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Building Serious Games to Exercise Computational Thinking: Initial Evaluation with Teachers of Children on the Autism Spectrum

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Abstract: Computational Thinking (CT) is a reasoning process focusing on problem-solving and developing cognitive skills. Serious games are an effective tool for exercising these skills, as they offer a playful and versatile approach that can be adapted to different audiences. This work presents the design of a serious digital game designed to help enhance cognitive skills in children with Autism Spectrum Disorder (ASD), using the fundamental principles of CT. The first game design phase was completed and submitted for evaluation by professionals in the Education field from a collaborating institution. The observations made and the feedback obtained are being discussed with the development and research teams so that the game can be implemented.

Keywords: Computational Thinking, Serious Digital Games, Autism Spectrum Disorder, Game Design, RUFUS Authoring Platform.

1 Introduction

Computational Thinking (CT) is a topic that has gained relevance in recent years [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, 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, 2017b].

In the context of inclusive education, all students should have access to CT concepts and opportunities to develop diverse skills, including students with disabilities or specific educational needs. The inclusive paradigm emphasizes the importance of adopting collective approaches, fostering community living, and acknowledging as well as respecting individual differences among all students. According to Stainback and Stainback [1999], the inclusive paradigm guides the adoption of collective approaches and the development of communal living environments that recognize and respect individual differences. This perspective highlights the critical importance of creating environments that promote inclusive learning, particularly when addressing the educational needs of individuals with Intellectual Disabilities (ID). Stainback argues that it is essential to engage in discussions about the specific characteristics and needs of students with ID, as this dialogue is instrumental in shaping and refining technological strategies that are designed to support and accommodate this group effectively.

ID is characterized by significant limitations in cognitive functioning and behavioral adaptation capacity, covering practical, interpersonal, and conceptual skills. This condition manifests itself from the early stages of development, usually before the age of 18 [AAIDD, 2021]. In ID, there is a limitation in the development of functions necessary to understand and interact with the environment (e.g., Autism Spectrum Disorder (ASD), Down Syndrome, among others) [Organization *et al.*, 1992]. People with ID may face challenges in developing skills such as attention, memorization, comprehension of concepts, generalization, and abstraction [Malaquias *et al.*, 2012].

CT can support children with ID by stimulating the development of various intellectual skills [Dutra *et al.*, 2022]. For this, it is necessary to intervene through appropriate methods and tools. Among the increasingly used resources in this context are Serious Digital Games (SDG). SDG can enable the acquisition of CT and stimulate the exercise of cognitive functions in children with ID through playful experiences [Oliveira *et al.*, 2015].

This paper presents the design process of an experimental serious game for exercising comprehension, generalization, and abstraction skills in children on the autism spectrum using CT pillars. From the analysis of the created experimental game and subsequently evaluated by stakeholders, a new game mechanic will be made available on the RUFUS[1] game authoring platform, developed and maintained by the author's research group. By using RUFUS, professionals can create customized games for their target population.

The final results of this project include, therefore, the provision of a serious game that can be used by Health and Education professionals throughout Brazil in exercising CT pillars; and the implementation of a new game mechanic in RUFUS that allows the instantiation not only of the experimental game outlined here but also of other games in the same mechanic, but personalized with the theme, texts, and media of interest to the professional for their audience.

For the design of the experimental game, the SemTh approach [de Souza *et al.*, 2019] was adopted. This approach was idealized to support the design of serious games that aim for co-production with the project's different stakeholders. The game design considered accessibility guidelines found in the literature for the development of digital games used by people with intellectual disabilities [Dutra *et al.*, 2021], as well as the GAIA guide, which contains 28 accessibility recommendations focused on autism aspects [Pichiliani, 2020]). These guidelines and recommendations will be considered from requirements gathering to game evaluation.

This paper is an extension of the paper published in the II Workshop on User Interaction and Research in Game Development (WiPlay[2]), of the XXII Brazilian Symposium on Human Factors in Computing Systems (IHC23[3]), whose title, in Portuguese, was: *Design de Jogos Digitais Sérios usados para o Exercício de Habilidades do Pensamento Computacional em Crianças com Transtorno do Espectro Autista* [Malpartida and da Hora Rodrigues, 2023].

This document comprises the following parts: Section 2 presents the theoretical foundation to understand the context, Section 3 presents related works, Section 4 details the game design process, the first evaluation of the game and, and finally, Section 5 covers final considerations and future works.

2 Theoretical Foundation

This section provides an essential theoretical foundation to understand the relationship between Computational Thinking and the development of serious digital games. Initially, we will explore the concept of Computational Thinking, analyzing its basic pillars. Next, we will discuss the importance of educational digital games as effective pedagogical tools to promote learning through interactivity, engagement, and immediate feedback. Additionally, we will delve into the RUFUS platform, highlighting its functionalities, resources, and potentialities in creating serious digital games.

2.1 Computational Thinking

The earliest concepts related to the term CT were introduced in 1980 by Seymour Papert in his book titled "Mindstorms: Children, Computers And Powerful Ideas". The work discusses computer culture and the relevance of technology in children's education. In this and other investigations by Papert, it is noted that CT ideas already existed but had not been named with this specific term, nor had their principles been disseminated at the time [Brackmann, 2017a].

In 2006, Jeannette Wing, director of computational research at the National Science Foundation (NSF), popularized the term CT through a scientific paper, describing CT as a problem-solving approach that combines logical thinking with programming constructs from Computer Science. She emphasizes that CT is a fundamental skill for everyone, not just Computer Science scientists [Wing, 2006].

Later on, the topic was revised for further clarification and described as: "the thought processes involved in formulating problems and their solutions, such that the solutions are represented in a way that an information processing agent can effectively execute". In this context, an information processing agent can be a human being, a computer, or a combination of both [Wing, 2010].

Over the years, the term gained greater importance, and researchers provided more comprehensive definitions. Brackmann [2017a] proposes that CT represents a critical, creative, and strategic skill of humans, allowing the application of Computer Science fundamentals in different areas, aiming at problem-solving either individually or collaboratively, following clear steps that can be efficiently executed by both humans and machines.

