# Designing Serious Digital Games Used to Exercise Computational Thinking Skills in Children on the Autism Spectrum

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***Abstract. Introduction****: Computational Thinking (CT) is a problem-solving approach that involves developing a set of cognitive skills. The literature indicates that there is a scarcity of research focused on the development of CT in minority groups, such as children with Autism Spectrum Disorder (ASD).* ***Objective:*** *In this sense, this work investigated how to design and evaluate serious digital games that enhance the exercise of cognitive skills in this population, utilizing the pillars of CT – pattern recognition, decomposition, algorithms, and abstraction.* ***Methodology****: A new game mechanic was created in a serious game authoring platform - RUFUS. Two evaluations were conducted and provided valuable insights into interface usability and target users' engagement.* ***Results:*** *The results indicate that games created using the CT mechanics present favorable conditions to support the exercise of CT skills, especially in educational environments aimed at serving children with ASD.*
***Keywords*** *Computational Thinking, Serious Digital Games, Autism Spectrum Disorder, Game Design, Game Evaluation, RUFUS Authoring Platform.*

## 1. Introduction

The development of Computational Thinking (CT) has gained prominence in recent decades. Studies reveal a shift in research trends in the field of CT recently [Tekdal 2021]. Coined by scientist Jeannette Wing, who described CT as a problem-solving approach that combines logical thinking with programming constructs from Computer Science. The author emphasizes that all individuals should learn CT and its principles, as it is not an exclusive skill for people in the technology field [Wing 2006].

The importance of CT in basic education is increasingly recognized, and countries like England and the United States, among others, have already incorporated strategies that allow these concepts to be integrated across basic education [Raabe et al. 2018].

In Brazil, one of the entities that supports the teaching of Computing in schools is the Brazilian Computer Society (SBC, acronym in Portuguese). SBC reinforces Wing's argument that a basic understanding of Computing is as fundamental for life in today's society as understanding mathematics, philosophy, physics, and other disciplines. Computing offers knowledge about the digital world and provides strategies and tools to address complex problems [Wing 2006, SBC 2017].

CT is defined as a thought process focused on problem-solving, based on fundamental concepts of Computer Science. This process involves everything from structuring reasoning to reflective human behavior in problem-solving. CT can also be observed in processes such as reading, writing, and learning mathematics, and it is part of an individual's analytical capacity from childhood. Computational Thinking and its precepts should be learned by all individuals, as they are not skills exclusive to people in technology and can be useful for solving everyday problems.

CT can be taught using four core principles that encompass problem-solving processes [Wing 2006, ISTE/CSTA 2011, BBC Learning 2015, Brackmann 2017]. These principles are known as the pillars of Computational Thinking, namely: Decomposition (segmenting a problem into smaller, more solvable parts), Pattern Recognition (identifying shared characteristics between problems and their solutions), Abstraction (filtering and classifying data, prioritizing relevant data, and discarding irrelevant data), and Algorithms (a set of clear and necessary instructions for solving a problem).

Inclusive Education, in turn, aims to support and promote schooling by recognizing diverse learning paces and providing targeted support for different learning needs. Intellectual Disability (ID) causes intellectual and adaptive deficits that affect an individual's social, conceptual, and practical domains.

The definition of Intellectual Disability used in this work is proposed by the AAIDD (American Association on Intellectual and Developmental Disabilities[1]), and is characterized by "significant limitations in intellectual functioning and adaptive behavior, as expressed in practical, social, and conceptual skills, originating before the age of 18". People with ID have limitations in skills such as attention, memory, concept understanding, generalization, and abstraction.

CT can help children with ID improve and exercise intellectual skills. To achieve this, interventions using appropriate methods and tools are necessary. Among the resources increasingly used in this context are Serious Digital Games (SDDs). SDDs can be used to facilitate CT acquisition and to promote the development of cognitive functions in children with intellectual disabilities through playful experiences [Oliveira et al. 2015].

Our goal, then, was to design and evaluate serious digital games that help children with autism spectrum disorder exercise skills in understanding, generalizing, and abstracting concepts through the pillars of Computational Thinking.

This paper comprises the following parts: Section 2 describes Educational Digital Games, Section 3 presents related works, Section 4 describes the RUFUS game platform, Section 5 details the game design process and the evaluation of the CT game, and finally, Section 6 covers final considerations and future works.

