, Munasinghe et al. 2023].

During our intervention, several examples highlighted the integration of concepts. One example comes from responses to $\mathcal{Q}6$, where children demonstrated an understanding of how movement sequences could be internalized. Like athletes and dancers who break down routines into manageable steps for recall and execution, the students showed a cognitive connection between movement and logical structure. Similarly, responses to $\mathcal{Q}2$ emphasized an essential principle of computational thinking: structured sequences govern movement. The children linked the robot's behavior to an algorithmic process, demonstrating their ability to recognize structured movement principles already embedded in their physical education curriculum.

Despite the positive results, two significant issues emerged from our expanded observations. The first is the presence of distractions ($D2$), particularly at the start of activities (Figure 1, orange and green areas). Although distractions decreased during gameplay, their initial impact disrupted the flow of activities and hindered the students' understanding of the games ($D4$). Notably, class $5-T2$ suffered the most severe distraction levels, manifesting in a concerning rate of assessment mistakes: 18.7% for question Qa and 37.5% for Qb. This outcome indicates a negative impact on learning. Moreover, the decision to skip the warm-up may have contributed to the situation, increasing time spent managing disruptions ($D2$). This situation highlights the essential role of warm-ups in regulating children's arousal and readiness for class. Research has shown that even a brief five-minute warm-up can be highly effective [Bentley et al. 2022].

We also observed limited collaboration among the $5 - T1$ and $5 - T2$ student groups. This lack of teamwork resulted in some of them producing less developed or incomplete work. The emphasis on individual activities and the inconsistent use of collaborative ones at the school may have contributed to this issue. Vygotsky stresses that social interaction is crucial for learning, as it aids students in progressing within their Zone of Proximal Development [Vygotsky 2004]. Additionally, Wallon underscores that consistent practices are essential for developing social and emotional skills [Van der Veer 1996].

Finally, this work has limitations. We did not collect behavioral or event data at the level of individual students or specific groups, which limits our ability to examine how these factors affected variations in learning and social skills within those levels. Additionally, we did not gather information on specific aspects of teacher facilitation and instructional choices, which prevented us from evaluating their impact on the effectiveness of the intervention. We collected data neither at the teacher nor individual student level due to the complexity and number of variables involved during the classes, and because video recording was prohibited. Observing multiple aspects at such a detailed level by one observer may have compromised the quality and completeness of the data.

7. Threats to Validity

To minimize disruptions from external presence, we engaged with the teacher early in the school year and observed the classes for a month before the intervention, creating a natural atmosphere. Additionally, we encouraged the teacher to maintain her style during activities. To ensure objective and consistent observations, we employed the structured observation method. It required a clear definition of observation events and accounted for the project's limitations and the complexity of classroom dynamics [Cohen et al. 2002].

8. Conclusion

This study demonstrated that cooperative games in Physical Education effectively teach CT concepts like sequencing and repetition. By incorporating these concepts into movement-based activities, 77 students grasped and applied them across contexts. The findings reinforced the interdisciplinary potential of embodied learning, showing how Physical Education can enhance CT development beyond motor skills. However, challenges emerged in student collaboration and engagement, as some students struggled with distractions and teamwork difficulties. For future works, we intend to conduct an ethnographic study to explore the underlying reasons for these challenges (e.g., emotional barriers, school context, teacher approach), even in activities centered around play.

Supplementary Materials

For the intervention summary, assessment, and tracks templates, visit here.

Acknowledgements

This study was conducted under ethical guidelines and was approved by the Federal University of ABC Ethics Committee (Approval No. 76829023.9.0000.5594).

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