In addition to researchers, various organizations also make efforts to define CT. In a study conducted by the Computer Science Teachers Association (CSTA) and International Society for Technology in Education (ISTE) [ISTE/CSTA, 2011], it was determined that CT is a problem-solving process that includes, but is not limited to, actions such as:

- Formulating and solving problems using a computer or other digital or analog artifacts;
- Organizing and analyzing data logically;
- Representing data through abstractions (models and simulations);
- Automating problem-solving through algorithms (ordered sequences of instructions);
- Identifying, analyzing, and implementing possible solutions to a problem, aiming to find effective combinations of steps and resources;
- Generalizing and transferring a problem-solving process to solve others.

In Brazil, the Brazilian Computing Society also offers its definition for CT. According to SBC, CT is the ability to understand, define, model, compare, solve, automate, and analyze problems methodically and systematically, using algorithmic construction [SBC, 2017a; da Cruz *et al.*, 2023].

From these concepts, it can be considered that CT is a mental approach that allows systematic and effective problem-solving, applying Computer Science concepts. Furthermore, it is important to mention that the scientific community has not yet adopted a formal definition for CT, considering it an emerging discipline in the process of maturation. However, it is recognized as a field in continuous evolution with a promising future [Kalelioglu *et al.*, 2016; Tekdal, 2021].

The literature discusses various skills related to Computational Thinking. In this work it is adopted the classifica-

[1] https://rufus.icmc.usp.br/
[2] https://wiplay.ufc.br/
[3] https://ihc.sbc.org.br/2023/index.html

tion proposed by authors such as Wing [2006], Brackmann [2017a], and organizations like BBC [2015] and the Center for Innovation in Brazilian Education (CIEB, acronym in Portuguese)[4]. They established four fundamental dimensions of CT, which are essential for problem-solving. These dimensions are known as the Pillars of Computational Thinking and include: Decomposition, Pattern Recognition, Abstraction, and Algorithms.

- **Decomposition**: This pillar involves breaking down the problem into smaller and more manageable components to facilitate its resolution [Raabe *et al.*, 2018]. This concept can be observed in games like puzzles, where the overall problem would be the complete image, and the individual pieces are the smaller parts that need to be assembled to form the whole. Another example can be found in adventure games, which are divided into missions or stages, each containing smaller activities or tasks. Each stage represents a part of the overall game, and solving them to progress is necessary;
- **Pattern Recognition**: Identifies common characteristics among problems and their solutions. These patterns share similarities among some problems, allowing for a more efficient solution [Brackmann, 2017b]. The application of this pillar can be observed in memory games, where children need to find pairs of cards with identical images. Pattern recognition is crucial for memorizing the location of the cards and finding the corresponding pairs. Another application is in sequence games, where numerical, color, or shape sequences are presented, and children need to identify and complete them correctly;
- **Abstraction**: This concept involves the analysis and categorization of data, excluding unnecessary elements and highlighting relevant ones. It also organizes information into structures that facilitate problem-solving [Raabe *et al.*, 2018]. This pillar can be exercised through games like treasure hunts, where children must identify and focus on the elements necessary to locate the treasure. In these types of games, by interacting with elements like maps or plans, children have the opportunity to simplify complex problems and work with symbolic representations of space and clues. In this way, they can develop the ability to think abstractly and generalize concepts;
- **Algorithm**: It is a comprehensive concept that encompasses the other pillars of CT. It consists of a plan, strategy, or set of clear and necessary instructions to solve a specific problem. These instructions are described and organized to achieve the desired goal [Raabe *et al.*, 2018]. A practical example of the application of this pillar can be observed in block-based programming games. In these types of games, children can create logical sequences of instructions in a visual and intuitive way, by dragging and dropping blocks that represent different commands or actions. These blocks must be organized coherently to achieve a specific objective in the game. By interacting with these games, children become familiar with the fundamental concepts necessary for understanding and building algorithms.

[4]`https://cieb.net.br`

2.2 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 Gee [2003], digital games possess intrinsic characteristics that can enhance learning, such as immediate feedback, gradual challenges, and the opportunity 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.

2.3 RUFUS - Digital Game Authoring Platform

The RUFUS platform enables professionals in the fields of Health and Education to create serious digital games. The platform comprises two interfaces: a Web application for authoring - aimed at planning and creating games by professionals, and a mobile application - intended for interaction by players with the created games, those target users are the populations of interest to Health and Education professionals.

In the Web interface, professionals can: register patients and their families, create games, and adjust elements such as visual content or feedback to be provided during the game [da Hora Rodrigues *et al.*, 2023, 2022; Rodrigues *et al.*, 2021].

The platform currently offers five game mechanics: questions and answers (quiz), puzzles, item collection (platform), storytelling, and inverted narrative. Through the Web interface, professionals are guided during the game creation process, and players access the created game using the RUFUS mobile application from credentials. Their interactions during the game are recorded and transmitted to the Web system, which generates reports on the player's performance. Professionals can analyze such reports, allowing for specific interventions and treatment optimization [da Hora Rodrigues *et al.*, 2023, 2022; Rodrigues *et al.*, 2021].

RUFUS will be used in the context of this work to materialize the proposed game. Therefore, a new mechanic should be created and evaluated with the defined target users.

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, 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, abstraction, among others [Dutra *et al.*, 2022]. The game also considers a set of accessibility guidelines that include: easy-to-understand interface, clear texts, simple language, feedback, gradual progression of levels, 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 and 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 [5], 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 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

[5] `https://education.minecraft.net/`

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 Design of serious digital games for the development of Computational Thinking skills

To guide the design process of the prototype game envisioned in this research, the SemTh [de Souza *et al.*, 2019] approach was employed, aiming to ensure the active contribution of stakeholders, especially experts from different fields, not just Computing, in the creation process of the solution. Additionally, SemTh seeks to facilitate stakeholder communication by defining stages and activities to be developed. SemTh proposes four fundamental stages: Clarification of the design problem, Interaction Modeling, Design Materialization, and Evaluation. In each stage, the approach provides a set of activities to be conducted, and it is possible to iterate between the stages.

This work employed the stages of SemTh, which supported progress on two fronts of the project: 1) the design of a specific game for the context and audience addressed here, 2) the identification of generalizable elements for a game mechanic that will be implemented in the RUFUS authoring platform, allowing other games to be created in the same mechanic for different contexts and by other professionals after. This latter front advances projects in the area of End-User Development Paternò and Wulf [2017] of the authors' research group da Hora Rodrigues *et al.* [2023, 2022]; Rodrigues *et al.* [2022, 2021].