## 2. Educational Digital Games

Educational games can provide a favorable, dynamic, and pleasant environment, allowing for more meaningful learning [Godwin-Jones 2014].

To be effectively integrated into educational settings, these games must include clearly defined pedagogical objectives and be implemented within a specific context, guided by a well-established educational methodology [Prieto et al. 2005].

According to Ge (2003), digital games possess intrinsic characteristics that can enhance learning, such as immediate feedback, gradual challenges, and the opportunity

[1]Available at: `https://www.aaidd.org/home`

for practical and engaging exploration of concepts. These features contribute to a learning environment where students can actively participate.

Furthermore, the integration of digital games into school curricula has demonstrated significant benefits in enhancing academic skills and promoting cognitive development. Papastergiou (2009) highlights that educational digital games can boost student motivation, improve information retention, and facilitate problem-solving skills acquisition. Similarly, Prensky (2012) emphasizes that game-based learning aligns well with the learning styles of contemporary and future students.

The next section describes games identified from a literature review that are used to exercise Computational Thinking.

## 3. Related Works

To contextualize this research in the current scenario, a bibliographic search was conducted on databases such as ACM Digital Library, Engineering Village, and IEEE Xplore, among others, using the search string *(("computational thinking") AND (“digital games” OR “educational games” OR “serious games” OR “learning games” OR gamification OR “game based learning”))*. The aim was to identify and analyze research discussing the creation of serious games aimed at developing CT in children on the autism spectrum. As a result of the search, relevant research studies were identified and are described below.

### 3.1. CodaRoutine

This work presents the design and implementation process of a serious game for children on the autism spectrum. The game aims to develop problem-solving skills and teach basic programming concepts (sequence, conditional, and interaction). The authors considered this audience’s characteristics and learning styles and implemented a simple, graphical interface with immediate feedback and rewards to stimulate children’s participation and engagement.

The game consists of three difficulty levels, each with three stages. The game presents tasks related to children’s daily activities, such as preparing the lunchbox for school, getting the backpack ready for the next school day, and decorating a Christmas tree. The player interacts in the kitchen, bedroom, and living room scenarios. The game evaluation was conducted through focus groups, initially with neurotypical children and later with children with ASD. The results showed that most children mastered the game, understood the tasks, and considered the game fun and interesting. From these conclusions, the authors stated that with proper exposure, the game could effectively teach programming concepts and problem-solving skills to children with ASD [Elshahawy et al. 2020].

However, it is essential to identify some inherent limitations in the game’s implementation: 1) the game was developed only in a web version and does not support mobile platforms, which may restrict its access and usability, considering the growing preference for mobile devices in educational contexts; 2) there are no customization options regarding scenario configuration, stages, and levels, which may limit the game’s adaptability to different learning contexts and the diversity of the target audience. Thus, although the game offers significant benefits in exercising CT, these limitations may influence its effectiveness and usefulness in certain educational scenarios.

### 3.2. Pensar e Lavar (Think and Wash)

This educational digital game aims to intrinsically develop Computational Thinking in neurotypical children and those with intellectual disabilities. The game focuses on the clothes laundry process, and throughout the three phases, the player must carry out tasks such as sorting clothes, then the washing process, and finally, storing the washed clothes. Each phase addresses the pillars of CT and allows the player to develop skills such as logical and critical thinking, problem-solving, and abstraction, among others [Dutra et al. 2022]. The game also considers a set of accessibility guidelines that include: easy-to-understand interface, clear text, simple language, feedback, gradual progression of levels, and motivating elements, among others [Dutra et al. 2021].

One of the limitations identified in the game is that it requires individual installation on each computer where it is to be used. There are no web or mobile versions, which limits access flexibility, especially considering the diversity of devices used in educational environments. Although the game allows for the configuration of stages and levels, it is not flexible regarding scenario configuration, which may not fully meet the customization and adaptation needs for different teaching contexts and the specificities of each player.

### 3.3. Virtuoso

The work is aimed at young people on the autism spectrum in school age (11-14 years old) with the goal that they can acquire specific social skills and simultaneously solve introductory computer programming problems with programmable virtual robots through a game-based learning intervention. The project uses a variant of an educational video game called MinecraftEdu[2], used in education to learn various areas such as geography, chemistry, and history. The environment allows players to program robots to perform various functions, such as digging or building a structure. Activities are carried out in a block-based interface, in which players drag and drop icons to program their robots. Additionally, an online guide welcomes students and presents challenges similar to a video game that must be solved collaboratively by programming robots [Schmidt and Beck 2016].

