Teaching Computational Thinking to Middle School Students using Rubik's Cube

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Abstract. *The present work describes the implementation of an activity aimed at teaching the main concepts of Computational Thinking to children starting in middle school. The primary concepts addressed are Decomposition and the use of Algorithms to solve the first face of a standard 3x3x3 Rubik's Cube using the daisy method. The activity was conducted with two groups of 20 students during 40-minute sessions. It is discussed that, depending on prior experience with the cube, this time might not be sufficient. Results indicate that solving the cube was a dynamic activity that engaged students and helped participants understand the importance of sequence and order in the steps to be followed.*

1. Introduction

Computational thinking (CT) is grounded in the potential and limitations of computational processes, whether executed by humans or machines. It is an essential skill for everyone, not restricted to computing specialists. It involves solving challenges, designing systems, and understanding human behavior. CT transforms seemingly complex problems into ones we know how to approach, whether through reduction, integration, adaptation, or simulation [Wing 2006].

Computational Thinking is built on four main pillars: abstraction, decomposition, pattern recognition, and algorithmic thinking. These pillars empower individuals to apply computational reasoning logically and systematically across various fields, fostering an innovative and efficient approach to problem-solving. Furthermore, the teaching of this form of reasoning often employs resources that connect students to social issues, encouraging their active participation in the learning process [Batista et al. 2024].

This approach supports the development of skills such as problem-solving, analytical thinking, continuous learning, collaborative work, adaptability, and flexibility. These competencies equip individuals to tackle the challenges of the contemporary world, regardless of their professional field [Garcia and Borges 2023]. Thus, this method is recognized as a transversal skill applicable to a wide range of knowledge areas, playing a crucial role in preparing individuals to address current global challenges with creativity and critical thinking [Lima et al. 2022].

The activity described herein was proposed in the context of an extensionist project leaded by female professors and formed by a group of female undergraduate and graduate students from Computer Science (CS) related courses in (omitted) Brazil. The project originated from the low number of girls entering STEM-related undergraduate courses, with the main goal of bringing unplugged CT workshops to middle school students offered by women to promote both CT knowledge and gender representation.

In a previous work the authors have briefly presented the workshop [citation omitted] and this work aims to delve into the details of another application of the workshop, highlighting the best practices that could be identified and pointing out what the authors believe that could be improved. The presented activity was structured as a practical workshop, conducted to explore the concepts of CT. During its application, a problem-solving-oriented method was used, in which the students were instructed by clear and sequential steps to solve the standard 3x3x3 Rubik's Cube. This approach allowed the participants to develop skills such as breaking tasks into smaller parts and formulating algorithms to solve the challenge logically and systematically.

The remainder of the text is organized as follows. Section 2 presents the theoretical background and related works considered developing the proposed workshop. Section 3 details the Materials and Methods. The Results and Discussion are presented in Section 4 including limitations and positive aspects and Section 5 concludes the text.

2. Theoretical Background and Related Works

Computational Thinking should not be confused with the ability to use specific applications or digital technologies (which pertains to digital literacy). Instead, CT entails the capability to develop abstract models (of information and processes) and to organize problem-solving systematically, along with skills in reasoning, critical thinking, and collaborative work [Ministério da Educação 2018].

The development of skills related to Computational Thinking has been gaining increasing relevance in the contemporary educational landscape. Recognized as essential for preparing citizens capable of solving complex problems creatively and efficiently, Computational Thinking goes beyond programming, encompassing skills such as decomposition, pattern recognition, abstraction, and algorithms. In Brazil, the National Common Curricular Base (BNCC) acknowledges the importance of these skills and establishes that education in computing should complement the school curriculum, promoting active and integrated learning from the early years of basic education [Sassi et al. 2023].

Several activities have been proposed to work with the aforementioned skills related to Computational Thinking [Minchillo et al. 2018, Guarda and García-García 2021, Ortiz and Pereira 2021, Grebogy et al. 2024]. Related works presented in the main Brazilian conference for Informatics Education from 2015 to 2019 were reviewed by [Carvalho and Braga 2022]. Giving the reality of most schools, unplugged activities which can be used in a common classroom without the need for computers are recommended by several authors [Guarda et al. 2022, da Cruz et al. 2023].