The following section describes the activities carried out in each stage of SemTh instantiated in this work.

4.1 Clarification of the design problem - First Iteration

This stage focuses on understanding the game's application scenario and formulating an appropriate approach for its conception. Initially, a literature study was conducted, and the findings were complemented by resources available in other repositories, such as digital gaming platforms and stores. The study aimed to identify games that promote the development of computational thinking and learning skills in neurotypical children and those with intellectual disabilities. The main games identified and considered in this work were those described in Section 3. Subsequently, elements were selected to compose the structure of the experimental digital game, here named "Our Routine". Accessibility guidelines, as mentioned above, were also considered for the prototype development [Dutra *et al.*, 2021; Pichiliani, 2020].

The educational objective of the game proposed in this work is related to CT and problem-solving, including the exercise of competencies and skills encompassing Decomposition, Pattern Recognition, Abstraction, and Algorithms. These pillars were considered in creating digital games found in the literature review and previously mentioned [Dutra *et al.*, 2022; Elshahawy *et al.*, 2020; Schmidt and Beck, 2016; Munoz *et al.*, 2018]. Regarding the competencies and skills that will be developed in the "Our Routine" game, the curriculum presented by the Brazilian Center for Innovation in Education (CIEB, in Portuguese) [Raabe *et al.*, 2018] is being considered as a reference. To practice these skills, the game should present activities related to the daily routine of the target audience. A summary of the skills related to daily life activities presented in the "Our Routine" game *versus* the pillars of CT is described in Table 1.

Table 1. Pillars of Computational Thinking and skills proposed in the game "Our Routine". Adapted from Malpartida and da Hora Rodrigues [2023].

Primary pillar of CT Game Our Routine	**CT Skills and Practices (CIEB) [Raabe *et al.*, 2018]**
Pattern Recognition Analyze the set of elements presented on the screen and identify the items that correspond to body hygiene activities. (Item Option).	Identify patterns in a set of objects. Practice: Find shapes, colors or melodies that are repeated in a set.
Decomposition Understand the set of elements that involve routine activities and identify the items necessary for each of them. (Activities Option).	Understand the concept of decomposition using physical toys. Practice: Identify which parts are needed to assemble a toy (Ex.: car - wheels, steering, etc.)
Algorithm. Define the sequence of steps necessary for each proposed activity, select and order the correct items. (Algorithm Option).	Understand the concept of an algorithm as a sequence of steps or instructions. Practice: Execute algorithms related to body movements.
Abstraction. Applied during all game options.	Identify important information and discard irrelevant information. Practice: Look for routine situations that can be converted into a sequence of instructions.

Daily life activities were initially selected based on exploratory research in studies and resources available on the Web. Digital stores with educational toys aimed at training children's routines were found, such as [6]: Educational Child Board and My Routine Magnetic Game. These games consider that routine activities are goals (e.g., waking up, taking a bath, brushing teeth) composed of elements or pieces (e.g., comb, soap, toothpaste), which the child must organize according to their daily life. The games are used by professionals such as therapists and teachers to assist in organizing children's routines, with family, in educational spaces, and clinics.

Regarding accessibility requirements, including those spe-

[6] `https://brinquedosbabebi.com.br/` and `https://nigbrinquedos.com.br/`

cific to people with ID, a systematic mapping previously conducted in the literature was considered, identifying the works of Dutra *et al*. [2021] and Pichiliani [2020]. Dutra's work focuses on 16 guidelines for intellectual disabilities, and Pichiliani's work brings 10 categories and 28 recommendations, with specific guidelines for designing interfaces focusing on people on the autistic spectrum. Based on the work of these authors, the recommendations, and guidelines considered most relevant for the development of games for children were selected. Table 2 presents the list of requirements generated in this stage of clarifying the design problem using SemTh approach.

Table 2. Table of Requirements (R) for the game "Our Routine" with origin source and degree of importance. Adapted from Malpartida and da Hora Rodrigues [2023].

No	Requirements	Origin	Degree
R1	Assist in the exercise of the basic concepts of CT (problem solving)	Definition of educational objectives [Raabe *et al*., 2018]	High
R2	Clearly address the four pillars of CT (Abstraction, pattern recognition, decomposition, and algorithm)	Definition of educational objectives [Raabe *et al*., 2018]	High
R3	Present daily life activities in a playful way.	Definition of educational objectives [Raabe *et al*., 2018]	High
R4	Have a simple interface, making it easier to understand and minimizing the inclusion of many elements on the screen (eliminate complex animations, unconventional fonts, elements that blink or glow)	Literature/Guidelines [Pichiliani, 2020] [Dutra *et al*., 2021]	High
R5	Present a standardized interface (e.g. colors, icons, symbols, etc.)	Literature/Guidelines [Pichiliani, 2020] [Dutra *et al*., 2021]	High
R6	Employ control buttons such as Help, Pause, Back and Cancel. Avoid automatic targeting.	Literature/Guidelines [Pichiliani, 2020] [Dutra *et al*., 2021]	High
R7	Provide different degrees of difficulty. The challenges must advance as the player's skills increase	Literature/Guidelines [Dutra *et al*., 2021]	High
R8	Incorporate engaging elements like punctuation and lives	Literature/Guidelines [Dutra *et al*., 2021]	High
R9	Provide visual and audio feedback	Literature/Guidelines [Pichiliani, 2020] [Dutra *et al*., 2021]	Half
R10	Allow customization of the game (e.g. choice of characters, stages and difficulty levels)	Literature/Guidelines [Pichiliani, 2020] [Dutra *et al*., 2021]	Half
R11	Allow a mediator (responsible professional) to customize the game, configuring the phases and difficulty levels.	Literature/Guidelines [Dutra *et al*., 2021]	Half

The requirements identified in the literature and from other games are being validated by Education professionals from a partner institution of this project through participatory workshops and brainstorming sessions.

4.2 Interaction Modeling - First Iteration

In this stage, the SemTh approach suggests using a Specific Domain Modeling Language for Therapeutic Applications [Garcia *et al*., 2016]. This language employs graphical representations for multimedia objects (e.g., background image, sound effect, text); seals (e.g., F for Flexibility options, P for Punctuation/scoring, OT to define Therapeutic Objectives, among others), and groupings (e.g., scenarios and subscenarios). The use of these elements facilitates communication among multidisciplinary professionals. These elements can be used during a brainstorming activity or Participatory Design practices [Schuler and Namioka, 1993].