Despite the project's benefits, the authors do not indicate whether they implemented specific design guidelines for young people on the autism spectrum. The absence of these guidelines may result in comprehension and engagement challenges for players. Additionally, authors should consider students' individual needs when designing game-based digital interfaces, ensuring that the experience is accessible, engaging, and effective for participants.

### 3.4. CT4All

The authors addressed the importance of CT and its application in adolescents on the autism spectrum. They proposed a collection of guidelines (CT4AII) for building educational activities to promote CT through digital game construction. The study

[2]Available at: `https://education.minecraft.net/`

included a Digital Game Programming Workshop with Scratch offered to adolescents on the autism spectrum. The meetings proposed interaction mechanisms for digital game construction involving programming structures (conditionals and loops). The results showed that participants developed skills such as abstraction, logical reasoning, and interpersonal skills [Munoz et al. 2018].

Although pedagogical guidelines are an important contribution, Scratch's resources and interface may not adequately consider specific design guidelines to meet the needs of the autistic audience. Therefore, players may face challenges related to the adequacy and accessibility of the chosen platform.

The described research shows promising results, indicating that children with intellectual disabilities can exercise CT-related skills through serious games. Therefore, this work aimed to design a serious digital game focused on exercising Computational Thinking skills. A differentiating aspect is the adoption of the RUFUS game authoring platform, as mentioned above, which will enable Education professionals to use the experimental game designed here or even create their own games in a customized way, according to each child's learning objectives, thus being a flexible resource. The following section details the process of designing the experimental game.

## 4. RUFUS Authoring Platform

RUFUS[3] game authoring platform is part of a larger research project and enables professionals in the fields of Health and Education to create therapeutic and educational digital games. This platform consists of a web-based authoring interface for professionals to plan and create games and a mobile application for direct interaction with players, the professionals' target users. On the web interface, professionals can: register patients and their families, create games, and adjust elements such as visual content, backgrounds, assets, or feedback to be provided during the game [da Hora Rodrigues et al. 2023].

The platform offers five game mechanics: quiz, puzzle, platforming, storytelling [Verhalen et al. 2022], and inverted narrative [Verhalen et al. 2024]. In the latter, the player has at their disposal elements that make up a story and must create their narrative from them, unlike storytelling games, where a professional defines the narrative and the player must interact with pre-defined routes.

Through the web interface, professionals are guided during the game creation process. This platform is built on the principles and techniques of End-User Development [Paternò and Wulf 2017] and offers a simple, intuitive interface that empowers non-computing specialists to create their own game instances.

## 5. Computational Thinking Game Mechanic

The last mechanic game – Computational Thinking – was designed using a co-production methodology [Schuler and Namioka 1993] in which different stakeholders actively participated in the development process. This article focuses on the final evaluation stage. Malpartida and Rodrigues (2025) describe details of the design and development stages, as well as other evaluations carried out.

[3]Available at: `https://rufus.icmc.usp.br`

This mechanic consists of three phases, each with three levels of difficulty, incorporating engaging elements such as scoring, a set number of lives, and immediate feedback. Players can choose their character, the phases, and the levels they wish to play (pre-configured options provided by the mediating professional). The aforementioned settings will be configured by the mediating professional through the Web interface, enabling customization to meet each player's specific needs.

Each of the three-game levels represents items and activities that are part of the children's daily routine: *Phase 1 (Pattern Recognition):* The player must match personal hygiene items with their corresponding shadows; *Phase 2 (Decomposition):* Displays personal hygiene items and routine activities, and the player must analyze which items correspond to the displayed activity; *Phase 3 (Algorithm):* The player observes the presented activity, selects the corresponding items and places them in a logical order of application.

Figure 1 illustrates the implementation of one of the interfaces of the Web interface of the game, with customization options, allowing teachers to choose the level, the phase, provide the instruction, and add associated images.

