Revista Brasileira de Informática na Educação – RBIE
Brazilian Journal of Computers in Education
(ISSN online: 2317-6121; print: 1414-5685)
https://sol.sbc.org.br/journals/index.php/rbie

Submission: 04/Sep/2024; Camera ready: 28/Jul/2025; 1st round notif.: 02/Jun/2025; Edition review: 19/Sep/2025; New version: 17/Jun/2025; Available online: 19/Sep/2025; 2nd round notif.: 09/Jul/2025; Published: 19/Sep/2025;

An Experience Report on Teaching Computer Science in Elementary School

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Abstract

The motivation to introduce computing in Basic Education arises from the growing importance of digital literacy in the modern world. Recognizing this, Brazil's National Common Curricular Base (BNCC) now includes an annex dedicated to Computing, structured around three main pillars: Computational Thinking, Digital World, and Digital Culture. However, this inclusion presents several challenges for implementation, such as the effective integration of computing concepts into school curricula, the development of appropriate methodologies for curricular activities, and the establishment of suitable assessment methods. This paper presents a seven-year experience report, from 2013 to 2019, on the introduction of computing activities in elementary schools. The report discusses the aforementioned challenges and provides insights into overcoming them. The findings emphasize that the physical space available, the layout of classrooms, and the contextualization of student groups are crucial for the planning of materials, lessons, and support teams, all of which contribute to achieving the desired learning outcomes. Additionally, the introduction of computing concepts is feasible and effective through unplugged methods, especially when using playful, incremental, and challenging approaches that align with students' contexts. The report also highlights that continuous and incremental assessment of the concepts introduced through exercises, games, and challenges proves to be effective. Furthermore, the strategy of evaluating learning gains through pre- and post-tests is successful when assessing the concepts and strategies incrementally and in contexts different from those presented in the classroom. This experience report demonstrates that the integration of computing in elementary education can be both viable and impactful, provided that careful planning and contextualization are prioritized.

Keywords: *Primary and Secondary Education; Computing Education; Computational Thinking; Digital Literacy; BNCC (Brazilian National Common Core Curriculum); Unplugged Activities; Curriculum Integration; Assessment Strategies*

Cite as: *Cavalheiro, S. A. C., Foss, L., Du Bois, A. R., Pernas, A. M., Piana, C. F. B., & Reiser, R. H. S. (2025). An Experience Report on Teaching Computer Science in Elementary School. Revista Brasileira de Informática na Educação, 33, 1305-1244. https://doi.org/10.5753/rbie.2025.4898.*

1 Introduction

The global trend has shown that adapting the education of young students to new technological demands is a significant challenge (Gangmei & Thomas, 2024; Voogt et al., 2013). This requires complementing traditional school activities with innovative approaches. A more effective strategy involves stimulating students' mental skills through the understanding and manipulation of processes and data science. One strategy has been to introduce computing and computational thinking skills from the early years of schooling (Åkerfeldt et al., 2024; Gretter & Yadav, 2016). This approach emphasizes better solutions to complex problems by fostering integration and interaction with new digital technologies (Åkerfeldt et al., 2024; Yadav et al., 2017).

Recognizing this, Brazil's National Common Curricular Base (*Base Nacional Comum Curricular* - BNCC) has included an annex dedicated to Computing since 2022 (BNCC, 2022). This initiative includes training from elementary school, offering technological knowledge through three distinct approaches: providing access to the digital world, introducing the concepts and strategies related to computational thinking, and promoting experiences in digital culture. Nonetheless, this inclusion presents several challenges for implementation, such as the effective integration of computing concepts into school curricula, the development of appropriate methodologies for curricular activities, and the establishment of suitable assessment methods.

This work reports on initiatives that took place well before this standardization, addressing both academic demands — focused on the participation of students, professors, and researchers in computing courses — and social demands, prioritizing the application of computational methodologies to aid learning in public elementary schools. The experiments reported were conducted between 2013 and 2019, and the results obtained offer insights into addressing the aforementioned challenges and suggest strategies for overcoming them. Student profiles, categorized into central, peripheral, and rural schools, ranged from the 3rd to 6th grade.

