Battleships: A Digital Game for the Development of Computational Thinking in Elementary School

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Abstract. *Computational Thinking is a method used to solve problems, based on the fundamentals and techniques of Computer Science, which is present in the norms on computing in Basic Education (complement to the BNCC). In a few years, schools should be implementing such norms. Thus, it is essential that didactic resources, tools, as well as adequate training be made available to the school network. Therefore, in order to contribute to this, this work proposes a digital game that deals with the organization and searches for information, in order to introduce some concepts and techniques of Computational Thinking; and it reports the results of training Basic Education teachers in the proposed activity.*

1. Introduction

The impact of **C**omputer **S**cience (**CS**) on daily life has guide initiatives and efforts to make the education in this area available to everyone. Influenced by Wing's (2006) important work on **C**omputational **T**hinking (**CT**), the perception of CS education has come to understand computing not only as coding/programming but as the ability to solve problems. For Wing (2006), CT skills, being general purpose, should be learned by everyone, not just CS professionals. In this sense, CT development already in the early years of learning is recommended [Barr and Stephenson 2011] and recent works show the application and effectiveness of different practices allied to CT in Basic Education, such as unplugged computing [Grebogy et al. 2021], block programming [Sousa et al. 2020], and robotics [Bakala et al. 2021].

Despite the expansion of research on CT in Brazil in the last years [França and Tedesco 2019], the recent approval of the Standards on Computing in Basic Education – Complement to the National Common Curricular Base (BNCC) [Brazil 2022] by the National Education Council, which has CT as one of the three main axes for the development of specific computing skills, can bring challenges to educators. Professional training, the availability of adequate teaching materials, and the application of effective methodologies are some examples. Additionally, activities that promote the development of the objects of knowledge[1] listed by the BNCC for each level of Basic Education are necessary. Therefore, considering the availability of adequate resources/training for the community, a digital game is proposed, tutorials were developed, and a training with teachers was carried out.

[1]In BNCC, objects of knowledge refer to contents, concepts, and processes organized into thematic units [Brazil 2017].

Thus, this paper presents an educational digital game for elementary students, named Battleships, which promotes the development of CT skills by exploring the concept of the main algorithms used as a basis for computer search; and a report on the formation/qualification of basic education teachers with the game – since not only the proposition of resources is necessary, but also the formation of teachers. The game is divided into three tasks, which correspond to three search methods for finding information: sequential/linear search, binary search, and hash-based search. The game is a "plugged-in" alternative to the unplugged activity "Battleships – Searching algorithms" [Bell et al. 2005]. This kind of games have a highly positive effect on the learning process, since they attract students simply and dynamically, turning them into protagonists of their learning processes [Noemí and Máximo 2014].

Some works also present proposals for "plugged" activities based on the activities of Bell et al. (2005), with the aim of developing CT skills. Lima and Rebouças (2021), for example, present the application "Computação Plugada Ordenação", which aims to teach basic computing concepts – related to sorting algorithms – to children and was based on the "Lightest and heaviest" activity. Figueiredo et al. (2021) present the "Pixel" application, based on the "Color by numbers" activity [Bell et al. 2005], which aims to teach about image representation through information and activities to exercise the contents presented. In the context of digital games, some works present proposals to promote the development of CT skills in children. Dutra et al. (2021) propose the educational game "Super ThinkWash" which aims to promote the development of CT skills in children at the beginning of the literacy process, as well as working on basic concepts of Mathematics. Henriques et al. (2021) present the game "Léo & Maia", a way to promote CT in children through the construction of algorithms from a specific set of instructions to complete the phases of the activity.

The rest of this paper is organized as follows. Section 2 presents the main concepts of CT and its contextualization. Section 3 describes the proposed game and details its tasks/phases, as well as exposes the CT concepts and BNCC skills covered by it. Section 4 reports on the training course offered to Basic Education teachers from the Pelotas public school system about the game. Section 5 presents the results and discussions regarding the course offered to the teachers. Section 6 concludes the paper and indicates future works.