Activities using the Rubik's cube have been proposed to stimulate logical thinking in the context of teaching mathematics [Vieira et al. 2017]. Another work used the cube as an example to show that given a solution to the standard Rubik's cube problem, one can efficiently route from one state to the other [Monteiro and Menasché 2020]. Fewer works have been found specifically using Rubik's cube to teach Computational Thinking [Dias et al. 2024]. Therefore, this is to the best of our knowledge the first paper that describes the application of the solution of one of the faces of the Rubik's cube using the daisy method to teach Computational Thinking to middle school students.

3. Materials and Methods

The workshop presented herein uses a student-centered hands-on approach. The materials developed to facilitate the workshop are available for download as detailed in this section.

3.1. Materials

The materials used in the workshop were twenty 3x3x3 Rubik's cubes (Figure 1), a slideshow prepared with Canva to serve as visual aid to explain how to manipulate the cube providing vocabulary to reference each side and movement (Figure 2), and pamphlets containing step-by-step instructions to solve the first face of the cube using the daisy method (Figure 3). This method consists of a series of eight steps leading to the complete resolution of the cube, and it was chosen because it is considered a simpler approach. This method involves fewer cases and less complex movements if compared to the Fridrich method, for instance, which, even though it involves four steps instead of eight, requires the memorization of a lot of different "cases" in order to find the solution. Therefore, we believe it to be a suitable approach for addressing the solution of the Rubik's cube for the target age group. As part of the workshop preparation process, the volunteers needed to practice solving the Rubik's cube and refine the chosen technique (the daisy method). Additionally, the preparation involved printing the pamphlets, which were originally in black and white. Later, it was agreed that, in future applications, printing the pamphlets in color would enhance the participants' visualization of the step-by-step instructions. Both the slideshow and the pamphlets were prepared by the project volunteers in Brazilian Portuguese and are available for reuse[1].

3.2. Participants

The workshop was conducted with a middle school class, divided into two smaller groups of 20 students each. This division was crucial to address two challenges: the limited availability of Rubik's Cubes and the need to provide personalized attention to every participant. By ensuring that each student had a cube to work with, we aimed to create an engaging and hands-on learning experience.

3.3. Workshop Structure

At the start of each session, a pre-scrambled Rubik's Cube was distributed to every student. This ensured uniformity in starting conditions and helped focus their attention on the guided steps of the activity. Following the distribution, we initiated a brief group

[1]link to the project website omitted for reviewing purposes

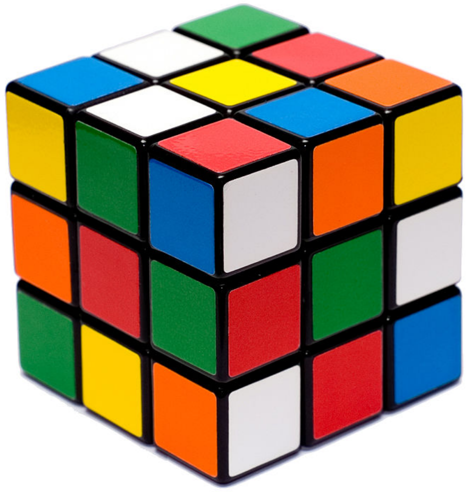

Figure 1. Illustrative image of a 3x3x3 scrambled Rubik's cube.

