Building games to exercise Computational Thinking in children on the autism spectrum through pre-defined templates and End-User Development concepts

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Abstract. *Computational Thinking (CT) is a reasoning process focused on solving problems, promoting the development of cognitive skills. Serious games can contribute to exercising these skills, as they are playful and adaptable tools for different audiences. This paper presents the design and evaluation of a Web template for building serious digital games to help improve the cognitive skills of children with Autism Spectrum Disorder (ASD), based on the fundamental principles of CT. The first phase of the Web template design was completed and evaluated by Education professionals from a partner institution. The observations and feedback collected are being discussed with the development and research teams to implement the functional version of the game.*

1. Introduction

Computational Thinking (CT) is an approach to problem-solving that integrates logical thinking with the foundations of Computer Science. Scientist Jeannette Wing highlights that CT is a skill that should be developed by everyone, not just restricted to technology professionals [Wing 2006]. The growing value of CT in basic education is evident in countries such as England and the United States, which have already implemented strategies to incorporate this knowledge into school curricula [Raabe et al. 2018]. In Brazil, the Brazilian Computing Society (SBC, in Portuguese) strongly supports the teaching of Computing in schools, arguing that it provides an understanding of the digital world and tools to solve complex problems [SBC 2017].

Considering the context of inclusive education, it is essential that all students, including those with disabilities or specific educational needs, have access to CT teaching. The inclusive paradigm promotes collective approaches that respect individual differences, creating environments conducive to inclusive learning, especially for people with Intellectual Disabilities (ID), who have limited abilities in attention, memorization, understanding concepts, generalization, and abstraction [Stainback and Stainback 1999, Malaquias et al. 2012].

Therefore, children with ID can benefit from CT by stimulating and exercising new intellectual skills through appropriate methods and tools. Serious Digital Games (SDG) are effective resources in this context because they facilitate the acquisition of a CT and promote the exercise of cognitive functions through playful experiences [Oliveira et al. 2015].

This paper presents the design, prototyping, and evaluation of a new game template for a platform for authoring serious games, named RUFUS[1], which already exists and currently has 5 templates for creating games by non-specialist professionals in Computing (namely: quiz games, puzzle, narrative, item collection, reverse narrative). The focus of the new template is to guide professionals in creating games that exercise comprehension, generalization and abstraction skills in children with Autism Spectrum Disorder (ASD), using CT principles.

[1]https://rufus.icmc.usp.br/login

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This document is composed of the following parts: Section 2 presents the theoretical foundation to understand the context, Section 3 presents related work, Section 4 details the design process and evaluation of the Web template and, finally, Section 5 covers final considerations and future work.

2. Theoretical Reference

This section addresses the main concepts that underlie this research. Understanding the interrelationship between such concepts is essential for developing inclusive educational tools, allowing CT to be exercised by children with ASD or ID through personalized games created by professionals using EUD platforms.

Papert first introduced Computational Thinking (CT) in 1980 [Papert 1980] through the development of constructionism, a theory based on Piaget's constructivism. This approach emphasizes the active role of children in constructing their own educational experiences. In his work, the author discusses computer culture and the relevance of technology in the teaching and learning process. In this and other investigations by Papert, it is clear that CT ideas already existed but had not been called with this specific term, nor was there, at the time, the dissemination of its principles [Brackmann 2017]. In 2006, Jeannette Wing,popularized the term CT through a scientific paper in which she described CT as a problem-solving approach that combines logical thinking with the programming constructs of Computer Science. She emphasizes that CT is a fundamental skill for everyone, not just computer scientists [Wing 2006].

The literature discusses several skills related to CT. For this work, the classification proposed by authors such as [Wing 2006, Brackmann 2017], and organizations such as BBC Learning [BBC 2015] and the Innovation Center for Brazilian Education (CIEB)[2]. They established four fundamental dimensions of CT, which are essential for problem-solving. These dimensions are known as the Pillars of CT and include: a) **Decomposition**: This pillar implies the fragmentation of the problem into smaller and more manageable components, aiming to facilitate its resolution [Raabe et al. 2018]; b) **Pattern Recognition**: Identifies the common characteristics between problems and their solutions. These patterns are similarities shared by some problems, which allows for a more efficient solution [Brackmann 2017]; c) **Abstraction**: This concept implies the analysis and categorization of data, excluding unnecessary elements and highlighting those that are pertinent. Furthermore, it involves methods of organizing information into structures that facilitate problem-solving [Raabe et al. 2018]; d) **Algorithm**: It is a comprehensive concept encompassing the other CT pillars. It consists of a clear plan, strategy, or set of instructions necessary to solve a specific problem. These instructions are described and organized to achieve the desired objective [Raabe et al. 2018].