Our main goal is to describe our experience and the results obtained through the application of unplugged activities that encourage methodologies based on computational thinking. These activities enhance skills such as data collection, analysis, standardization, and representation through abstractions. Models and simulations, discussed through experiments, incorporate playful activities and educational games (Campos et al., 2014; Cavalheiro et al., 2016; Ferrão et al., 2024; Martin et al., 2018; Oliveira et al., 2021; Pinho et al., 2016; Rosa et al., 2021; Rosa, Reiser, Cavalheiro, et al., 2021; Rosa, Reiser, Oliveira, et al., 2021; G. Santos et al., 2015; J. Silva et al., 2023; Weisshahn et al., 2016). Student performance assessment and corresponding statistical analysis facilitate group comparisons, normal distribution evaluation, and variance homogeneity analysis.

The seven years of experience in teaching Computer Science offer valuable perspectives for developing new strategies to improve the implementation of Computing-BNCC standards. In this context, the results discussed highlight significant achievements and key challenges in structuring and implementing tasks to develop computational skills in elementary school students. Beyond reporting our specific experience, this work also aims to contribute to the broader discussion on how to effectively address the persistent challenges involved in adapting education to new technological demands. By presenting practical methodologies, assessment strategies, and context-aware approaches, we seek to inform future initiatives and foster a more effective and meaningful integration of computing education in Brazilian schools. Expanding this debate involves not only acknowledging existing limitations, such as resource constraints, methodological difficulties, and lack of consensus, but also pointing toward actionable and scalable solutions for overcoming them.

This article is organized as follows. Section 2 provides an overview of how computing is being integrated into Basic Education in Brazil, reviewing related work on activities that emphasize computational tools, technologies, and unplugged learning methodologies. Section 3 summarizes the contextual foundations of the study, covering the main computing concepts considered in the activities reported, the advantages of related unplugged methodologies, and the statistical techniques applied in the data analysis. In Section 4 the project experience is detailed, reporting the actions and methodological details chosen for each year/period of application. The analysis of results is described in Section 5 and the lessons learned is presented in Section 6. Finally, conclusions and future work are outlined in Section 7.

2 Computing in Basic Education in Brazil

This section provides an overview of how Computing is being addressed in Brazilian Basic Education. Subsection 2.1 outlines the organization of the Brazilian education system, while Subsection 2.2 presents some related work.

2.1 Organization of Brazil's Educational System

Brazil divides its education system into basic and higher education levels. The basic level includes: early childhood education (ISCED 0, and in Portuguese, *ensino infantil*); primary and lower secondary education (ISCED 1 and 2, also known in the country as elementary education, and in Portuguese, *ensino fundamental*); and upper secondary education (ISCED 3, and in Portuguese, *ensino médio*) (for details, see Figure 7 in Appendix A). Compulsory education starts at the age of four, in pre-school education, and lasts 14 years, up until the end of upper secondary education. Both public and private institutions operate under this structure, adhering to the same general guidelines.

2.2 Related Work

In Brazil, over the past few years, several studies propose activities aimed at developing skills related to computing concepts, and they also report on the application of these activities with students from early childhood through upper secondary education. Table 8 (see Appendix B) summarizes the related works. For readability reasons, references to the works are encoded[1].

