# Computational Thinking Game Design Based on the Bebras Challenge: A Controlled Experiment.

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***Abstract.*** *The use of games is a promising approach to engage students and to teach computational thinking (CT). However, few educational games are related to this topic. One reason for that is the difficult to create CT Game Designs. In this context, this work has the objective of verifying if interesting computational thinking games can be created from the analysis of Bebras Challenge tasks, an international initiative that presents a set of attractive and well-elaborated tasks to exercise and evaluate computational thinking (CT) abilities. A controlled experiment was performed and the achieved results indicate that Bebras tasks are a good source of inspiration for designing CT games. Hence, their use can support the creation of new CT games, ensuring a balanced level of educational and entertainment aspects.*

## 1. Introduction

According to [Prensky,2001], today's youngsters are considered digital natives and are born in a world surrounded by technology with access to computers, video games, and the Internet. It is noticeable that the technology has had a substantial impact on society and the requirements of modern vocational training. Indeed, the list of competencies required for this century is extensive, and computational thinking is one of the most significant of them [Blikstein, 2008].

Computational Thinking (CT) can be defined as a problem-solving process that encompasses the concepts, skills, and practices of Computer Science [ Wing,2006]. In this context, CT provides one of the most important contributions of computer science to the world since it trains citizens with the expertise and skills needed to live and thrive in a world that is increasingly technological and global [Sica, 2008]. Because of that, logical reasoning and computational thinking is taught in several countries since the first scholar years.

In this sense, some initiatives use digital games to work on CT skills, such as Hour of Code (Code.org). However, there is a lack of research and development of digital educational games focused on computational thinking [Silva et. al. 2007]. Most of the existing games are limited to teach basic program concepts. This lack is due to several factors, such as the difficulty of idealizing games that develop the different skills related to CT: data collection, analysis, and representation; problem decomposition; abstraction; algorithms; automation; parallelism; and simulation. As a result, despite the significant number of digital educational games available, only a few of them focus on CT skills.

To make the development of CT games easier, game designers can use materials developed by renowned international initiatives such as the Bebras Challenge, which aims to motivate students to become interested in computing [Dagienė et al. 2008]. The Bebras Challenge was created in 2004, and more than 1.5 million students from 38 different countries attended the 2016 edition. Studies show that Bebras have played significant role in promoting reasoning, innovative learning, and the strengthening of computational thinking using carefully chosen computer concepts [Dagienė et al. 2016].

In this context, this article presents a controlled experiment that investigates the elaboration of CT game designs based on the tasks proposed by the Bebras Challenge. Positive results indicate the potential that this material has of boosting games focused on computational thinking, with an appropriate level of educational and entertainment aspects.

This article is structured in seven sections. Section 2 shows an overview of Blended Courses. Section 3 describes experimental planning and its characteristics. Section 4 introduces the Execution and Data Collection. Section 5 presents data interpretation. And section 6 presents the final considerations and finally we have the future work section.

## 2. Computational Thinking

The concept of Computational Thinking (CT) is related to aspects that go from logical reasoning to problem-solving [Wing et al. 2016]. In the international scenario, this theme has provoked transformations in the curriculum in several countries where programming or Computer Science is being introduced at schools [UK DEPARTMENT FOR EDUCATION, 2013].

In collaboration with the Computer Science Teachers Association (CSTA) and the National Science Foundation (NSF), The International Society for Technology in Education (ISTE) has developed an operational definition of computational thinking which describes the skills that students must have at the end of high school [CSTA&ISTE, 2011], including the following:

- data collection, or the ability to collect appropriate information;
- data analysis, which means giving meaning to data, finding patterns, and drawing conclusions;
- data representation, which involves organizing and describing the data in graphs, words, images, and tables;
- decomposition, or dividing tasks into smaller pieces to find a solution;
- abstraction, that is, the ability to identify and extract relevant information to define main ideas;
- algorithmic thinking, defining sequences of instructions to solve similar problems or to perform a particular task;
- automation, or making computers or machines perform repetitive tasks;
- parallelism, which means organizing resources for the accomplishment of simultaneous tasks and in a cooperative way to reach a specific objective;
- simulation, which develops models to mimic real-world processes;
- and generalization, or creating models, rules, principles, or theories from observed patterns to test the expected results.