Intellectual Disability (ID): Is characterized by significant limitations in cognitive functioning and behavioral adaptation capacity, covering areas such as practical, interpersonal, and conceptual skills. This condition manifests itself from the earliest stages of development, generally before the age of 18 [AAIDD 2021]. In ID, there is a limitation in the development of the functions necessary to understand and interact with the environment (*e.g.*, Autism Spectrum Disorder (ASD), Down Syndrome, among others) [WHO et al. 1992].

Autism Spectrum Disorder (ASD): Is described as a complex and genetically heterogeneous neurodevelopmental disorder whose characteristics are due to difficulties in social interaction, difficulties in recognizing facial expressions, and repetitive and/or stereotypical behavior patterns [American Psychiatric Association 2014]. People with ASD may exhibit a variety of symptoms that are not specific to the disorder, including differences in cognitive abilities, expressive language, base-

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

line patterns, and psychopathological comorbidities. These variations can help identify subtypes within ASD [American Psychiatric Association 2014]. Thus, there is a wide range of symptoms and behaviors among individuals with ASD, both specific and non-specific to the disorder, which demands a personalized approach for each case.

In this context, the proposal to incorporate CT into pedagogical practices assumes a fundamental role, requiring an in-depth understanding of the individual characteristics of people with disabilities. This approach makes it possible to evaluate the relevance of applying each pillar of the CT, seeking to progressively expand the options and levels of complexity. Pedagogical practice must involve solving everyday problems, otherwise it will not be possible for people with disabilities to reach high levels of development [Ribeiro et al. 2021].

End-User Development (EUD): Is an approach that can be defined as a set of methods, techniques, and tools that aim to allow end-users who do not have programming experience to develop and adapt systems according to their needs, whether professional, educational, or leisure [Lieberman et al. 2006]. EUD generally refers to "active participation of end users in the software development process" [Costabile et al. 2005]. Two types of end-user activities can be identified from a user-centered design perspective: **Customization or Parameterization**, where users choose between alternative behaviors or interaction options already present in the application. In adaptive systems, the system performs this personalization automatically based on user behavior. **Program creation and modification** includes activities that involve creating or altering an existing software artifact [Lieberman et al. 2006].

The game template presented in this paper will be included in an authoring platform designed so that education professionals can create digital games. It is essential that these professionals (even without advanced technical experience) can create and customize games intuitively. This adaptation will allow players (the population of interest to professionals) to receive challenges suited to their level of knowledge and skill.

3. Related Work

To contextualize this work in the current scenario, a bibliographical search was carried out in databases such as *ACM Digital Library, Engineering Village, IEEE Xplore*, SBC-OpenLib 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 objective was to identify and analyze research that discusses the creation of serious games aimed at developing CT in children on the autism spectrum. As a result of this search, relevant papers were located in both international [Schmidt and Beck 2016, Munoz et al. 2018, Elshahawy et al. 2020] and national [Dutra et al. 2023, Honda et al. 2022, Macena et al. 2022, Souza and Mourão 2023] contexts. Below are three papers that were selected based on quality criteria.

CodaRoutine is a serious game for children on the autism spectrum, aimed at developing problem-solving skills and teaching basic programming concepts (sequence, conditional, and interaction). The game consists of three difficulty levels, and each has three stages. The game presents tasks related to children's daily activities, such as preparing a lunch box for school, preparing a backpack for the next school day, and decorating a Christmas tree [Elshahawy et al. 2020]. **Think and Wash** is an educational digital game that aims to intrinsically develop CT in neurotypical children and those with intellectual disabilities. The game focuses on the process of washing clothes, and throughout the three phases, the player must perform tasks such as separating the clothes, then the washing process, and finally, storing the already washed clothes. Each phase deals with the pillars of the CT and allows the player to develop skills such as logical and critical reasoning, problem-solving, and abstraction, among others [Dutra et al. 2022, Dutra et al. 2023]. **Virtuous** is aimed at young people on the autistic spectrum at school age (11-14 years old). The objective is that they can acquire specific social skills and, in parallel, be able to solve introductory computer programming problems with programmable virtual robots through a learning intervention based on digital games. The project uses a video game variant called MinecraftEdu, used in education to learn various areas such as geography and history. The environment allows players to program robots to perform various functions, such as digging or building a structure. Activities are performed in a block-based interface where players drag and drop icons to program their robots [Schmidt and Beck 2016].