2. Computational Thinking

The term "Computational Thinking" became popular and started circulating in the scientific community in 2006, when Jeanette Wing published an article analyzing a set of skills that computer professionals develop for problem-solving [Wing 2006]. Back to the present, all current students will live a life heavily influenced by computing – and many of them will work in fields involved in or influenced by computing. Therefore, it is no longer sufficient to wait until higher education to begin CT development [Barr and Stephenson 2011]. However, for CT to be properly and effectively explored in Basic Education, Barr and Stephenson (2011) point out some questions that must be answered, such as:

- What would CT look like in the classroom?
- What are the skills that students would demonstrate?

- What would a teacher need in order to put CT into practice?
- What are teachers already doing that could be modified and extended?

In order to answer these questions, the Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE) [ISTE and CSTA 2011] have collaborated to create support materials and references for CT development, such as the Computational Thinking Leadership Toolkit [ISTE 2011]. In this material, 9 important skills that are part of the CT are defined. Table 1 shows these skills and their definitions objectively.

Table 1. Skills of CT defined by [ISTE 2011]

Data Collection	**Data Analysis**	**Data Representation**
The process of gathering appropriate information.	Making sense of data, finding patterns, and drawing conclusions.	Depicting and organizing data in appropriate graphs, chart, words, or images.
Problem Decomposition	**Abstraction**	**Algorithms & Procedures**
Breaking down tasks into smaller, manageable parts.	Reducing complexity define main idea.	Series of ordered steps taken to solve a problem or achieve some end.
Automation	**Simulation**	**Parallelization**
Having computers or machines do repetitive or tedious tasks.	Representation or model of a process. Simulation also involves running experiments using models.	Organize resources to simultaneously carry out tasks to reach a commom goal.

3. Battleships Game

Computers are often required to find certain information in large collections of data and consequently need to develop agile and efficient methods to find this information. In this sense, Battleships consists of the incremental application of a game that deals with the organization and search of information, by demonstrating different search methods: sequential/linear search, binary search, and hash-based search. Thus, the educational game allows identifying, understanding, and comparing different methods (algorithms) for searching data in lists. The game is meant for elementary students and promotes the development of CT skills – according to the Standards on Computing in Basic Education [Brazil 2022] – as well as BNCC related skills. The skills of the CT (1 to 3) and BNCC (4 to 7) are as follows:

1. (EF02CO01) Identify behavior patterns (examples: playing games, day-to-day routines, etc.).
2. (EF05CO06) Identify, understand and compare different methods (algorithms) for searching data in lists (sequential, binary, hashing, etc.).
3. (EF06CO07) Identify problems from different areas of knowledge and create solutions using the problem decomposition skill.
4. (EF03MA01) Read, write and compare natural numbers up to the order of thousand units, establishing relationships between numerical records and in the native language.

5. (EF04MA01) Read, write and sort natural numbers up to the order of tens of thousands.
6. (EF05MA01) Read, write and sort natural numbers up to the order of hundreds of thousands with an understanding of the main features of the decimal number system.
7. (EF07MA03) Compare and sort whole numbers in different contexts, including history, associate them with points on the number line, and use them in situations involving addition and subtraction.

Battleships[2] is an educational game (Figure 1) developed on the Unity platform [Technologies 2022], using C# codes, based on the "Battleships – Searching algorithms" unplugged activity [Bell et al. 2005]. The game was developed in Portuguese and has the same objective as the original Battleships game: sink the opponent's ship with as few shots as possible. The activity consists of three tasks (phases) and, in each one, the player plays against the computer. Before the game starts, the player chooses a number that will represent his chosen ship, that is, the one that the opponent (computer) must sink. The battlefield is composed of 26 ships that are identified by numbers, while their positions on the board are represented by letters. Additionally, the identification (number) of each ship is hidden, only its location (letter) is visible. So every time a ship is hit, the number hidden by it is shown. The number of the opponent's ship that the player must sink is shown at the top of the screen. Therefore, the player must try to sink this ship with the fewest shots possible, according to the search strategy in each of the tasks. When the chosen ship by the player or the opponent is sunk, the game is ended and the number of shots spent to find the correct ship is shown on the screen.

Figure 1. Initial menu of Battleships game

As a complement, video tutorials[3] were made as a way to assist students in remote

[2]Available for download on: https://wp.ufpel.edu.br/pensamentocomputacional/atividadesvirtuais/.
[3]Tutorials link available on: https://wp.ufpel.edu.br/pensamentocomputacional/atividadesvirtuais/.

activities. In the videos, the student learns how to download and play the game, as well as is introduced to discussions about the topics worked on in each task.