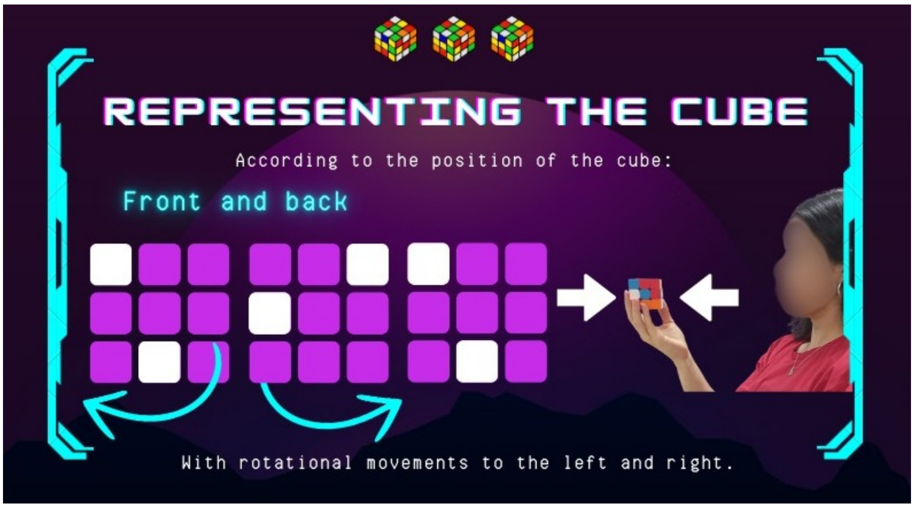

Figure 2. Example of one page of the slideshow used as visual aid for manipulation of Rubik's cube.

discussion. The discussion was centered on general questions designed to assess the participants' prior knowledge and familiarity with the Rubik's Cube, as well as their understanding of related concepts such as algorithms and problem-solving strategies. This interaction also served as a preliminary data collection stage, where the students' responses and observations about their engagement were registered for later analysis.

To lay the groundwork for the activity, we delivered a presentation introducing the concept of Algorithms. This foundational concept was presented in a simple and accessible manner, emphasizing how algorithms can be understood as ordered sequences of steps designed to solve a problem. The presentation included practical examples unrelated to the cube, such as instructions for making a sandwich or tying shoelaces, to help students connect the abstract idea of algorithms to real-world activities.