In this context, works in the literature that work on computational thinking skills such as the one by [Raabe et al. 2017] presented a puzzle game that uses performance in solving activities at each stage to bring up a TC score per player. As we can also see in the study [Araújo et. al 2018] , which brings an investigation of the questions produced by the Bebras test that addresses and assesses CT skills working with the Item Response Theory method to estimate the parameters of the item.

Another environment in which computational thinking emerged is in mathematics teaching studies such as that of [Bobsin et al 2020] which addresses activities developed in an extension project, applied in elementary schools, which aims to contextualize Mathematics with Computational Thinking.

## 2.1 Bebras Challenge Tasks

Bebras is an international initiative that aims to promote informatics and computational thinking among students of all ages [Dagienė et al. 2006]. According to its founders, this initiative intends to make children and adolescents interested in typical problems of Computer Science without requiring any knowledge as a prerequisite [Dagienė et al.2017]. Currently, the challenge is organized in more than 38 countries and aims to get students from all around the world to become enthusiastic about computing.

A Bebras test consists of 18 to 24 multiple choice tasks (assignments) to be solved by students in 45 to 55 minutes. In general, all the questions are indirectly related to concepts of computational thinking and logic [Dagienė, 2006]. These tasks are created following a rigorous process to ensure their quality. A sample task is presented in Figure 1, and its commented answer is shown in Figure 2.

**Figure 1: Bebras Challenge's sample task (ice cream).**


**Figure 2: Answer and comments for the "ice cream" task.**

**Answer:**
... Strawberry, Smurf and Chocolate!

**Explanation:**
What is on top must be put there last! Similarly, the first flavour requested must be the first scoop on the cone. So we need to reverse the order:

To get a cone with Chocolate on top of Smurf both of which are on Strawberry we must ask for "an ice-cream with Strawberry, Smurf and Chocolate!"

**It's Computational Thinking:**
*Concepts - Abstraction (AB), Generalisation (GE)*

Order matters! If we asked for the flavours in a different order, we would have an entirely different ice cream cone.

One of the first things computer scientists learn is how important it is to have everything correctly ordered. They also need to understand how others understand. Without knowing exactly how the ice-cream shop works, we could not determine the correct order! We had to imagine first what will happen based on what we say. Just like computer scientists, who like to think ahead. The actual order used in this task is stack order. In particular "Last in, First out" or LIFO.

## 2.2 Games and Computational Thinking

There is research in the literature related to the use of games and the development of CT abilities. [Kazimoglu et al. 2014] describes a digital game model for learning computational thinking skills. In their work, the authors created a game infrastructure in which students can practice and develop their computational thinking skills with little or no programming knowledge.

Another work investigated if students can recognize computational thinking patterns from game programming experiences [Basawapatna et al. 2011]. They concluded that most of the participants understood and identified patterns in a variety of contexts. In this study, the authors paused to understand whether participants could transfer the knowledge they gained from the programming game to scientific simulations. Although there are many publications related to the use of games in education, most of them are not associated with CT.

# 3. Experimental Planning

This section presents the planning of a controlled experiment, which follows the method defined by [Wohlin et al. 2012]. This type of is study was considered appropriate for the goal of this work since it allows the development of causal and effect analyses.

## 3.1 Research Goal and Hypotheses

This experiment aims to investigate the benefits and limitations of creating CT Game Designs inspired by tasks from the Bebras Challenge.

To guide the planning of this study, the following research hypotheses were defined:

RH1. Bebras Challenge tasks facilitate the idealization of CT games.

RH2. The game does not lose its attractiveness, engagement, and creativity aspects when based on Bebras tasks.

RH3. Elaborating game designs based on Bebras tasks favors the creative process.

RH4. Elaborating game designs based on Bebras tasks increases the quality of the pedagogical aspects.