For the first version of the experimental game, daily life activities of children, such as brushing their teeth and taking a bath, were considered. The items of each activity are the necessary components to practice such activities, namely: toothbrush, toothpaste, soap, etc. In each phase of the game, the pillars of CT (abstraction, decomposition, pattern recognition, and algorithm) will be exercised, with one primary pillar for each phase and the others complementary to solving the established tasks.

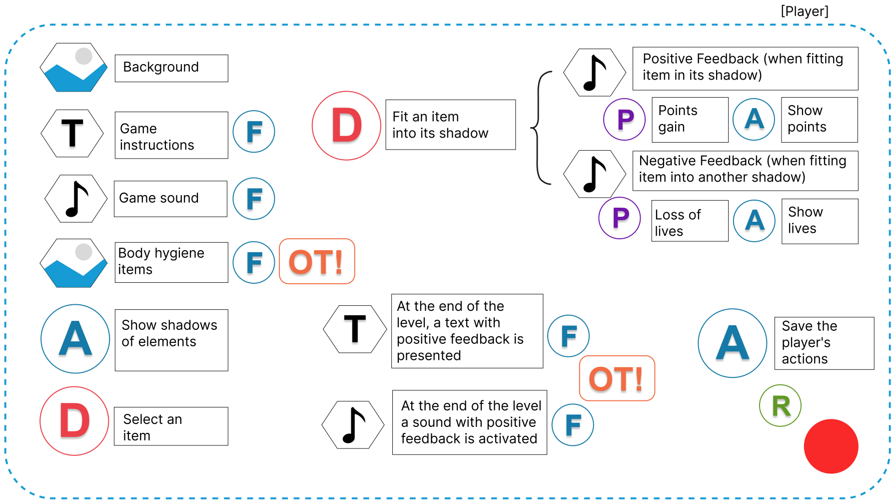
Figure 1a illustrates the modeling of the first phase for the CT exercise, related to the primary pillar - Pattern Recognition. In this screen, the player must identify the items and place them in the correct place (action D). The flexibility seal (seal F) corresponds to the choice the player will make, where the possibilities were configured by the professional mediating the interaction with the game, considering the number of items that will be viewed by the player (which can be 2, 4, or 6 items). The number of items is linked to the therapeutic objective (seal OT!), indicating the player's ability to identify such items. It is also possible to note that this screen of the game provides a background image. At the end of each phase, a positive feedback message (visual and hearing), previously configured by the professional, is presented.

Regarding negative feedback (visual and hearing), the player will have five attempts to solve the game; if unsuccessful, a message may be displayed suggesting to play again (if the professional deems it relevant to the game's goal). Actions must be saved for report generation (seal R). The player's punctuation is collected for items placed in the correct locations or not (seal P) and is associated with a player action (A).

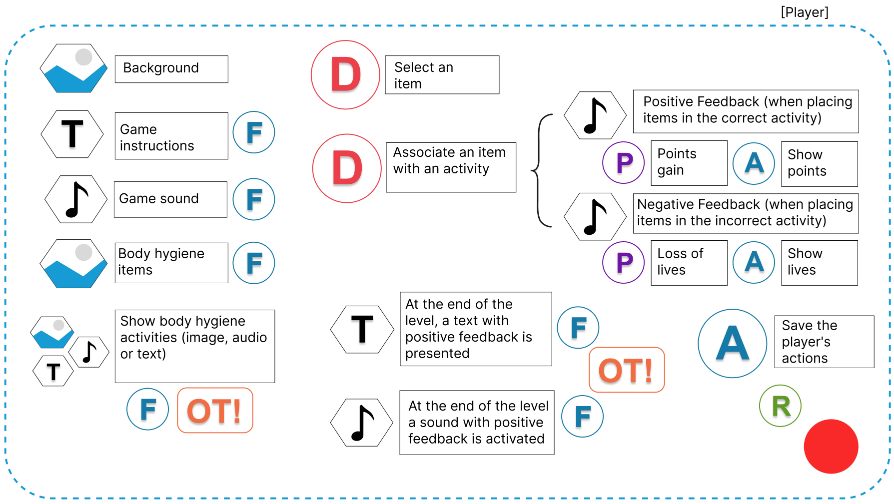
In the second phase, which has Decomposition as the primary pillar, illustrated in Figure 1b, the player must identify and select the items corresponding to each displayed activity (action D). The flexibility seal (F) indicates that the player can make choices defined previously by the mediating professional, in this case: the selection of the number of activities to be displayed and their format - which can be audio or image. These activities are linked to the game's therapeutic objective (OT!), which determines the number of correct items the player should collect.

Figure 1c, in turn, illustrates the modeling created for the third phase of the game, related to the Algorithm pillar. In this screen, the player must identify the order of items for each activity, establishing an organized sequence (action D). The flexibility seal (F) is displayed because it represents the player's choice, previously defined by the mediating professional. In this case, it is the determination of the order and the items that will be displayed.

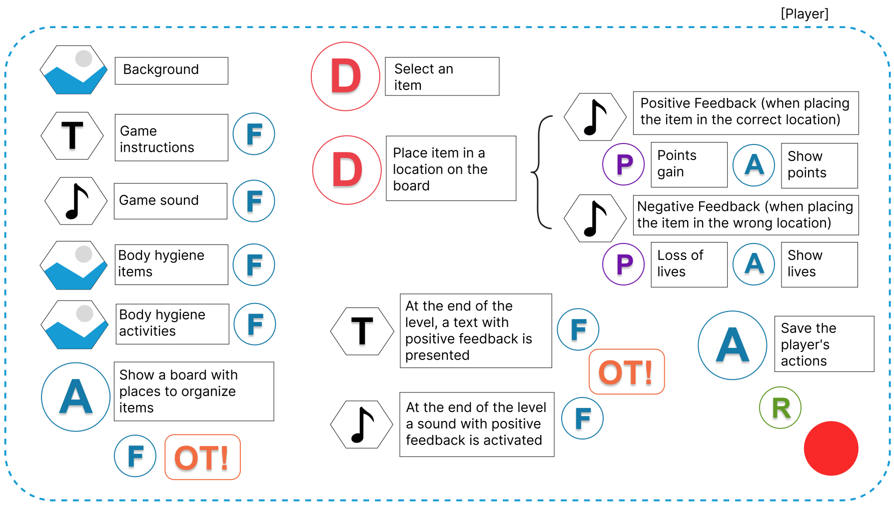
All player actions will be stored to generate reports (seal R), and will be available afterward for the mediating professional, so that they can analyze the time, score, errors, and choices of the children during the game.