We then introduced the Rubik's Cube itself, starting with a visual demonstration

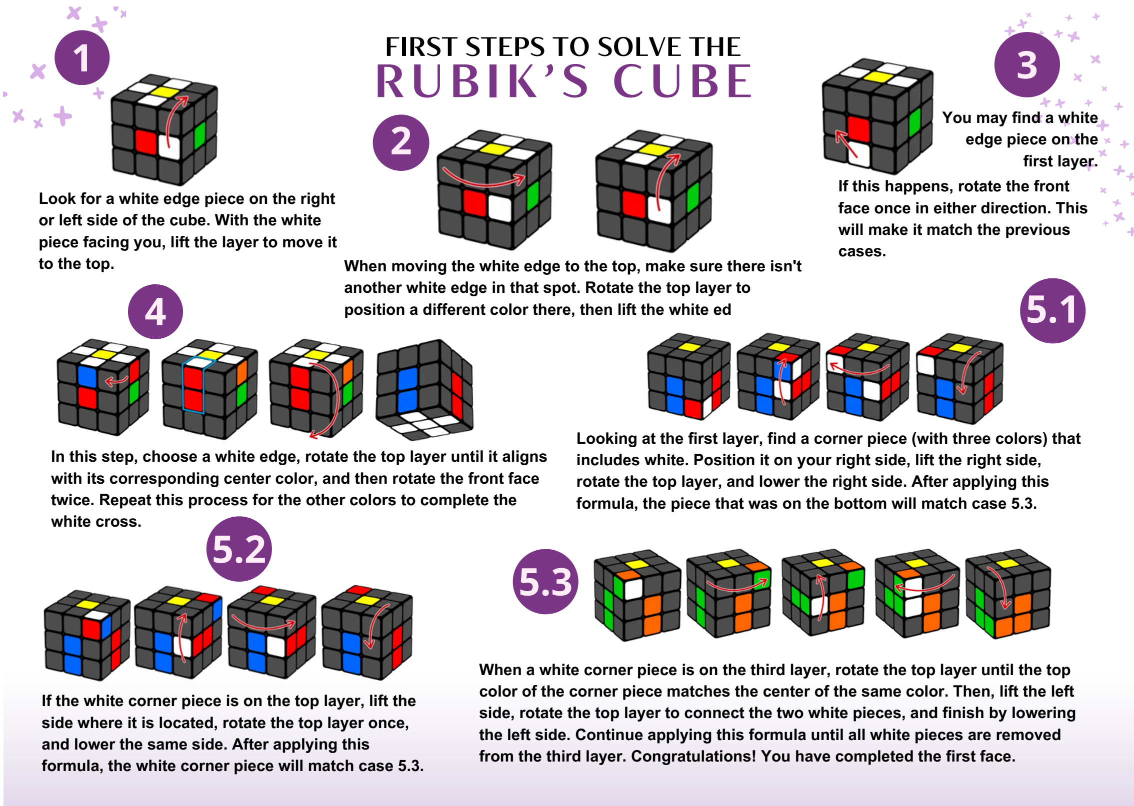

Figure 3. Pamphlet containing the step-by-step of Rubik's cube manipulations to solve the first face using the daisy method (original text in Portuguese).

of its structure and components. Each face of the cube was named and color-coded for clarity, enabling consistent terminology throughout the session. Basic movements of the cube were demonstrated, including clockwise and counterclockwise rotations of individual faces, with repeated emphasis on the notation used to describe these movements. This introduction aimed to demystify the cube, helping students feel more comfortable handling it and setting the stage for the problem-solving steps to follow.

To ensure comprehension, students were encouraged to replicate the demonstrated movements on their own cubes while asking questions about any difficulties they encountered. This step not only familiarized the participants with the mechanics of the cube but also established a collaborative atmosphere, where students felt supported in their learning.

Following the introduction, the session transitioned to the main task: solving the first layer of the Rubik's Cube using the daisy method. This method involves forming a "daisy" pattern on the cube, where white edge pieces surround the yellow center. To support the students, each participant received a detailed pamphlet designed as an educational aid (Figure 3). The pamphlet contained visual illustrations and a step-by-step guide that broke down the process into manageable segments. Each step was paired with diagrams and explanations to ensure clarity. The daisy pattern can be seen on Figure 3 step 4.

As the students worked through the steps, they were encouraged to reflect on the logic underlying each movement and reminded of the importance of following the sequence precisely, as small variations could disrupt the solution process. Throughout the session, the instructors circulated among the students, providing individual support and addressing specific challenges. Common difficulties, such as misaligned edge pieces or misunderstanding rotation notations, were addressed through real-time demonstrations and explanations. Students who completed the daisy pattern were guided to assist their peers, fostering a sense of collaboration and reinforcing their understanding of the process.

Each session lasted approximately 40 minutes, which allowed time for both guided activities and independent practice. The average time spent on the introduction was 10 minutes, while the practical part took between 20 and 25 minutes. The conclusion lasted approximately 5 minutes. By the end of the activity, most students successfully completed the daisy pattern, and some progressed further with additional guidance to solve the first face. Feedback was collected informally through discussions about the activity, where students shared their experiences, challenges, and what they learned about both the cube and the concept of algorithms. This iterative process of demonstration, guided practice, and reflection formed the core of the workshop's methodology.

4. Results and Discussion

The students were divided in two groups of 20 students. In both classrooms, the students had an age range varying from 11 to 13 years old. Before the workshop, some questions were asked to the students in order to assess their previous knowledge of the University and Computer Science as undergraduate course and related concepts, as shown in Table 1. Four questions were asked orally, and the students were requested to raise their hands, and we counted them grouping by gender and classroom (C1, C2).

	Female		Male	
Questions	**C1**	**C2**	**C1**	**C2**
1. Have you been to the University before?	0	2	0	1
2. Do you intend to attend an undergraduate course in STEM?	1	1	1	1
3. Do you know the difference between Computer Science related courses?	0	0	0	0
4. Do you know what Computational Thinking mean?	0	0	0	0

Table 1. Quantitative results grouped by gender and classroom of questions asked before the workshop was applied.

The collected data provide insights into the students' lack of familiarity and interest in the university environment and the field of Computer Science. Each question is discussed below:

Question 1. Previous experience with the university: Only three students (two from the C2 female group and one from the C2 male group) had visited the university before. This highlights the limited exposure most middle school students might have to academic environments, underscoring the importance of initiatives like this workshop to introduce them to such settings.