## 3.2 Experimental Design

This experiment manipulates two treatments to gather evidence about the presented research hypotheses: (i) the proposed treatment, which is the development of game designs inspired by Bebras tasks; and (ii), the standard treatment, which is the idealization of CT game designs only based on the definition of the target CT abilities.

In such an experiment, two factors can significantly influence and compromise the results. The first one is the participants' experience since previous knowledge and experience can directly impact the performance of the game design activity. The second factor is the target CT ability, which can facilitate or not the game design activity.

To control the influence of these two factors in the experiment results, we use the Latin Square experiment design [Box et al. 2005]. The goal of this design of experiment is to control the effect of two noise factors. In this experiment, the Latin Square is organized as a two-by-two matrix, as shown in Table 1. Thus, participants are shown as indexes of the lines, and abilities are portrayed as indexes of the columns. Therefore, participant 1 will apply treatment 1 to create a game design considering ability "n", and apply treatment 2 to create a game design considering ability "n+1". A similar procedure (but inverted) is performed by participant 2. With that, all participants will have contact with all treatments and skills involved in the experiment. Allocations of treatments, skills, and participants are performed randomly.

**Table 1: Latin Square used in the experiment.**

| Latin Square | CT Ability n | CT Ability n+1 |
|---|---|---|
| Participant 1 | Treatment 1 | Treatment 2 |
| Participant 2 | Treatment 2 | Treatment1 |

We chose to replicate the Latin Squares by varying the abilities (columns) and keeping the same participants (lines) in each Latin Square. With that, it is possible to have a greater diversity of abilities (large capacity of generalization of results) without inserting significant variability of participant profile.

Five Latin Square replicas are planned. Thus, the experiment requires the selection of two participants and ten CT abilities, two different abilities per square.

### 3.3 Experimental Material

The ten CT abilities selected for this experiment are those presented in Section 2: collection, analysis, data representation, problem decomposition, abstraction, algorithms, automation, parallelism, generalization, and simulation. In this way, the standard treatment is to create a game design based on the description of the ability given by the International Society for Technology in Education (ISTE), in collaboration with the Computer Science Teachers Association (CSTA) and the National Science Foundation (NSF).

For the proposed treatment, one Bebras task (and its commented answer) was selected for each ability manipulated by the experiment. For both treatments, participants received documents showing the description and tips or examples of how that skill can be worked on with students.

### 3.4 Participants and Their Tasks

For running the experiment, two participant profiles are required. The first profile is for those developing the game designs. For that, the selection process considered developers with good and similar experience (two years) in game design and development.

The second profile is for evaluating the quality of the game designs produced during this experiment. Three experienced game developers and eight computer science professors were considered for this profile since the subject involves both game designs and computational thinking. All participants had at least four years of experience in their profession.

### 3.5 Experimental Procedures

The experiment was organized in several meetings, according to the participants' availability. The first meeting was used to allocate participants to the Latin Squares (randomization procedures) and explain the experiment process. The participants received a simplified model of a Game Design Document to organize their game design proposals, containing the following fields: game title, objectives, general description, target CT skills, and input (Bebras task or CT ability description).

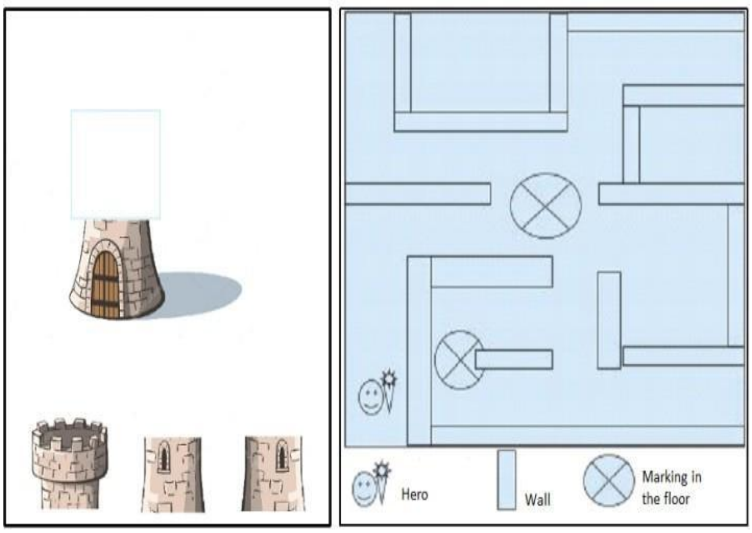
The following meetings were used to develop the game designs, using the input (CT ability description or Bebras task) according to the configuration of the Latin Squares.