(a) Phase 1.



(b) Phase 2.



(c) Phase 3.

Figure 1. Game screens modeled at this stage. Adapted from Malpartida and da Hora Rodrigues [2023].

4.3 Materialization of Design - First Iteration

Following the steps of SemTh, and considering the results of the previous stages, a first materialization of the game was suggested. This consists of a medium-fidelity prototype.

At this stage, the creation of the Game Design Document (GDD) is recommended. This document is a textual instrument that covers a game's characteristics, from initial concepts to details such as level design and sounds [Pedersen, 2003]. Some of the most important components of the GDD include: overview, fundamental aspects, essential game objectives, characters, among others [Schuytema, 2008]. In the GDD of this work, the characteristics of the game[7] were described based on the results of the requirements survey (see Figure 2).

The following subsections describe the fundamental aspects of the game, as well as its phases and how it should be implemented on the RUFUS platform, in its final version, to be made available to players and involved professionals.

4.3.1 Fundamental Aspects of the Game

The serious digital game of this work aims to assist in the exercise of comprehension, generalization, and abstraction skills in children on the autism spectrum, through the use of the CT pillars (requirements R1, R2). The items and activities of the game corresponding to children's daily routines (R3) should be configured on the RUFUS authoring platform. This existing platform has two interfaces: a Web interface - for professionals to configure games from predefined game templates, and a mobile interface (Android application) - where players interact with the configured game. In addition to allowing game creation and user registration (R11), the Web interface provides the player's interaction report with the game. Following accessibility guidelines, the game has a simple (R4) and standardized (R5) interface, including control buttons, such as help and pause (R6).

The game, in the mobile application, consists of 3 phases, with 3 levels of difficulty (R7), which incorporate engaging elements such as scoring, a predetermined number of lives (R8), and immediate feedback (R9). The player can choose their character, phases, and levels they want to play (R10) (options previously configured by the mediating professional). The mentioned configurations will be carried out by the mediating professional through the Web interface, enabling customization to meet the specific needs of each player (R11).

4.3.2 Phases of the Game

Each three-game phase represents items and activities in children's daily routines. In Phase 1 (Pattern Recognition), the player must relate personal hygiene items to their corresponding shadows. Phase 2 (Decomposition) shows personal hygiene items and routine activities, and the player must analyze which items correspond to the displayed activity. In Phase 3 (Algorithm), the player must observe the presented activity, choose the items corresponding to that activity, and place them in a logical order of application. Figure 2 illustrates the screens of the three-game phases, materialized in a first medium-fidelity prototype, following the modeling created in the second stage of SemTh.

The Figma[8] tool was used to create the prototype and the interaction between the projected screens. Additionally, free resources available on the Freepik and Flaticon platforms[9] were used for the game images.

4.3.3 Implementation of the New Mechanic on the Authoring Platform

The serious digital game developed in this work was analyzed to identify its generalizable elements, allowing for the subsequent creation of different games in the same style. The goal was to enable the selection and positioning mechanic of items, described in the previous section and materialized in the medium-fidelity prototypes of the game, to be included in the RUFUS authoring platform, thus allowing not only the creation of this game in its functional version, but also other games of interest to professionals, who could make use of this same mechanic, reusing the theme and media of "Our Routine", or creating completely new games.

Considering the project's proposal to insert a new mechanic into the authoring platform to enable the creation of the game designed here and others like it, the first prototyping of the RUFUS Web interface for game configuration was carried out. This proposal is in the validation phase with the platform development team, to analyze the feasibility of implementation. It is worth mentioning that currently, this platform already provides predefined templates for five other game mechanics (question and answer, fitting/puzzle, item collection, narrative - where the professional configures the narrative and its routes, and inverted narrative - where the player creates their story from elements predetermined by the professional).