The research shows promising results indicating that children with intellectual disabilities can develop CT-related skills through serious games. Therefore, this work aims to design and evaluate a template for creating serious digital game focused on exercising CT skills. A differentiating aspect is the adoption of the game authoring platform [da Hora Rodrigues et al. 2023, da Hora Rodrigues et al. 2022, Rodrigues et al. 2021], which will enable Education professionals to use them to create their own games in a personalized way, according to the learning objectives of each child, thus being a generalizable resource. The next section details the design and evaluation process of the game Web template designed in this work.

4. Authoring Platform for Digital Games

The authoring platform [da Hora Rodrigues et al. 2023, Malpartida and Rodrigues 2023] enables the creation of serious digital games by professionals in the areas of Health and Education. This platform consists of an authored Web interface aimed at planning and creating games by professionals, combined with a mobile application intended for direct interaction by players, target users of Health and/or Education professionals. Using 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. The platform currently offers five game mechanics (here called pre-defined templates): questions and answers (quiz), fitting (puzzle), collecting items (platform), narratives (storytelling), and inverted narrative. Through the Web interface, professionals are guided during the game creation process, and players access the game created using the platform's mobile application using credentials. Your interactions during the game are recorded and transmitted to the Web system, which generates detailed reports on the player's performance. Professionals can analyze such reports, allowing for specific interventions and treatment optimization. The following section describes the process of creating and evaluating the new Web template.

4.1. Template to create Computational Thinking games

The initial stage of **collecting requirements** focused on understanding the game's application scenario and formulating an appropriate approach to its design. Initially, a literature study was conducted, complemented by findings from resources available in other repositories, such as platforms and digital game stores. The study sought to identify games that promote the development of CT and learning skills in neurotypical children and children with ID. The main games identified and considered in this work were those described in Section 3. Accessibility guidelines were also considered when developing the prototype [Dutra 2022, Britto 2016, Pichiliani 2020].

The educational objective of the games to be developed with the template proposed in this work is related to the CT concept and problem-solving, including developing skills and abilities that encompass Decomposition, Pattern Recognition, Abstraction, and Algorithms. These pillars were considered in research into creating digital games found in the literature review and mentioned above [Dutra et al. 2022, Elshahawy et al. 2020]. Regarding the skills and abilities that will be developed in the game template, the curriculum presented by the Innovation Center for Brazilian Education (CIEB, in Portuguese) is being considered as a reference.

The activities of daily living were selected from exploratory research into studies and resources available on the Web. Digital stores with educational toys aimed at routine training in children were found. The two games selected were: Quadro Educativo and Magnetic Game My Routine. These games consider routine activities as goals (*e.g.*, waking up, taking a shower, brushing teeth) made up of elements or pieces (*e.g.*, comb, soap, toothpaste) that the child must organize according to their daily routine. The games are used by professionals such as therapists and teachers to help organize children's routines with their families in educational spaces and offices.

Regarding accessibility requirements, including those specific to people with ID, the works of [Dutra 2022] and [Britto 2016, Pichiliani 2020] were considered. Dutra's work presents 16 guidelines for ID, and Pichiliani's work presents 10 categories with specific guidelines for designing interfaces that focus on people with ASD.

Table 1 presents the list of generated requirements. The requirements identified in the literature and from other games were validated by education professionals from a partner institution of this project through guided use.

Table 1. Requirements Table. Source: Adapted from [Malpartida and Rodrigues 2023].