## 4. Execution and Data Collection

The experiment was performed according to its planning and took one month to be concluded. Each participant developed ten game designs, resulting in 20 game designs in total. Figure 3 shows the game designs developed for the CT ability "abstraction". The game design on the left side (Medieval Building) was developed based on the Bebras task shown in Figure 2 (ice cream). The other game design (Maze) was idealized based only on the ability description.

In the Medieval Building game, the player must stack the blocks in the right order. The score is defined by the time used to reach the solution and the number of correct and incorrect moves. The buildings used in the game change in appearances, shapes, and sizes. It is possible to notice the relation between the game design and the Bebras "ice cream" task.

**Figure 3: Medieval building and maze game designs.**



In the Maze game, the player must find the labyrinth's exit, moving his or her character using the keyboard's arrow keys. The game has a top-down view, and the character can move in eight directions. Player's vision is defined by the intensity of a torch that illuminates the scene. While exploring the maze, visited locations are marked on the floor, allowing the player to know if he or she is walking in circles. Also, the player's torch will become weaker or stronger, depending on the distance to the end of the maze. Therefore, the player should combine the use of the torch and the marking on the floor to find a solution.

In addition to the development of the game designs, participants of the first group answered a questionnaire comparing the proposed and the standard treatments. A summary is shown in Table 2 and results are interpreted Section 5.

**Table 2:Participants' opinion.**

| Question | Proposed Treatment (Bebras tasks) | Standard Treatment |
|---|---|---|
| How effective was the creation of the game design? | P1: Extremely effective<br>P2: Very effective | P1: Not effective<br>P2: Not effective |
| How was the demanded effort? | P1: Medium<br>P2: Low | P1: High<br>P2: Medium |
| How did it affect creativity? | P1: Helped<br>P2: Helped | P1: Restricted<br>P2: Helped |
| Did you have enough time? | P1: Yes<br>P2: Yes | P1: Yes<br>P2: Yes |

The second phase of the experiment evaluates the developed game designs using a questionnaire (https://goo.gl/XSvkp4). The 20 game designs were evaluated by a group of 11 professionals (game designers and educators), and a summary of the results is presented in Table 3.

**Table 3: Evaluation of the game designs.**

| % of game designs considered: | Proposed Treatment | Standard Treatment |
|---|---|---|
| Interesting | 70% | 20% |
| Comprehensive | 80% | 60% |
| Funny | 60% | 20% |
| Creative | 80% | 60% |
| Aligned with the proposed CT abilities | 60% | 40% |

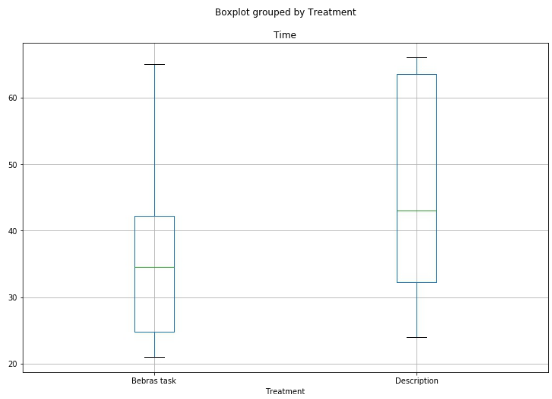
## 5. Data Interpretation

In this section, the collected data is interpreted and used to support or reject each hypothesis related to this experiment.