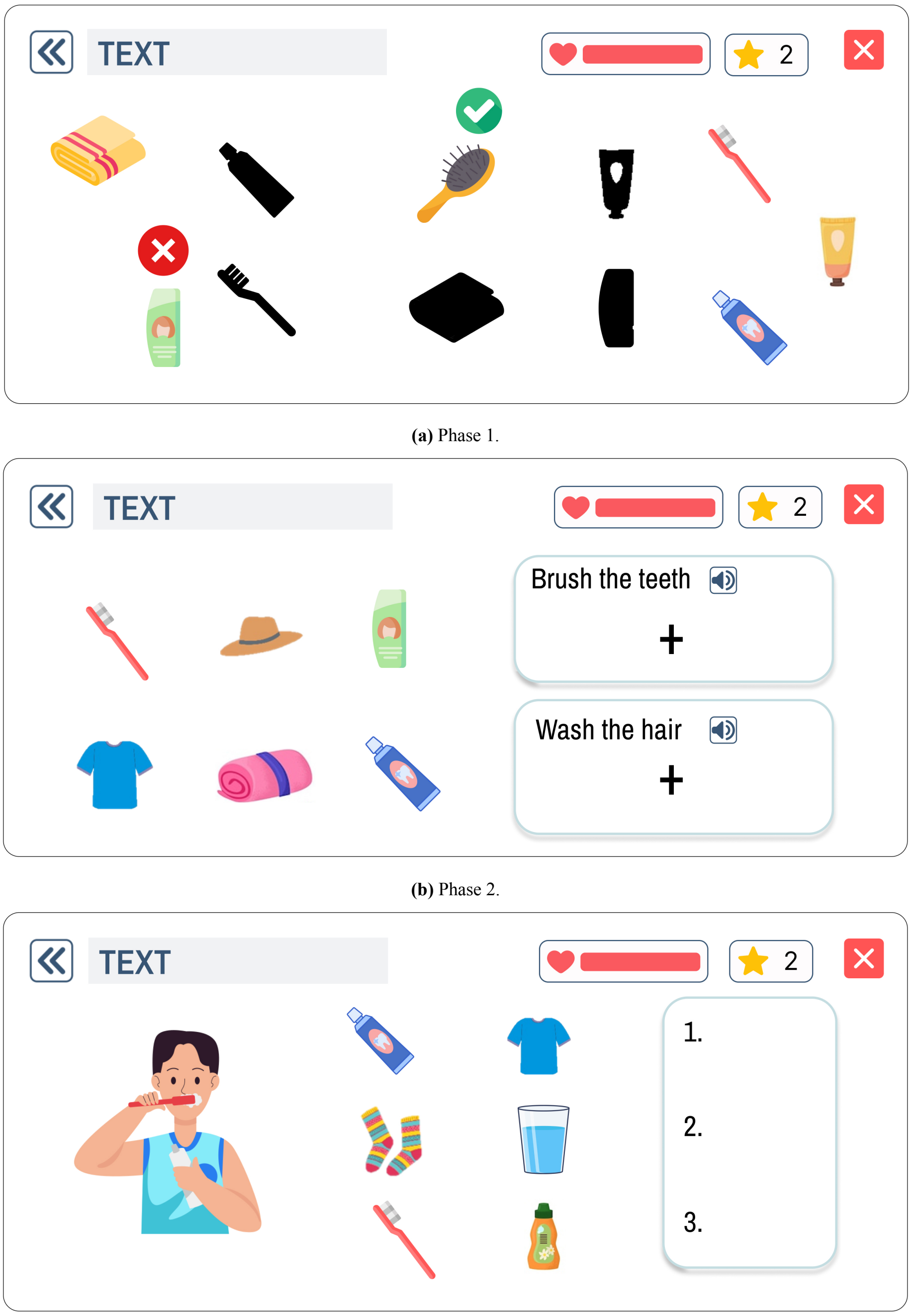
In the prototyping, the mechanics already implemented on the platform were analyzed to have a reference for configuring the new mechanic and observing the reuse of existing parts/mechanics. The same dimensions, colors, and positions of the buttons used in the platform's visual identity were considered. The initial screens collect common information in all other games, namely: name, description, associated audio, and background image. The professional can upload elements such as: 1) character images that will allow the player to choose an avatar to use in the game, 2) images of personal hygiene items (e.g., soap, towel, toothpaste), 3) routine activities of children (e.g., washing hands, taking a bath, waking up) these activities can be in text, image, or audio format to facilitate children's understanding. Figure 3 illustrates the configuration of these elements.

The professional must also configure the phases and levels, according to educational goals, assigning names, icons, and background images to each phase and level created. Then, the professional can adjust the items and activities displayed to the player, configuring three options related to the development of CT pillars: 1) Items Option - employs Pattern Recognition as the primary pillar, and the other pillars are complementary. Figure 4a illustrates this option; 2) Activities Option - refers to the development of the primary Decomposition pillar, this option is illustrated in Figure 4b, and 3) Sequence Option - linked to the Algorithm pillar, as illustrated in Figure 4c. The Abstraction pillar is implicitly developed throughout all game phases.

[7] Available for consultation (in Portuguese) at: `https://docs.google.com/document/d/12vtUZ7-J1b5ZUrlYWq9T4XV6VqeP8hjyKciYmwjoAEg/edit?usp=sharing`

[8] `https://www.figma.com/`

[9] `https://www.flaticon.com/` and `https://br.freepik.com/`



(a) Phase 1.

(b) Phase 2.

(c) Phase 3.

Figure 2. Prototyped game screens. Adapted from Malpartida and da Hora Rodrigues [2023].

Finally, as in other mechanics, the professional can configure positive and negative feedback parameters in textual or sound format.

4.4 Evaluation of the Prototype

This stage aims to identify and correct any potential problems or errors before the game implementation, allowing the team to backtrack to previous stages to promote corrections or inclusion of new requirements until the completion of the approach outlined [de Souza *et al.*, 2019]. Semth suggests using a set of instruments that can be carried out to evaluate games. The instruments used in this evaluation and suggested by the approach are aligned with those most used for evaluations in this context, according to the study of Carvalho *et al.* [2024]. For this work, the Cognitive Walkthrough (CW) method [Polson *et al.*, 1992] was used, an inspection method that evaluates usability by analyzing the path a user would supposedly take to achieve their goal when interacting with the interface of an interactive system. Also, a variant of CW called Cognitive Barriers Walkthrough (CBW) was used to verify the ease of learning digital games [Santos *et al.*, 2023]. In addition, semi-structured interviews and two questionnaires (usability and emotional response) were used and applied throughout the design and evaluation stages. The questionnaires are: 1) SUS - System Usability Scale, is an instrument that measures users' perception regarding the ease and effectiveness of interaction with a

Figure 3. First materialization of the new mechanics - Item configuration. Adapted from Malpartida and da Hora Rodrigues [2023].

specific system [Brooke, 2013]; 2) SAM - Self-Assessment Manikin is an emotional response instrument that uses images categorized into three dimensions: pleasure, arousal, and dominance [Bradley and Lang, 1994]).

4.4.1 Mobile Interface Evaluation

The evaluation took place at ACORDE[10], an institution partnered with the research group to which the authors of this work belong. This institution provides specialized assistance to children and adolescents on the autism spectrum. It is important to note that the Brazilian research ethics committee approved the project (with Certificate of Presentation of Ethical Review number 76853723.3.0000.5504), ensuring compliance with ethical and legal standards. The following activities carried out during the prototype evaluation, according to CBW [Santos *et al.*, 2023], are detailed below.