Most works focus on programming logic and algorithmic thinking ([1],[3],[6],[7],[8],[9], [10],[11],[12],[13],[14],[15],[16],[17],[19],[20],[21],[22],[23]), primarily using block-based pro-

[1] [1] de Santana Oliveira et al., 2020; [2] Amador et al., 2021; [3] Torcatte et al., 2017; [4] Barata et al., 2023; [5] A. P. Ferreira and Lucchese, 2020; [6] Queiroz et al., 2016; [7] Pires and Prates, 2019; [8] V. Silva et al., 2016; [9] N. Santos et al., 2023; [10] da Silva Bisneta, 2019; [11] Franzen et al., 2022; [12] W. P. de Oliveira, 2018; [13] do Nascimento, 2019; [14] Widthauper, 2020; [15] J. B. Santos and Lima, 2020; [16] Pinheiro, 2019; [17] T. de Oliveira et al., 2017; [18] Gonçalves, 2022; [19] Aguiar and Menezes, 2019; [20] de Lima, 2017; [21] de Farias Pimenta, 2019; [22] Black, 2024; [23] Brito de Oliveira et al., 2023; [24] Junior et al., 2023.

gramming languages (like Scratch) to solve problems such as navigating characters through mazes. Additionally, other languages and methods are employed to develop algorithms and programs, including natural language ([9],[13],[19]); pseudocode and Logo language ([6]); movement instructions (using keys/joystick/arrows) ([3],[7],[8],[9],[20]), and Python ([15]). Some works also describe experiences with various activities derived from CS Unplugged ([6],[9]). Other works, however, propose activities with more specific focuses, such as databases ([2]); computing theory, computational thinking, and digital literacy ([3]); binary coding and error detection in data transmission ([5]); information compression ([8]); propositional logic and optimization and sorting algorithms ([9]); software engineering and user experience ([16]); machine learning and the impacts of AI ([18]); sorting algorithms and network devices and technology's impact on nature ([24]). The target audience for these activities is very diverse, encompassing students and teachers from pre-school to upper secondary education.

The use of Scratch ([1],[10],[11],[21],[22],[23]) and Code.org ([12],[14],[21],[23]) platforms is common in several works, though many are based on the unplugged methodology ([2],[4],[5],[6],[8],[9],[19],[21],[23]). Some works adopt a problem-solving approach ([4],[16]), while others combine traditional lectures with practical and project-based activities ([13],[15],[18]). Constructivism is another approach highlighted in the considered works ([3],[6]). Additionally, one of the studies employs tangential learning in games as a methodological approach [24].

Different assessment methods have been identified, with the most prominent being questionnaires, informal surveys ([3],[5],[6],[9],[10],[11],[12],[13],[15],[16],[17],[19],[21]), and observations ([7],[8],[12],[15],[23],[24]) that assess students' motivation, interest, and preferences regarding the activities. Several studies also use questionnaires to determine the level of knowledge about the subject before starting the activities ([2],[9],[14],[16],[19]) and to evaluate the importance attributed to the addressed concepts after completing the activities ([10],[11],[14],[16],[22]). To assess learning, self-assessment questionnaires are conducted on the addressed concepts and the difficulty level of the activities ([10],[11],[12],[13],[23],[24]). Alternatively, tests comprising questions relevant to the covered content during the activities may be administered, either at the outset and conclusion ([7],[21],[22],[23]) or solely at the conclusion of the activities ([15],[16],[19]). Additionally, observations made during the activities ([20]) or evaluation of artifacts resulting from them ([16],[20]) are considered. Notably, most studies employ multiple evaluation methods.

Most studies involve intervention teams composed of students and teachers with degrees in B.Ed in Computer Science (CS) Education, B.Sc in CS, or B.Sc in Computer Engineering. In some cases, individuals from other disciplines are also involved in the preparation and implementation of activities, including those with degrees in B.Sc in Information Systems, B.Ed in Pedagogy, B.Sc in Civil Engineering, BA in Graphic Design, Neuroscience, and MSc in Mathematics.

Our approach differs from previous works by applying different methodologies over an extended period of time, which allowed not only for a deeper discussion of the various types of assessment used and the knowledge and skills targeted, but also for the ongoing revision of both methodological and assessment strategies. We conducted statistical analyses, including significance testing of learning gains, and complemented these with a qualitative discussion of both successful strategies and the challenges encountered. This combination provided a broader and more nuanced understanding of the educational impact.