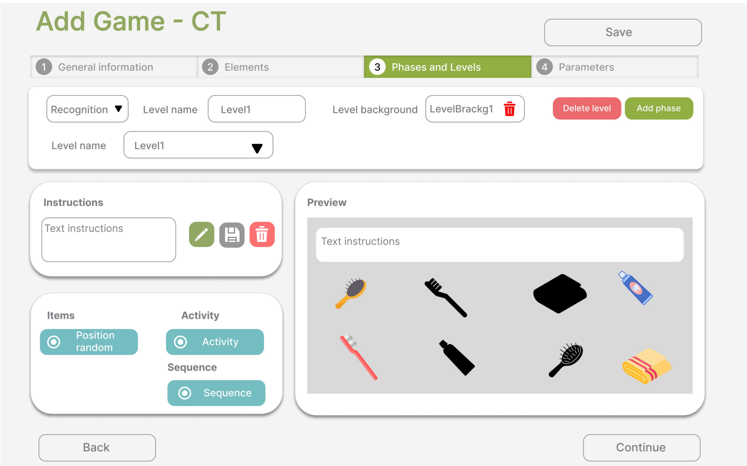


**Figure 1. Example of Game CT Web Interface - Level 1.**

### 5.1. Evaluation with the first group of target users: The institution's teachers

This version was evaluated by two teachers at the partner institution. It should be noted that all activities in this work were planned and validated by a Brazilian research ethics committee, with protocol number 76853723.3. 0000.5504. The following describes the activities conducted during the evaluation of the Web interface for the game's functional version.

In the *preparation stage*, the task defined was to create a Computational Thinking game consisting of three levels (Level 1: Matching; Level 2: Decomposition; Level 3: Sequencing). The *participants* were teachers from the partner institution – ACORDE[4] – who assist children and adolescents with intellectual disabilities.

About the *execution stage and feedback collection*, the teachers were invited to create a game on the Web interface. The Zoom tool was used to record their

[4]Available at: `https://institutoacorde.org.br/`

interactions with the platform. After creating the game, they responded to the SUS (System Usability Scale) [Brooke 1996] and SAM (Self-Assessment Manikin) [Bradley and Lang 1994] questionnaires, followed by a semi-structured interview. Each session lasted approximately 50 minutes.

As a *result of the evaluation*, it was possible to observe that the game's functional Web interface did not reveal any critical usability issues. The participants completed the assigned task. However, some difficulties and improvement suggestions were identified:

- *Difficulty entering text:* Fields for the game name, levels, and instructions contained pre-filled text that had to be manually deleted before typing;
- Sound option not tested: Limited evaluation time prevented testing this functionality;
- Avatar upload confusion: One participant struggled to locate the correct option for inserting an avatar image;
- *Understanding game levels:* Although teachers were familiar with the game, they needed a reminder to better understand what each level was about;
- *Finding the "Edit Game" option:* The edit button was small and contained only a pencil icon, making it difficult to identify;
- Terminology confusion: During the creation of the Decomposition level, the teachers suggested replacing the term "Activity" with "Group";
- *Lack of error messages when saving settings:* The system did not display alerts when required fields were left blank, leaving participants unsure of what was happening;
- *Persistent Form Data:* After saving a game level, fields would remain filled when starting a new creation, confusing.

The SUS questionnaire results illustrated that both participants rated usability as acceptable, scoring above the SUS average of 68 points (P1 - 100; P2 - 100). The SAM questionnaire results indicated positive outcomes in valence, arousal, and dominance dimensions for both participants. In all three domains, both participants scored 9.

During the semi-structured interview, the teachers shared relevant insights about the serious digital game and its applicability in the education of children with ASD:

- *Pedagogical suitability:* The game is appropriate for children with ASD as it allows the complexity of activities to be adjusted according to their age and cognitive development level;
- *Institutional infrastructure:* The implementation of the game may be affected by the lack of technological resources, such as tablets and updated computers;
- *Content personalization:* The inclusion of a built-in image and audio database would facilitate teachers' adaptation of games to their pedagogical context;
- *Autonomy in usage:* Providing tutorials and detailed instructions would help teachers use the tool independently;
- *Thematic diversity:* The game can be applied to various themes in the annual curriculum, such as nutrition and commemorative dates, making it a flexible tool.

The development team, composed of master's and undergraduate research students with experience in Web and digital game development, implemented a functional version of the mobile game, including configurable sound and visual reinforcement options; an icon for recording or loading audio instructions, facilitating accessibility for illiterate players or those with reading difficulties; and customization options, allowing teachers to adjust the number of attempts available and insert motivational messages at the end of each level. These were the demands of the teachers from the partner institution.