No	Requirements	Source
R1	**Fundamental CT Concepts:** Provide activities that facilitate exercise and understanding of concepts CT basics, aligned with objectives established educational institutions.	Definition of educational objectives [Raabe et al. 2018]
R2	**Daily Activities Presented in a Playful Way:** Include activities everyday life is presented in a game to engage players and facilitate learning through practical and fun experiences	Definition of educational objectives [Raabe et al. 2018]
R3	**Simple and Intuitive Interface:** Have a simple user interface and intuitive that facilitates understanding, avoiding the inclusion of too many elements on the screen. Complex animations, no fonts conventional, and flashing elements or shining must be eliminated.	Literature/Guidelines [Pichiliani 2020, Dutra et al. 2021]
R4	**Standardized Interface:** Present a standardized interface with colors, consistent icons and symbols in all screens and features.	Literature/Guidelines [Pichiliani 2020, Dutra et al. 2021]
R5	**Essential Control Buttons:** Include control buttons like Help, Pause, Back, and Cancel, avoiding automatic redirects to ensure the player has control total during the game.	Literature/Guidelines [Pichiliani 2020, Dutra et al. 2021]
R6	**Text and Narration Options:** Offer text and narration options to make it accessible to children who do not have full capacity to reading or who are starting to literacy phase.	Literature/Guidelines [Pichiliani 2020, Dutra et al. 2021]
R7	**Progressive Difficulty Levels:** The game must offer different levels of difficulty, with challenges that increase gradually as the player's skills progress.	Literature/Guidelines [Dutra et al. 2021]
R8	**Elements of Engagement:** Incorporate engagement elements like scores and lives to keep player motivation.	Literature/Guidelines [Dutra et al. 2021]
R9	**Visual and Sound Feedback:** Provide Immediate visual and audible feedback on response to players' actions, helping them understand their answers and actions.	Literature/Guidelines [Pichiliani 2020, Dutra et al. 2021]
R10	**Personalization by Mediator:** Allow a mediator, such as a teacher or guardian, personalize the content, configuring phases and difficulty levels according to the specific needs of players.	Literature/Guidelines [Dutra et al. 2021]

After collecting requirements for the new game template for the authoring platform, a medium-fidelity **prototype** was created using the Figma tool.

Games created using this template should help develop concept understanding, generalization, and abstraction skills in children on the autism spectrum using the pillars of the CT (requirement R1). The game items and activities corresponding to the children's daily routine (R2) must be configured on the authoring platform. In addition to allowing the creation of games and user registration (R10), the platform's Web interface provides a report on the player's interaction with the game. Following accessibility guidelines, the game has a simple (R3) and standardized (R4) interface, including control buttons such as help and pause (R5). It also provides text and narration options (R6), essential for children who are illiterate or have reading difficulties. The new template should allow the construction of games in 3 phases, with 3 difficulty levels (R7), which incorporate engaging elements such as scoring, a determined number of lives (R8), and immediate feedback (R9). The aforementioned settings will be carried out by the professional mediator through the Web interface, enabling customization to meet the specific needs of each player (R10).

Each game's three phases represent items and activities in children's daily routines. In Phase 1 (Pattern Recognition), the player must match personal hygiene items with their corresponding shadows. Phase 2 (Decomposition) requires the player to match hygiene items with corresponding routine activities. In Phase 3 (Algorithm) the player places items in a logical order based on the activity presented.

During prototyping, the mechanics/templates already implemented on the platform were analyzed to reference the configuration of the new mechanics and to observe the reuse of existing parts/mechanics. The home screens collect information common to all other mechanics, namely: name, description and associated audio. 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 body hygiene items (*e.g.*, soap, towel, toothpaste), 3) children's routine activities (*e.g.*, washing hands, taking a shower, waking up) these activities can be in text, image or audio format to facilitate children's understanding. Figure 1 illustrates the configuration of these elements for the first two phases (for space reasons).

[a] [b]

Figure 1. Prototyping of new template screens: a) Screen with Pattern Recognition and b) Screen with Decomposition.

The professional must also configure the phases and levels according to the educational objectives, assigning names, icons, and background images to each phase and level created. Then, the professional can adjust the items and activities that will be viewed by the player, configuring three options related to the development of the pillars of CT, they are: 1) Fit - employs Pattern Recognition as the primary pillar, and the other pillars are complementary. Figure 1 (a) illustrates this option; 2) Decomposition Option - refers to the development of the Decomposition primary pillar. This option is illustrated in Figure 1(b) and 3) Sequence Option - linked to the Algorithm pillar. The Abstraction pillar is developed implicitly during all phases of the game. Finally, as with other mechanics, the professional can configure the positive and negative feedback parameters, and can be in textual or sound format.

The **evaluation** step sought to identify and correct any problems or errors before implementing the mechanics on the platform so the team could go back to previous steps to promote corrections or the inclusion of new requirements.

For the evaluation, the Cognitive Walkthrough (CW) [Polson et al. 1992] method was used, an inspection method that evaluates usability by analyzing the route a user would supposedly take to achieve their objective when interacting with a system interface interactive. A variant of CW was also used, called Cognitive Barriers Walkthrough (CBW), aimed at verifying the ease of learning digital games [Santos et al. 2023].

Furthermore, 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 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].

The evaluation was carried out at the partner institution of this project, which assists children and adolescents with intellectual disabilities. It should be noted that these activities were planned and validated by a Brazilian research ethics committee, with protocol number 76853723.3. 0000.5504. The activities carried out are detailed below.