3 Foundations

When planning the interventions described in this article, we aimed to draw upon existing literature to delineate the conceptual, methodological, and evaluative pillars to be addressed. The selection of computing concepts to be introduced in elementary education was based on certain findings from a project summarized in Subsection 3.1. Considering the infrastructure of municipal schools, it was decided to adopt the unplugged computing teaching approach, which is briefly presented in Subsection 3.2. The interventions included quantitative assessment procedures that generated numerical data, necessitating statistical analysis described in Subsection 3.3.

3.1 Computing Concepts in Basic Education

Amid discussions surrounding Education 4.0, 21st-century skills, and the reevaluation of education to meet the demands of our rapidly evolving digital era, the term Computational Thinking (CT) has experienced a resurgence (Wing, 2006), garnering attention in academia and bringing Computer Science to basic levels of education.

The International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA) developed a leadership toolkit (CSTA & ISTE, 2011a) to underscore the significance of integrating CT for all students, delineating the necessary resources for its implementation. In the toolkit, CT is definded as "a problem-solving process that includes (but is not limited to) the following characteristics: formulating problems in a way that enables us to use a computer and other tools to help solve them; logically organizing and analyzing data; representing data through abstractions, such as models and simulations; automating solutions through algorithmic thinking (a series of ordered steps); identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources; generalizing and transferring this problem-solving process to a wide variety of problems."

Building upon this operational definition, the document explicitly describes the implicit concepts within it, as following (CSTA & ISTE, 2011a, 2011b): *Data Collection* - the process of gathering appropriate information; *Data Analysis* - making sense of data, finding patterns, and drawing conclusions; *Data Representation* - depicting and organizing data in appropriate graphs, charts, words, or images; *Problem Decomposition* - breaking down tasks into smaller, manageable parts; *Abstraction* - reducing complexity to define main idea; *Algorithms & Procedures* - series of ordered steps taken to solve a problem or achieve some end; *Automation* - having computers or machines do repetitive or tedious tasks; *Simulation* - representation or model of a process. Simulation also involves running experiments using models; *Parallelization* - organize resources to simultaneously carry out tasks to reach a common goal.

3.2 Unplugged Computing Education

Unplugged computing education (Bell et al., 2015) refers to teaching computational concepts and skills without the use of computers or digital devices. It relies on hands-on activities, games, and exercises to teach fundamental principles of computer science, such as algorithms, programming logic, and problem-solving, using tangible, real-world materials. Advantages of unplugged computing education include (Caeli & Yadav, 2020):

Accessibility: it makes computer science education more accessible to students who may not have regular access to computers or digital devices, ensuring inclusivity and equity in learning opportunities.

Conceptual Understanding: unplugged activities help students develop a deep conceptual understanding of fundamental computer science concepts by engaging them in physical, interactive experiences that illustrate abstract ideas in a concrete manner.

Engagement: hands-on, interactive activities make learning more engaging and enjoyable for students, fostering their interest and enthusiasm for computer science from an early age.

Creativity and Collaboration: unplugged activities often involve group work and problem-solving tasks, promoting creativity, communication, and collaboration among students as they work together to solve challenges.

3.3 Statistical Analysis

In educational research, statistics play a crucial role by providing analytical tools to understand and improve educational processes. Through statistics, it is possible to identify trends, detect hidden patterns, compare results between different groups, identify disparities, and evaluate their statistical significance.

Among the various statistical techniques used in education, the Student's t-test stands out as a powerful tool for determining whether there is a statistically significant difference between the means of two samples. The hypothesis under verification, called the null hypothesis (H_0), assumes that the difference between the means is zero. By calculating a test statistic based on data variability and sample size, the t-test allows us to determine whether observed differences between sample means are real or should be attributed to chance. However, for inferences arising from statistical tests to be valid and precise, certain assumptions must be met. For the t-test, three assumptions are required: normal distribution of the data, homogeneity of variances, and independence of observations.