3.1. Task 1: Sequential Search

Task 1 is intended to introduce the concept of sequential search. Sequential search has a simple strategy, that consists in comparing a certain element with each other elements of a vector (or another type of linear data structure) starting, generally, from the first position. In Task 1, position letters are ordered and the ship identification numbers are not in order (Figure 2). The player chooses the number of his ship – between 1 and 26 (Figure 5) – and the game begins. At each round of the game, one player chooses a letter where the enemy ship may be hiding. After the player chooses a letter, his opponent reveals the hidden ship (number). In each round, both the player and the computer have one shot. In order to shoot, the letter of the ship that the player wants to sink is chosen. If the opponent's ship has not been found, the ship hit by the shot is sunk, so that no shots are fired at that position again. Since there is no corresponding order for ships, students are then indirectly introduced to the concept of sequential search.

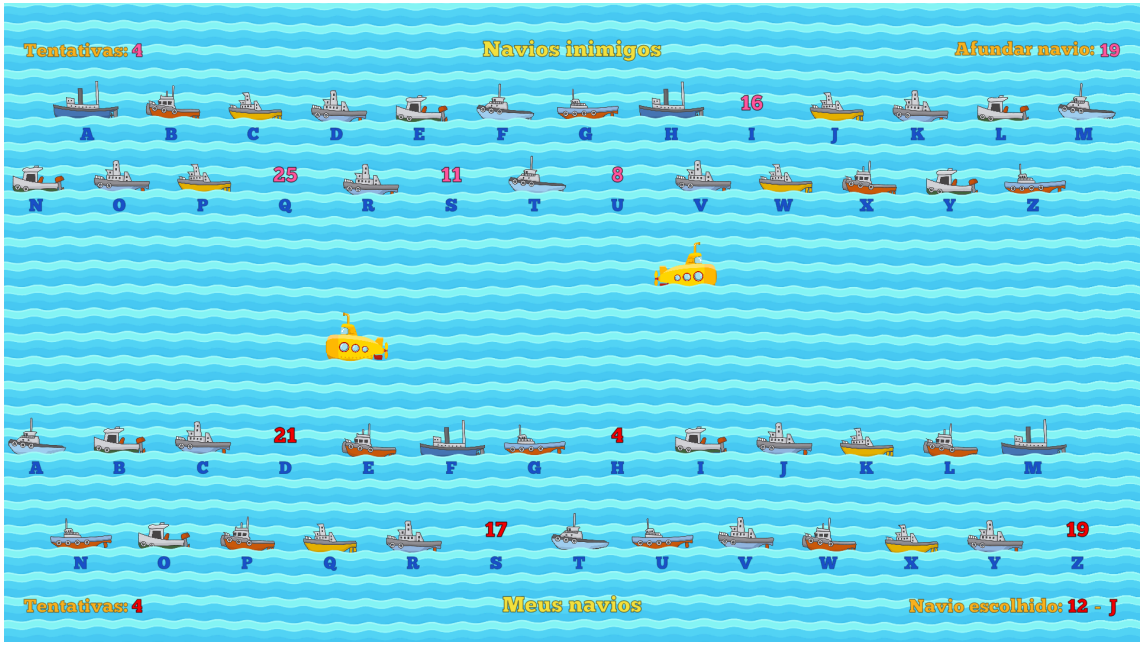

Figure 2. Task 1 in Battleships game: sequential search

3.2. Task 2: Binary Search

Task 2 is intended to introduce the concept of binary search. The binary search is an efficient algorithm that follows the "divide-and-conquer" paradigm. Assuming that the vector/list is ordered, the search consists in finding a certain element from successive divisions of the list that contains the item, until the possible locations are reduced to one. In Task 2, position letters and the ship identification numbers are both sorted in ascending order (Figure 3). The gameplay is the same as in the previous task, that is, the player chooses the number of his ship – among 50 options of random numbers between 500 and 2000 (Figure 5) – and each round chooses a letter where the enemy ship may be hiding. In this task, considering the increasing ordering of the ship identification numbers and the

advantage of choosing the right place to take the next shot (excluding half of the ships from being chosen by him in the next turn), the students are then indirectly introduced to the concept of binary search.