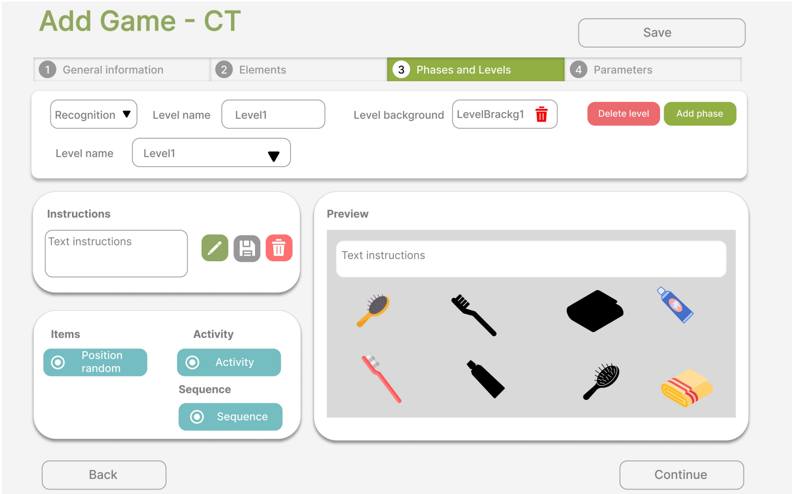
- **Preparation:** Tasks and actions necessary for the evaluation with professionals of the institution were defined, as well as all the documents and terms necessary. We sought to define tasks that would allow professionals to explore the main actions available to the player in the game - the mobile version (see Figure 2). The task assigned to the participants was to interact with the game prototyped on easy, medium, and advanced levels; to check the score achieved and the lives remaining;
- **Participants:** Two teachers from the partner institution participated in the evaluation. These teachers are referenced in this text as participants (P) - P1 and P2. The teachers were selected and invited by the institution's pedagogical coordinator. They were two women, specialists in Pedagogy, with at least five years of experience in pedagogical activities with children and adolescents on the autism spectrum. One has experience using technologies for this target audience, and none has experience using digital games for educational purposes;
- **Conduction and Data Collection:** For data collection, a face-to-face meeting was coordinated with the participants. During the meeting, the research context, its goals, and how the evaluation would be conducted were described. They read and signed consent forms, profile questionnaires, and image and data usage authorization. They were then invited to interact with the game using a Figma tool. The evaluation took place individually with each participant. During the interaction, they were encouraged to share their impressions. They answered the 7 questions of the CBW method (see Table 3) during the execution of the predefined task. The Google Meet tool was used to observe and record each participant's interaction with the prototype. After interaction with the prototype, they responded to the SAM and SUS questionnaires, and finally, a semi-structured interview was conducted. The evaluations lasted approximately 40 minutes. Figure 5 illustrates the participants interacting with the game prototype;

Table 3. CBW questions [Santos *et al.*, 2023].

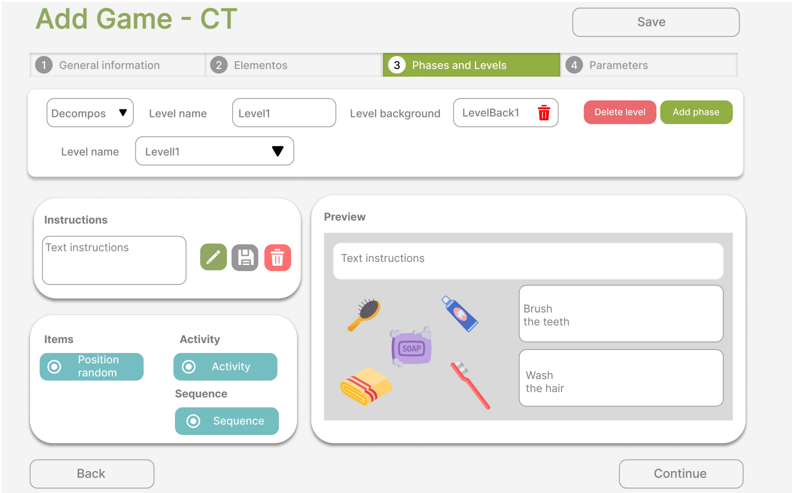
Initial-Q: Will the user be able to describe the task to be carried out?
Questions: (repeat for each action) Q1: Will the user try to achieve the right effect? Q2: Will the user stay focused on the task? Q3: Will the user notice that the correct action is available? Q4: Will the user associate the correct action with the effect they are trying to achieve? Q5: If the correct action is carried out, will the user see that progress is being made toward the solution of their task?
Final-Q: Will the user perceive an incentive to continue the task?

- **Consolidation of Results:** During the evaluation, some problems were found on the prototype, such as: 1) The

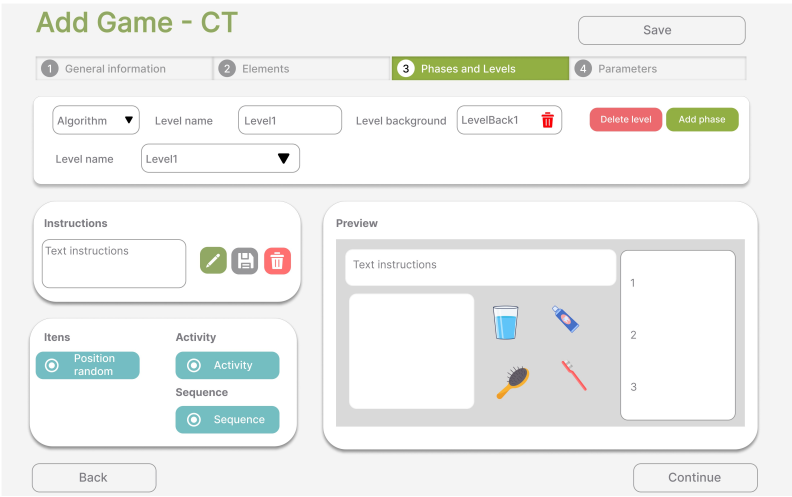
[10] `https://institutoacorde.org.br/`



(a) Pattern Recognition Screen.



(b) Decomposition Screen.



(c) Algorithm Screen.

Figure 4. First materialization of the proposed new mechanic's screens. Adapted from Malpartida and da Hora Rodrigues [2023].

player's score is too subtle (P1 pointed out); 2) The feedback should have sound (P1 and P2 pointed out); 3) The instructions should have audio (P1 and P2 pointed out). The participants also pointed out: "*The order of the elements is not evident*" (by P1), "*The arrangement of elements to place a sequence needs to be clearer*" (by P1), or "*Elements like soap should be as close as possible to what children use*" (by P2). For this last problem, participants were informed that they could customize all these aspects during the game creation on the Web interface. The SUS questionnaire results (see Table 4) pointed out that both participants rated game usability as Acceptable, defining a score above the average suggested by the questionnaire, 68 points. For the SAM