The first assumption suggests that the observations within each compared group follow a normal distribution. This assumption is crucial because it classifies statistical methods into two broad categories: (1) parametric, which assume data normality, and (2) non-parametric, which do not assume a specific data distribution. Therefore, checking the normality of the data is essential to ensure the correct application of parametric methods. Several tests are available for this purpose, each with its own assumptions and limitations. The choice of the most appropriate test depends on the sample size, data distribution, and the specific context of the analysis. The Shapiro-Wilk test is considered an excellent normality test, often exhibiting greater power than its competitors (D. Ferreira, 2005). Some researchers use multiple tests to make a robust assessment of data normality. When the assumption of normality is violated, the Wilcoxon signed-rank test is a non-parametric alternative to the Student's t-test for comparing two samples (Bussab & Morettim, 2017; Siegel, 1981).

The second assumption of the t-test, homogeneity of variances, indicates that the variances of the groups being compared should be approximately equal. Finally, the assumption of independence presupposes that observations in one group are not influenced by observations in another group. However, violation of this third assumption does not preclude the use of the t-test. When there is no independence between the samples of the populations whose means are being compared, such as when the observations of the two samples are made on the same individuals, the paired sample t-test is recommended. This situation occurs, for example, when a characteristic is measured before and after an individual is subjected to a certain treatment or intervention (Bussab & Morettim, 2017).

In the paired t-test, the variable analyzed is the difference between the two values observed in the same individual, and the null hypothesis (H_0) assumes that the mean of these differences is equal to zero. Rejecting this hypothesis leads to the conclusion that the effect of the treatment or intervention was significant. The procedures used in this experience are detailed in section 5.

4 Project Experience Report

The general plan for the ExpPC project is to raise awareness in the community about the importance of teaching Computer Science fundamentals starting from Elementary Education. It involves a multidisciplinary team comprising Computing, Education, and Statistics professors and researchers, along with professionals from the municipal education network, undergraduate and graduate students, and elementary school students. The project is supported by the Pelotas Municipal Department of Education and Sports and has already implemented activities in three schools within the municipal network concurrently.

The aim of the experiments conducted between 2013 and 2019 was to assess the viability of integrating computing concepts into classes for students in the 3rd to 6th grades of elementary school, taking into account the infrastructure available in the city's schools. Specifically, during this period, only a limited number of municipal schools had accessed a computer laboratory or other adequate computing resources for conducting activities. Additionally, it was not until the latter years covered in this report that national discussions regarding the inclusion of computing in school curricula started. Hence, the questions we aimed to analyze and reflect, in the scope of the 3rd to 6th year, based on the experiments were:

Computer Science Concepts What factors influence the feasibility and effectiveness of integrating computational concepts into the elementary school curriculum?

Methodology What are the perceived benefits and challenges of implementing unplugged computing education in elementary schools?

Assessment Do the developed activities lead to a statistically significant gain in the requirements that the tests are intended to evaluate?

During the period of the experiments, from 2013 to 2019, the project has developed numerous activities, benefiting approximately 450 students from four municipal schools. These activities are accessible on the project's website[2], currently available in Portuguese and English (up until 2016), enabling teachers to incorporate them into their classrooms. The activities aim to cultivate various computing-related skills that can be applied to problem-solving across different subject areas. Each activity includes a Teaching Plan and is tailored with tasks adapted for each year of elementary school. Generally, the activities are unplugged (Bell et al., 2015), designed to be low-cost, and detailed materials are made available on the project website whenever possible.

Each year, activities were proposed and conducted in at least one classroom at a municipal school. The planning of these activities was done collaboratively with pedagogical coordinators and elementary school teachers, who identified the class(es) suitable for the activities and specified the skills they wish to develop together. In the classroom, the activities were conducted by undergraduate students who had undergone prior training, under the supervision of university professors, and always with a supporting team. School students participate in these activities during their class sessions, with parental consent obtained through signed Free and Informed Consent Form[3]. Task plans were adjusted and refined based on classroom progress.