**RH1.** Bebras Challenge tasks facilitate the idealization of CT games.

In terms of effort (data available at https://goo.gl/1arjXz), Figure 4 shows that the time in minutes to create the game designs using the proposed treatment was slightly shorter when compared to the standard treatment. However, the difference was not considered statistically significant by ANOVA analysis (p-value=0.18) at α=0.05, supporting the null hypothesis of a similar effort in the average. In terms of participant opinion, both participants rated the proposed treatment better than the standard treatment (first two questions presented in Table 2). Also, both participants thought the standard treatment was not effective in practice. This is probably due to the high level of abstract concepts involved in the definition of each skill.

**Figure 4: Time in minutes taken to create the Game Designs.**




In summary, the results of this experiment weakly support the research hypothesis RH1, since the time difference did not show statistical significance and the number of participants creating game design was small. However, actual results justify the conduction of further studies with a large number of participants.

**RH2.** The game does not lose its attractiveness, engagement, and creativity aspects when based on the Bebras tasks.

All these game design aspects (attractiveness, engagement, and creativity) were analyzed by a group of game designers not involved in the first part of this experiment (idealization of the game designs). According to the data presented in Table 3, in both treatments, not all of the produced game designs had these characteristics. However, the proportion of game designs contemplating each aspect individually is higher when considered the proposed treatment. For instance, 70% of the game designs produced based on the Bebras tasks were considered interesting. On the other hand, only 20% of the game designs produced based on the ability description were considered interesting. Therefore, these results support the research hypotheses H2.

**RH3.** Elaborating game designs based on Bebras tasks favors the creative process.

Evidence for this hypothesis is also provided by Table 4 since 80% of the produced game designs based on the proposed treatment were considered creative. This means that two game designs were not considered creative. However, four game designs produced using the standard treatment were not considered creative.

Based on that, research hypothesis H3 is supported by the results, since the creative aspect was more frequently found in the game designs produced using the proposed treatment.

**RH4.** Elaborating game designs based on Bebras tasks increases the quality of the pedagogical aspects.

Regarding this research hypothesis, evidence can be collected using the last question presented in Table 3. Computer science educators provided the answers to this question. They evaluated the game design documents and indicated which CT ability was present. Then, their responses were compared to the ability proposed for the game design. A higher percentage of game designs produced using the proposed treatment were considered aligned with the target CT abilities. This way, there is evidence that supports research hypothesis 4.

### 5.1Threats to Validity

Concerning the participants, only two of them performed game design development activities in the experiment. The remaining participants executed game design evaluations. This way, the results of the experiment are limited to the profile of these two participants. However, both participants had good experience with game design and game development, which is a standard profile in many game companies. Because of that, we expect that similar results should be observed in industrial contexts.

Another threat to validity is that game design is a creative process. Therefore, the same participant can have different performances according to intrinsic factors. For instance, one participant took 120 minutes to elaborate a specific game design, almost four times longer than taken in most other game designs. However, in the 20 game designs developed, there was only one case like that. For this reason, we believe the results of the experiment were not significantly affected by that.

## 6. Conclusion

This paper presented an experimental study that investigated four hypotheses about the idealization of game designs based on Bebras tasks. The Bebras challenge is an international initiative that elaborates tasks involving computer science concepts in a rigorous process.

With this experiment, evidences were provided supporting the investigated research hypotheses. It was verified that the Bebras Challenge tasks facilitated the idealization of CT games in different ways. It also enabled the creation of games with essential aspects, such as recreation, engagement, and creativity. It was observed that the use of the Bebras tasks did not limit the game design's creative process. Also, we found that it increased the chance to achieve interesting CT games in terms of educational aspects.

As a result, the evidence collected through this experiment supports that the Bebras Challenge is a good source of inspiration for creating CT games. Hence, this result can promote the development of more exciting games that can disseminate Computational Thinking at schools.

## 7. Future Works

There are some future works that can be carried out from this work, such as example:

• The implementation and evaluation of the digital games of each game design produced in the studies, as well as their application in schools, aiming to verify the real impact on the development of computational thinking skills in students.

• Develop a detailed game design process for digital games aimed at work on computational thinking.

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