Question 2. Interest in STEM: The proportion of students interested in pursuing STEM-related undergraduate degrees was consistent across genders, with one student in each group expressing this intention. However, the total number was very low, possibly reflecting a lack of knowledge or initial interest in these areas. This finding suggests a need for programs designed to spark curiosity and engagement in STEM fields for middle school students.

Question 3. Familiarity with CS-related concepts: None of the students demonstrated knowledge of the differences between CS-related courses. This indicates a general lack of understanding of career pathways in this field related to the previous question, reinforcing the importance of including detailed explanations and practical examples during the workshop. As the participants were still in middle school, it is comprehensible that they were not familiarized with the differences before. A brief explanation of the main difference between CS-related courses offered by the institution was given to the participants.

Question 4. Computational Thinking: Similarly, no participant knew what the term "Computational Thinking" meant. This highlights the need to introduce this concept early on as a foundation for understanding logic and problem-solving, which are essential skills in today's world.

The results underscore a significant lack of exposure among middle school students to topics related to University life and Computer Science. Additionally, differences between the groups (C1 and C2) were minimal, suggesting a homogeneous level of prior knowledge within both groups. This highlights the importance of educational interventions in connecting young students to academic and professional areas they may not otherwise consider due to a lack of information or prior exposure.

4.1. Limitations

Despite the positive results observed during the workshop, some limitations were identified, highlighting opportunities for improvement in future applications. One of the main challenges faced was the lack of a more detailed explanation about the sides of the Rubik's Cube before starting the solving steps. Although we named the faces to facilitate communication, this introduction was brief and did not include practical exercises to help students become more familiar with handling and identifying the cube's faces. As a result, some participants showed initial confusion, particularly when interpreting the steps described in the support pamphlet. Another significant limitation was the variation in students' familiarity with the Rubik's Cube and activities involving sequential logic. Not all participants had the same level of prior knowledge or motor skills, which resulted in an uneven learning pace. While some students could progress quickly, others struggled to follow the initial steps of the solution, leading to moments of frustration.

Also, the limited amount of time (40 minutes) for each group has narrowed the possibility of grasping the concepts more comprehensively and restricted the opportunity of offering more individualized attention for students that showed some struggle in the solving process. Dividing the class helped to mitigate this issue, but even so, the short time available underscored the need for more flexible planning to accommodate different learning paces. These limitations will be taken into account in future adaptations of the workshop, aiming to make the experience more inclusive and productive for all participants.

4.2. Positive Aspects and Educational Impact

The workshop was engaging and after the initial challenge of understanding how to manipulate the cube, all the students were able to form the daisy pattern and most of the students were able to finish solving the first face. Considering the main goal was to teach Computational Thinking concepts, the authors believe the activity is well-suited as the participants understood they had to decompose the problem and follow a specific set of steps to put each piece of the cube in the correct place.

Moreover, the workshop not only introduced important concepts but also served as an essential introduction to the university and career possibilities in technology. It was observed that the activity successfully achieved its objective of broadening students' perspectives on careers in the field of technology. They were able to acquire not only theoretical knowledge related to computational thinking and practical experience through solving the Rubik's cube, but they were also provided with a social perspective, particularly regarding female representation in the field of computing. After all, the workshop was conducted by female undergraduate and graduate students and female professors, which offers gender representation. It represented a crucial first step in inspiring greater interest and involvement among students in these fields.

5. Conclusion

A workshop to teach Computational Thinking Concepts to middle school students using a 3x3x3 Rubik's cube was presented. The workshop was offered by an extensionist project composed of girls from several undergraduate courses and one graduate course related to Computer Science aiming to bring CT concepts to middle school students and also offering female representation related to the field.

Several positive aspects were observed, such as the participants' willingness and interest in understanding how the Rubik's Cube works. Additionally, it was noticed that going through the initial steps of solving the cube gave the students a sense of possibility, helping them realize that they are capable of solving complex problems simply by following a logical sequence of steps. All of this contributed to the students' intellectual self-esteem, as they expressed satisfaction upon completing the first layer of the cube. And also to their understanding of the Computational Thinking, an essential skill for problem-solving in our current world.

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