The following subsections report the actions taken during the study period, outlining the activities conducted, the methodologies employed, and highlighting successful and unsuccessful strategies. Table 1 presents a summary of activities conducted each year, along with their respective target audience, the number of meetings per activity, the computing concepts covered, the arrangement (duration of meetings and the team involved in the school classroom), and the assessment method employed.

4.1 Report from 2013 and 2014

In 2013, we started the activities in schools, which were planned for fourth-grade elementary school students. These activities were either adapted, extended, or modified and then reintroduced in 2014, for the same target audience. However, the search algorithms activity was not included in the reapplication. Instead, it was revamped and reintroduced to a fifth-grade class in 2015. A notable observation was the time-consuming nature of evaluation exercises conducted at the end of each class in 2013. Consequently, in 2014, a decision was made to conduct a single assessment per activity, scheduled for the final class (thus, at least one new task was added in 2014 to each activity). Detailed descriptions of each activity include the changes implemented in each year of application.

Activity – Binary Numbers (BN and BNm)

- **Materials**: for the teacher, a large EVA board featuring 5 pockets and for students, A4-sized boards, each with 5 colored positions. Additionally, five colored cards are provided, representing binary values (containing 1, 2, 4, 8, and 16 black dots). The color corresponding to each position on the board precisely indicates where each card should be placed (inspired by (Bell et al., 2015)). In 2014, plastic bottle caps were introduced to assist in successive division operations.

[2] https://wp.ufpel.edu.br/pensamentocomputacional/pt/
[3] CAAE: 73891417.0.0000.5317

Table 1: Summary table of experiments conducted between 2013 and 2019

Year	Target audience	Activity (number of meetings)	Computing concepts	Class duration and class team	Assessment method
2013	4th year 2 classes from the periphery	BN (3)	information encoding	1h30min 3 undergraduate students, and 2 professors	exercises at the end of each meeting
		CN (2)	information encoding		
		SA (2)	sorting algorithms		
		Bs (3)	search algorithms		
2014	4th year 3 classes: one central, one rural, and one from the periphery	BNm (5)	information encoding	1h30min 2 undergraduate students, and 1 professor	a written test at the last meeting of each activity
		CNm (5)	information encoding		
		SAm (6)	sorting algorithms		
2015	5th year 3 classes: one central, and two from the periphery	TH (4)	search algorithms	1h10min 2 undergraduate students, 2 professors, and eventually extra undergraduate volunteers	a written test at the last meeting of each activity
		FF (7)	collection, organization, and analysis of data/information		
		A (7)	data abstraction, algorithms, and simulation		
2016	3th year 2 classes: one rural, and one from the periphery	IA (9)	algorithms, debugging, and analysis (cost)	1h10min 1 undergraduate student, 2 professors, and eventually extra undergraduate volunteers	observational and qualitative
2017	6th year 1 class from the periphery	S (5)	sorting algorithms, and analysis (cost)	1h 1 undergraduate student, and 2 professors	a written test at the last meeting
		SC (5)	algorithms, and analysis (cost)		exercises at the end of each meeting
2018	3th year 1 class from the periphery	Co (6)	sequential algorithms	1h 1 undergraduate student, and 1 professor	a written test at the last meeting of each activity
		Cl (5)	pattern recognition, and (efficient) classification		
2019	4th year 1 class from the periphery	Ex (4)	data representation, decomposition, and pattern recognition	1h 1 undergraduate student, and 2 professors	exercises at the end of each meeting
		E-RPG (6)	algorithms, pattern recognition, generalization, and abstraction		