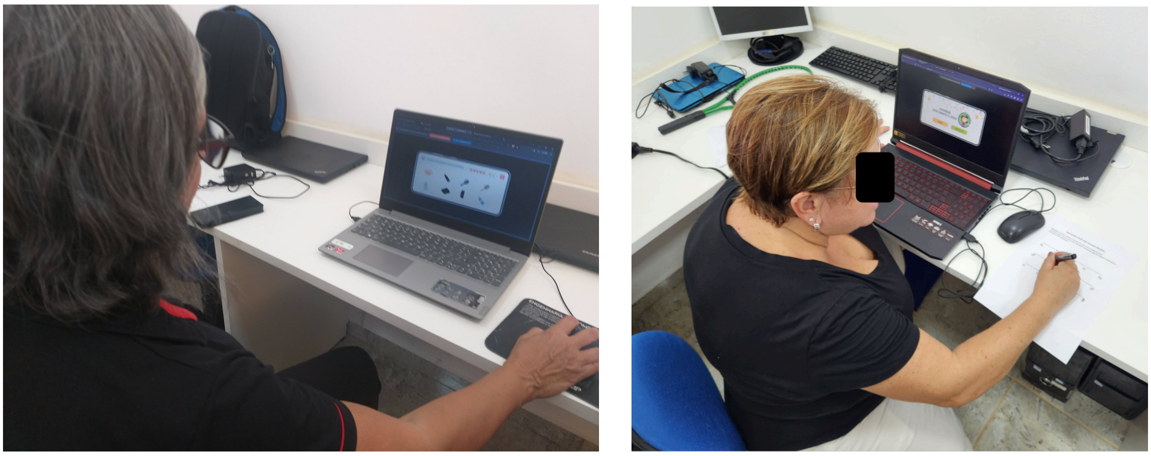


Figure 5. Participants evaluating the game prototype.

questionnaire (see Table 5), the domains of pleasure, arousal, and dominance had positive results from both participants.

Table 4. Results of the SUS questionnaire.

Participants - P	Score	Result
P1	100	Excellent
P2	72.5	Good

Table 5. Results of the SAM questionnaire.

	P1	P2
Pleasure	7	7
Arousal	7	7
Dominance	9	7

During the semi-structured interviews, participants expressed positive opinions, but also suggested some corrections for the problems found, such as: 1) Adding clapping or congratulations sound when the player earns a point to make it clearer (by P1); 2) At the end of each level, show the points earned (by P1); 3) If the player has frustration issues, lives can be replaced by other motivational elements. For example, upon completing the Easy Level, the player may receive 4 points and three stars as positive reinforcement (by P2); 4) Adding audio to the instructions would help non-literate or dyslexic players (by P1 and P2);

Results Report: During the prototype evaluation, some significant problems were identified that might impact the user experience. Below are the main problems found, as well as the improvement and correction suggestions proposed by the participants:

- **Subtle scoring:** Participants observed that the player's score is too subtle, making it difficult to understand progress during the game. The improvement suggestion is to increase the visibility of the score through clearer and more prominent visual and hearing elements;
- **Feedback without sound:** Participants indicated that the feedback in the game lacks sound; this absence can affect the player's perception of correctness and mistakes during activities. The improvement suggestion is to include feedback sounds, such as clapping or congratulations, to indicate the player's performance in a more precise and motivating way. However, it is essential that these sound effects have the option to be muted, considering that some children with autism may have hypersensitivity to auditory stimuli;
- **Instructions without audio:** The instructions in the game lack audio; this absence can hinder the understanding and participation of non-literate or dyslexic players. To improve this aspect, audio can be added to the instructions to assist in understanding and the participation of players with different reading abilities;
- **Motivation and positive reinforcement:** Given the possibility of a player feeling frustrated due to the limitation of lives in the game, additional motivation and positive reinforcement elements can be implemented, such as including stars or other motivating elements upon completing a level. This can help reinforce desirable behaviors and maintain player interest.

Overall, participants emphasized the game's ease and clarity. They highlighted that the playful environment keeps children focused on the proposed activities, favoring the learning process. Additionally, they emphasized the importance of practicing sequence exercises, as many children struggle to follow the order of activities.

The results of professional evaluations are being analyzed together with the platform development team. This analysis may lead to adjustments in the proposal, modeling, and materialization of the game and, thus, adjustments in the Web and mobile interfaces of the platform. Changes in design elements and game interaction may also emerge from the evaluations and will be analyzed by the group.

It is worth mentioning that more meetings are currently being coordinated with professionals to continue the game evaluation process, especially with the authoring interface. After the game's implementation, longitudinal case studies with children and adolescents will be conducted to verify its effectiveness.

5 Final Remarks

This paper describes activities of a broader project aimed at providing a serious digital game to support Education professionals in exercising skills related to computational thinking pillars in children on the autism spectrum. Participatory Design practices are being adopted [Schuler and Namioka, 1993], so that the different stakeholders in the project can participate in the solution-building process. The instantiation of the SemTh approach represents one of the contributions of this work, as it can be used by other researchers in designing serious games for the described audience.

The literature presents other similar games; however, the differential of this proposal is to allow Education professionals to personalize the game to suit the specific needs of each player. Additionally, game interaction data is sent to professionals so that they can analyze and conduct interventions they deem necessary during therapy time.

Regarding the future limitations and challenges of the research, it is possible to consider that they reside mainly in the target audience, whose participation in the research requires special attention in terms of support, communication, and adaptation to individual needs. Additionally, children's participation must be consented to by themselves, and there is a challenge in gaining the trust of this audience, as well as keeping them engaged. Furthermore, the evaluation stage will specifically focus on children's interaction with the game and the exercise of CT skills without directly assessing the development of these skills over time. These limitations, although challenging, represent an opportunity for an interdisciplinary and user-centered approach.

As a work in progress, the group is evaluating the Web prototype with Education professionals from the partner institution through participatory workshops. The Web prototype currently already brings changes added from the evaluation of the mobile game, such as the possibility of inserting sound feedback into game instructions. Subsequently, the implementation of the prototyped game will be done on the authoring platform to conduct new evaluations with the professionals of the institution and, after, case longitudinal (medium-term) studies with children on the autism spectrum from the same institution to evaluate the exercise of CT skills, especially in the context of activities of daily living.

Declarations

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Authors' Contributions

Katherin Felipa Carhuaz Malpartida: Conceptualization, Investigation, Writing. **Kamila Rios da Hora Rodrigues:** Conceptualization, Investigation, Supervision, Writing.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

All data generated and analyzed during this study are included in this paper.

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