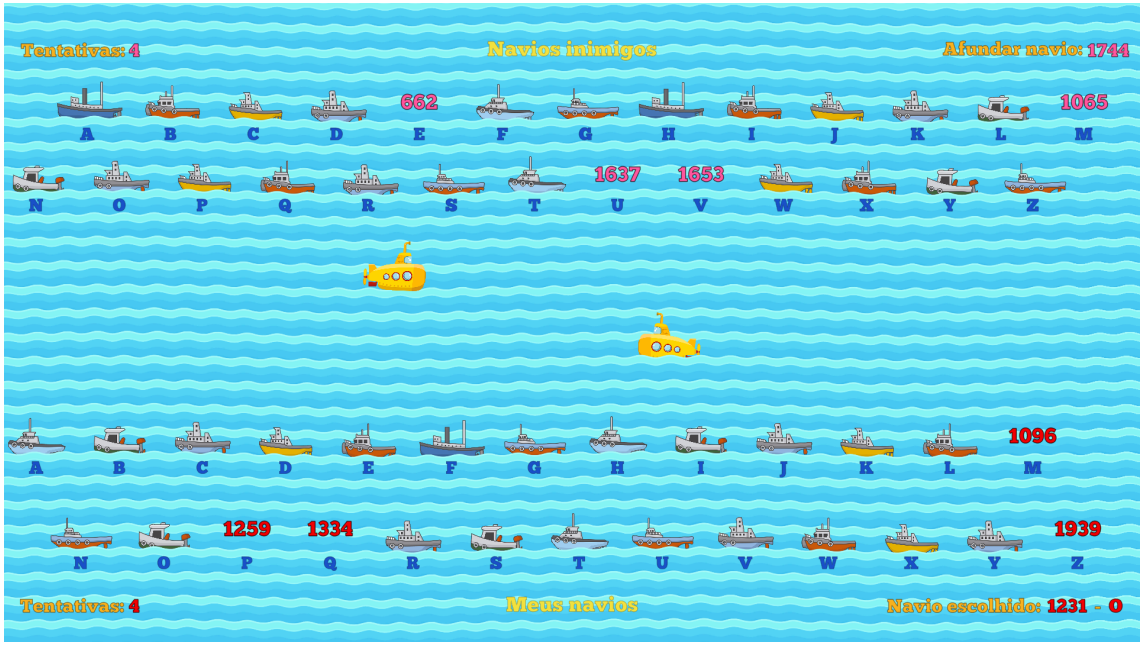

Figure 3. Task 2 in Battleships game: binary search

3.3. Task 3: Hash-based Search

Task 3 is intended to introduce the concept of hash-based search. A hash table is a generalization of the idea of a vector, which uses a function to spread out the stored elements. This causes the elements to be dispersed and disordered within the vector that defines the table. A hash table allows the association of "values" (position of the element in the vector) to "keys" (part of the information that makes up the element to be inserted in the table), which improves the search. In other words, from a key, it is possible to quickly access a certain position of the vector. In Task 3 (Figure 4), the player can find out in which column (0 to 9) the opponent's ship is by adding up the digits of the ship's number – the last digit of the sum is the column the ship is in. For example, to locate ship 823, simply add 8+2+3, which is 13. Since the last digit of the sum is 3, the enemy ship has to be in column 3, decreasing the possibilities of choice. With this, students are indirectly introduced to the concept of hash-based search. In this task, the player also chooses his ship number before the start of the game – among 50 options of random numbers between 500 and 2000 (Figure 5).

3.4. Concepts of Computational Thinking in the Battleships Game

The educational game presented in this work addresses different CT concepts. Although the game focus is search algorithms, skills such as data analysis, problem decomposition, and abstraction are also encouraged. Regarding **data analysis**, for example, in Tasks 2 and 3 pattern recognition becomes a useful strategy to find the correct ship, considering their ordering way. **Decomposition**, otherwise, is also present in non-sequential search strategies since in each task the problem is partitioned in order to facilitate the discovery of