- **Motivation and Methodology**: students were invited to join a secret club, requiring them to uncover a hidden number from a provided binary code. The goal was to instruct them on decoding binary sequences into secret numbers. Taking into account the target audience of fourth-grade elementary school children, a playful methodology was employed to engage students in the club activities. Initially, students utilized cards on the board to distinguish between the presence or absence of dots, representing 0's and 1's respectively. They then progressed to translating words into binary codes, employing 0's and 1's for word representation. In these exercises, students encoded their names and favorite fruits using binary code on a sheet, which was then passed to another classmate for deciphering the message. Initially, encryption and decryption were conducted using the cards on the board, later transitioning encryption to the successive division method.
- **Successes and Failures**: since it was the first activity implemented by the group, it provided an overwhelmingly positive learning experience and encouraged the production of new editions of this and other activities. This first experience also created more opportunities for interaction between the University and the Public Education Network, improving the future methodologies for the implementation of project activities. The practice in 2013 revealed that students encountered difficulty in performing successive division calculations, which were essential for creating codes without the aid of cards and the board. Consequently, a new task (in addition to the final assessment task) was introduced in 2014 to strengthen division calculations for encoding binary numbers.

Activity - Coding with Numbers (CN and CNm)

- **Materials**: for the teacher, a large styrofoam board measuring 48cm x 48cm with 64 pixels of 6cm x 6cm each and black cardboard squares, used to represent pixels, pinned to the styrofoam board using pins. A4 sheets for students. In 2014, the exercise sheets contained questions featuring screens with higher resolution (greater quantity of pixels), and pixels in different colors were explored, namely: blue, brown, red, yellow, green, black, and white, all in the same dimensions.
- **Motivation and Methodology**: the students were instigated to comprehend how images are reproduced on computer screens, tablets, mobile phones, or even TV screens. The styrofoam board simulated the screen of the device in question, with the squares representing the pixels. The first two tasks were introduced using an expository and dialogic approach. The styrofoam board was displayed, and students were encouraged to interpret the images depicted on it, representing them through codes and vice versa. Each line was encoded with a sequence of squares, either painted black or left unpainted. In the examples, large letters or images were displayed on the screen, and students were tasked with representing each line in terms of the number of painted and unpainted squares, thus creating the encoding of the image. In 2014, greater attention was given to the distinction between the colors of the pixels, as larger and colorful images were generated in the tasks. We aimed to diversify the types of exercises to challenge the students further and align them with real-life scenarios. To accomplish this, two new tasks were devised.
- **Successes and Failures**: overall, students found the tasks to be simple and straightforward.

Even when tasked with creating an image from the code, they found it to be easy and engaging. However, a notable drawback was the students' quick loss of interest in the tasks, possibly due to the lack of challenging elements. In 2014, students appeared to be more engaged in encoding and decoding color images, as well as discussing the effect on the resolution of an image with more or fewer pixels.

Activity - Sorting Algorithms (SA and SAm)

- **Materials**: weighing scales; sets of 8 bottles, all identical but with varying weights, painted so that their contents cannot be seen; sets of 30 squares made of black cardboard measuring 6 cm x 6 cm each; a board containing 8 horizontally aligned positions, one for each bottle; and rubber bands. Each trio of students was provided with one kit of material. In 2014, each kit contained 10 bottles filled with different volumes of sand (with a weight difference of 100g between each), eliminating the need for scales to obtain comparison results. Black cardboard cards were replaced with miniature 1 Real bills. Additionally, stickers with images on one side and numbers on the other, along with trays for the stickers were also used.
- **Motivation and Methodology**: students were motivated to learn strategies for sorting a large quantity of everyday items, such as cards or stickers. Before introducing the sorting algorithms, the concept of comparison was introduced by separating any two bottles and comparing them based on weight. It was demonstrated that to sort the bottles from lightest to heaviest, they needed to be compared one by one. Each comparison task required to sort the bottles involved adding a point (characterizing a cost), represented by a black square/-bill. Thus, when dealing with a group of bottles with different weights and black squares, the sorting algorithms were introduced. In order to introduce the selection sort method, each group of three students received a kit with bottles and cards/bills. They were instructed to select two bottles from the set, compare them, leave the lighter one on the table, and place the heavier one on the floor. A black square/bill was added for each comparison. This process was repeated multiple times until the lightest bottle was separated. Then, the entire process was repeated until all bottles were sorted. Finally, students added up the squares to evaluate the number of comparisons needed to sort the set. In another task, the quicksort method was introduced. A bottle from the kit was chosen as the pivot and identified with a rubber band. Each bottle was compared to the pivot one by one, and a black square/bill was assigned for each comparison. If the bottle was lighter than the pivot, it was placed to the left; if heavier, it was placed to the right. At the end of all comparisons, the pivot was in the correct position. The process was then repeated with the two groups of bottles, those heavier and lighter than the pivot. Following each method, a discussion was held. The teacher facilitated a comparison between the approaches, emphasizing that depending on the method chosen, sorting could be achieved in fewer steps (time). Given the difficulties encountered by students in understanding the sorting methods, in 2014 the activity was expanded to cover six meetings. The first meeting was dedicated to introducing the material, explaining the weighting process, and discussing the concepts of cost in sorting. At this meeting, stickers were employed to introduce the concepts of comparison and cost, with the search for a sticker with a specific number serving as motivation. The significance of whether the stack of stickers was in order or not was also addressed. The second to fourth meeting covered