Figure 2 illustrates a game created by the teachers on a web interface, displayed in a mobile application, the interface where the professionals' target users play. These games were evaluated by children from a partner institution.

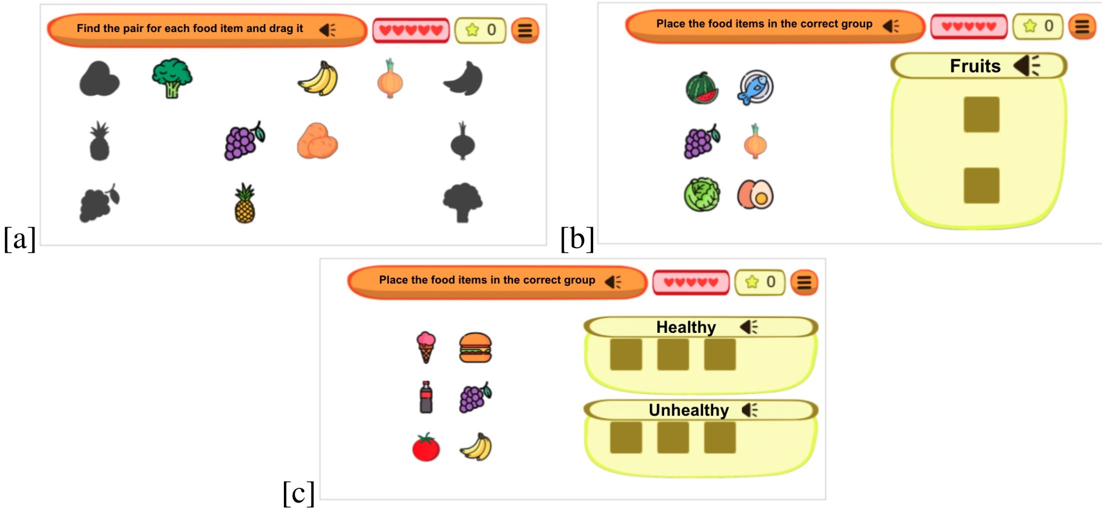


**Figure 2. Games previewed on the platform's mobile app - functional version of the interface: a) Level 1, b) Level 2, c) Level 3.**

### 5.2. Evaluation with the second group of target users: Children and adolescents with ASD

The members of the research group participated as volunteers in the institution's activities to establish a bond and become familiar with the children. This monitoring lasted nine months, with weekly classroom visits led by the institution's teachers.

In the *preparation stage* of this evaluation, the game's theme was defined in consultation with the teachers, as the class's pedagogical planning included work on food. The institution adopts an after-school model so that those assisted attend school in the morning and carry out the institution's activities in the afternoon;

In this evaluation, we are a group of two *participants*: (1) two teachers (T) responsible for classrooms 1 and 2 – they had already been present at previous evaluations and monitored the process, as well as helping mediate the activities; and (2) children and adolescents (A) – the group participating in this stage consisted of 10 children and adolescents aged 9-16 years. Nine had a diagnosis of Autism Spectrum Disorder at different levels of support, five had mild intellectual disability, and two had ADHD (Attention-Deficit/Hyperactivity Disorder). Most had more than one associated diagnosis. Regarding the use of digital games, nine participants reported playing regularly, mainly through smartphones, and cited a preference for games such as Free Fire, Roblox, and painting or dress-up games.

About the *execution stage and feedback collection*, weekly meetings were held involving children and teachers from two classrooms. Before conducting the study, consent forms were sent to the children's parents, in accordance with the ethics committee's guidelines for conducting research with human subjects for this project. Only children whose guardians authorized their participation were included in the research. Participants' interaction with the platform took place in the institution's computer lab, with prior consent from the children/adolescents to participate in the research. Each participant used a tablet to interact with the game, and the Vidma Recorder tool recorded the screen, logging all actions performed during the activity. The evaluation was carried out individually. In parallel, Zoom was used to record and observe each child's interaction with the game, enabling monitoring of their behavior while using the platform. After the interaction, the children answered the SAM questionnaire in a tangible format made with styrofoam balls. The results are presented in Table 1.