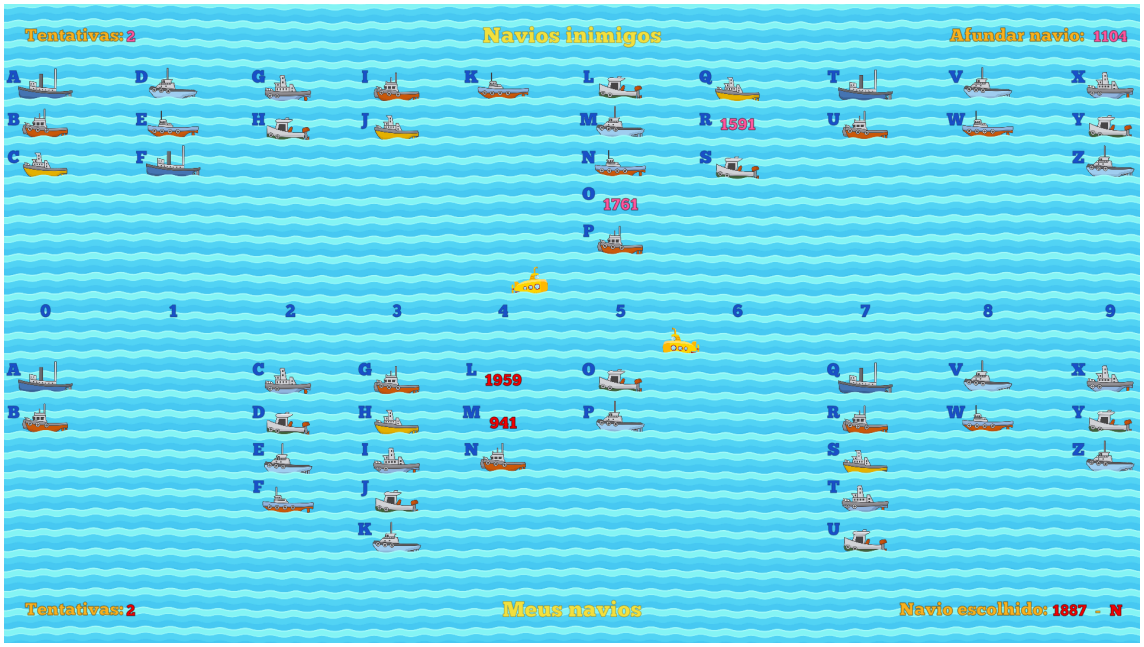

Figure 4. Task 3 in Battleships game: hashing

Figure 5. Options for player ship number in Task 1 (left) and in Tasks 2 and 3 (right)

the correct ship according to the organization (in ascending order or by columns). Finally, **abstraction** is also used, since, in Tasks 2 and 3, the ship hit is what matters to define the next shot, ignoring the other information. In this way, different concepts of the CT are addressed during the game as a way to help in the efficient search for the chosen ship.

4. Teacher Qualification Course

The proposed activity was presented to teachers in a remote training course, with the objective that the participants could understand the game, the involved concepts, and apply it (both in face-to-face and remote formats), to different contexts and subjects. Before the course, all participants read and signed an Informed Consent Form (ICF), indicating they decided to take part in the course (and later research) of their own free will and are aware of the usage of the collected data.

The course was composed of two synchronous meetings and one asynchronous activity to be sent, totaling a workload of 14 hours. In the synchronous meetings, the basic concepts and methodology involved in the application of the activity were presented,

while in the asynchronous activities, complementary reading materials were made available (teaching and lesson plans of the activity)[4], as well as a brief tutorial (available as a video) for downloading and playing the game. During the synchronous meetings, teachers were asked to play each task and then discussions were held on the number of shots needed to find the enemy ship depending on how the data was organized. These discussions were held before the lecturer presented the ideal/generic strategy to find the enemy ship with the least number of attempts in each of the tasks.

The asynchronous activity requested consisted of planning an activity that promotes CT skills, based on the Battleships game, that is, an activity that integrates the search for information (with different forms of organization) integrated to the context of the participants' area of activity. A form[5] (in Portuguese) was made available to guide the task. Finally, after completing the course, the participants were asked to answer, anonymously, a socioeconomic and course evaluation form[6] (in Portuguese).