Preparation: Tasks and actions necessary for the evaluation were defined with professionals from the institution, as well as all documents and terms necessary for conducting it. The defined task was to interact with the prototyped game by creating a Computational Thinking type game composed of three levels, where the first is of the Fitting type, the second level of the Decomposition type, and the last level of the Sequence type.

Participants: Two teachers (here called P) from the institution participated in the evaluation. The teachers were invited by the institution's pedagogical coordinator. There were two women, specialists in Pedagogy, with at least five years of experience in pedagogical activities with children on the autism spectrum. One has experience in using technologies for this target audience and neither has experience in using digital games for educational purposes.

Conduction: For data collection, a face-to-face meeting was held at the institution with the participants. They were already aware of the research context, and it was explained that they would evaluate the Web interface prototype, where they would have to create a game. They read and signed the consent form and authorization to use images and data.

Then, they were invited to create a game using the Figma tool. The assessment was carried out individually, and they shared their impressions during the interaction. Each participant answered the 7 questions of the CBW method while performing the task: Initial-Q: Would the user be able to express the task to be performed?; Q1: Would the user try to achieve the correct effect? Q2: Would the user stay focused on the task? Q3: Would the user realize that the correct action is available? Q4: Would the user be able to associate the correct action with the effect they are trying to achieve? Q5: If the correct action is taken, would the user realize they are progressing toward completing the task? Final-Q: Would the user perceive an incentive to continue the task?

The Zoom tool was used to observe and record each participant's interaction with the prototype. After interacting with the prototype, they responded to the SUS and SAM questionnaires, and finally, a semi-structured interview was carried out where they verified the requirements considered by the researchers to carry out the game design. Assessments lasted approximately 40 minutes. *Consolidation of results:*

No relevant problems were found during the prototype evaluation, and the participants could complete the assigned task. The main contributions were related to the game's customization options, such as the color range and font size, which must be appropriate depending on the player's characteristics. Regarding font size, P2 indicated that *"It is important to be considerate of those students who could have low vision problems. The institution, for now, does not have these cases, but the professional should have this option in the game creation process"*. Regarding the color configuration, P2 indicated that *"Some students, depending on the color, may have a crisis. An example is the color yellow. The teacher configuring the game must identify these characteristics and have the option to activate or deactivate certain colors"*.

For this last observation, it was mentioned that these aspects can be customized by the professional during the game creation process. Currently, the authoring platform offers 8 Families of assets, where professionals can configure the game's visual identity with up to 8 options with color ranges and elements that can be included in the game's appearance.

The results of the SUS questionnaire both participants rated the usability of the template's web interface as Acceptable (P1 pointed out 90 points - Excellent; P2 pointed out 100 points - Excellent). For the SAM questionnaire, all domains had positive results in both participants (P1: Pleasure = 7; Arousal = 7; Dominance = 9. P2: Pleasure = 9; Arousal = 9; Dominance = 9).

Report of results: The evaluation of the Web template did not reveal any significant problems, and the participants could complete the proposed task. *Font Size*: Implement an option to adjust the font size, enabling the game to be adapted for students with low vision;

Color Settings: Develop a functionality that allows the teacher to activate or deactivate certain colors to avoid crises in sensitive students. Respecting this suggestion, the authoring platform already provides options for configuring the game's visual identity. Professionals can choose between eight color ranges and visual elements.

In general, participants emphasized the ease and clarity of the template. They highlighted that the playful environment keeps children focused on the proposed activities, favoring the learning process. Furthermore, they highlighted the importance of practicing sequence exercises, as many children have difficulty following the order of activities.

The results of the professionals' assessments are being analyzed with the platform's development team. This analysis can lead to adjustments in the proposal and, thus, to the Web template. It should be noted that game implementation activities are currently being carried out and after implementing the mechanics on the platform, longitudinal case studies will be conducted with children and adolescents from the institution to verify its effectiveness.

5. Final Remarks

This paper described part of the activities of a broader project that aims to provide a serious digital game to support health and education professionals in exercising skills related to the pillars of CT in children on the autistic spectrum.

The literature presents other similar games. However, the difference in this proposal is that it allows education professionals to customize the game to suit each player's specific needs. Furthermore, interaction data with the game is sent to professionals so that they can analyze and conduct interventions that they deem necessary, for example.

As a work in progress, the group is improving the implementation of the web game template, which has already brought added changes based on the evaluation of the interfaces. Once implementation is complete, longitudinal case studies (medium term) will be carried out with children on the autism spectrum from the same institution, to evaluate the exercise of CP skills, especially in the context of daily living activities.

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