**Table 1. Results of the SAM instrument.**

| Domain | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Valence | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | - |
| Arousal | 9 | 9 | 7 | 7 | 9 | 9 | 3 | 1 | 9 | - |
| Dominance | 9 | 5 | 9 | 7 | 9 | 9 | 9 | 9 | 9 | - |

In the tangible SAM, most participants obtained positive results (scores above 5) across all three domains. Participants A7 and A8 reported lower scores (3 and 1, respectively), possibly influenced by situational factors, as both appeared distracted during their responses. Participant A10, who has level 3 autism and Down Syndrome, showed interest in the game but completed only the first level and required substantial support; therefore, the SAM questionnaire was not administered, since the child was unable to answer. Each session lasted approximately ten minutes per participant. The teachers accompanied the entire process, taking notes that were later discussed with the research team. Figure 3 illustrates some children interacting with the game.

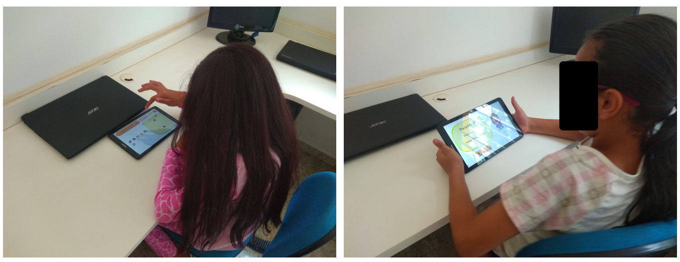

**Figure 3. Children interacting with the game's mobile interface.**

As a *result of the evaluation*, the information obtained during the interaction of children and adolescents with the game was compiled, including responses to the SAM questionnaire, interaction time, number of errors, and performance at each level. In the SAM, most participants had positive results in all three domains. The interaction time with the game ranged from approximately 3 to 10 minutes, revealing differences in the pace of activity execution.

The error record for each level shows that some children progressed fluently, while others had difficulties at specific points. The times per level show a progressive increase in cognitive demand throughout the stages, with longer durations in activities related to the Algorithm pillar. This pattern is consistent with the increasing complexity of the tasks and the observations made during the interaction.

Among the participants, cases A10 and A5 highlight the diversity of profiles present in the group. Participant A10, as mentioned above, has multiple diagnoses, needed more support, and completed only the first level. Participant A4, with a hearing impairment, completed all levels, demonstrating that the game's mechanics and visual feedback can guide progress when auditory stimuli are unavailable. The combined analysis of the tables, figures, and behavioral observations shows that most participants understood the actions necessary to advance in the game and also identified specific points that require adjustments to improve the flow of interaction. These results reinforce the importance of gradually increasing task complexity and implementing additional mediation strategies to expand the tool's use across different cognitive profiles.

## 6. Final Remarks

The implementation of the new Computational Thinking mechanics on the authoring platform involved a five-iteration process with teachers, children, and adolescents, allowing for the review of elements and adjustments to the game design. The teachers' contributions helped define the interface screens and organize the sequences used to configure the games.

Interactions with students provided data on execution times, errors, questions, and ways of interpreting the activities. A greater need for support was observed in tasks related to the Algorithm pillar, whereas the initial levels required less mediation. The records indicate variations among participants, influenced by individual characteristics and environmental conditions.

The participation of students with different cognitive profiles showed that the game can be used when there is adequate mediation and gradual presentation of actions. Paper-based activities, conducted in parallel, allowed for comparison of the execution of the same tasks outside the digital environment and highlighted differences in pace and resolution methods, mainly due to the classroom context and the use of materials. The series of steps taken resulted in a functional version of the game, structured around the pillars of Computational Thinking and adjusted to the demands observed during interactions. These records form the basis for further analysis and for the continued development of digital resources aimed at children or adolescents with ASD (Autism Spectrum Disorder).

The study presented a challenge related to the diversity of the participating audience. Although the members of the research group volunteered weekly in the two classrooms that would participate in the game evaluation, and the visits allowed them to observe classroom interactions and establish prior contact with the participants, some interactions remained difficult.

Future work includes expanding the number of participants or including institutions with varied profiles to observe differences in interaction with the game as a digital tool. Furthermore, additional evaluation instruments could be integrated to focus on changes over time and to explore how the pillars of CT can be articulated with specific school content at different stages of Basic Education.

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