5. Results and Discussions

The Battleships activity course received 35 registrations, but 14 participants attended the course. Of these, 9 answered the socioeconomic and activity evaluation form[7]. All participants were female. The majority (77.8%) live in Pelotas/RS, while the rest live in neighboring towns (Canguçu and Morro Redondo). One participant is from a rural area while the others are from an urban area. All participants have completed their graduate studies and work in the Secretaria Municipal de Educação e Esporte de Pelotas, as teachers, educational advisors, or pedagogical coordinators. The invitation to participate in the course was sent to all schools in the municipality via the Education Department and each school had guaranteed a vacancy in the course. However, according to the directors of the Secretaria, the number of enrollments was low due to the period in which the course was offered (end of the year).

About the course general evaluation[8], 77.8% of the participants gave grades from 8 to 10 for the course, while the others gave grades from 4 to 6. Regarding their participation in the course, 66.6% rated themselves between 9 and 10, 11.1% rated themselves 7, and the rest (22.2%) rated themselves between 4 and 5. The majority (88.9%) considered that they understood all the stages of the activity and the same percentage thought the course was useful for their professional performance, stating that they intend to replicate the activity in the classroom. Additionally, several positive points were mentioned, in particular the activities presented were described as dynamic, attractive to the students, and allowing new learning and knowledge. As negative points, it was mentioned that the activity could be made up of more modules and that the course could consider face-to-face meetings.

Only 6 participants finished the requested asynchronous activity[9]. One of the proposed activities for the Mathematics area consists of solving problems with up to 4 variables and some information about these data. Based on this, the student should order

[4]Class plan of the activity available (in Portuguese) at: https://wp.ufpel.edu.br/pensamentocomputacional/planos/.
[5]Available (in Portuguese) at: https://bit.ly/3as3f1u.
[6]Available (in Portuguese) at: https://bityli.com/xisrnF.
[7]Socioeconomic information about the participants is available on: https://curt.link/9SzBnv.
[8]Detailed evaluation information is available on: https://curt.link/9SzBnv.
[9]Available on: https://curt.link/9SzBnv.

the information in order to relate them. The teacher provided the following example of a problem: "Artur, Henrique, Júlia, and Sandra are playing a kite tournament. The kites are colored brown, yellow, green, and red. Read the information below and find out who won the championship and what color of their kite. Artur's kite is neither brown nor yellow. In the final classification, Sandra was better positioned than Artur. Júlia's kite is green. The participant who owns the red kite was in fourth place. The green kite is of the participant who came in second. The one who came in first had the brown kite. Sandra's final classification is between Júlia and Artur." In this activity, **data analysis** and **problem decomposition** skills are developed, as students must analyze and partition the information provided to find the problem solution. Additionally, **abstraction** is also developed, as students deal with undescribed but deducible information.

Another example of a proposed activity, now for the Religious Education area, has the objective of studying traditional religious characteristics. Based on the structure of the Battleships game, the activity consists of organizing the world's religious traditions according to their size (number of followers), so that the student finds the characteristics that match each religion. In addition to **data analysis**, this proposal also works on the concept of **data representation**, since students must organize data from each religion in order to relate them. Finally, another activity to be highlighted, in the area of Physical Education, was based on the movement of ships in the Battleships game to work on the concept of laterality and letter dominance. That is, identify the right and left sides, having as a reference your own body. This activity develops the concept of **algorithms & procedures**, as the student must fulfill a series of ordered steps taken to achieve some end proposed by the teacher.

6. Conclusion

This paper presented an educational game that allows the development of CT skills (data analysis, problem decomposition, and abstraction) from the search for information (with different forms of organization). The activity aims to exemplify the behavior of three search algorithms in a ludic way, through an educational digital game. The activity was presented in a training course offered to teachers of the municipal school system. From the game, teachers from different areas were able to propose activities within their area of expertise, in addition to relating them to the CT concepts. From the qualification course, we learned that some teachers have difficulty using/manipulating computers and face-to-face meetings facilitate this support; the simultaneous use of the tool helps in understanding the objectives of each stage of the activity, as well as what can be explored in the classroom; in general, teachers like to interact and present their ideas, thus, more moments of discussion about similar examples that work the same CT concepts could have brought better results and better engagement in the asynchronous activity. We hope that this activity can offer positive experiences, introducing, complementing, or even helping the practice and integration of computing in teaching and learning in the curricula of elementary schools in Brazil. Finally, as future work, we intend to apply the activity in elementary school classes, as well as analyze its potential for integration into these classes.

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