the sorting methods: mergesort, selection sort, and quicksort, respectively. In the mergesort class, a board was utilized to facilitate the division and combination tasks. At each level, from top to bottom, the bottles were compared and sorted within their respective groups. Once sorted within their groups, the task of combining bottles from different groups started from the bottom and proceeded upward until all bottles were sorted at the highest level of the board. Students repeated this procedure in pairs, using their kits and boards. With each comparison task, one unit was added to the total cost. The fifth session involved a review of the methods covered, and the sixth session was solely dedicated to evaluation.

- **Successes and Failures**: In 2013, the explanation of sorting methods through comparisons was time-consuming, nearly occupying the entire duration of the meeting, thus leaving little time for final remarks and evaluation. Additionally, it was challenging for students to grasp the concept of cost, and they frequently struggled to keep track of the black squares, leading to confusion. While students generally enjoyed the application of the tasks, they did not demonstrate the expected level of understanding of the concepts. In 2014, the students simulated the algorithms correctly and did not struggle with keeping track of the costs, although it was not possible to verify their mastery in differentiating the methods.

Activity - Battleship (Bs, applied only in 2013)

- **Materials**: game boards containing two groups of ships: at the top, the player's ships (identified by letters and numbers), and at the bottom, the enemy's ships (only identified by letters). One large game board for the teacher, mounted on a foam board for demonstration to the students, as well as multiple game boards in A4 paper size for the students. Additionally, small squares made of black cardboard measuring 6cm x 6cm were provided, along with pins to secure the squares on the foam board, and beans for counting. Both were utilized to demonstrate the rules of the game by marking the sunken ships on the teacher's board.

- **Motivation and Methodology**: The students were invited to play the game Battleship with each other. The goal is to sink a specific ship (the target ship, identified by a number) chosen by the opponent. Each pair of players is positioned opposite each other, with each having their own board. The game proceeds in turns, and during their turn, a player attempts to sink one of their opponent's ships (indicating the position of the ship to be sunk by its letter). Upon receiving a shot, the opponent responds with the ship number (indicating whether the player hit the target or not). Each of the three activities explores one of the strategies to be learned: linear search, binary search, and hashing. In the first task, the ships are randomly arranged, exploring the application of linear search. Here, players take turns attempting to guess the position of the opponent's ship, placing a bean for each attempt made. The second task explores binary search, so in this case, the ships are ordered, and students are instructed to take advantage on this characteristic. In the third task, the instructor introduces a "trick" used by computers, which involves calculating the potential position of the ship using a function (hashing). Following the explanation, students engage in the game and are encouraged to employ the same trick. Ultimately, the three search methods are discussed, and the time taken to sink the opponent's ship using each method is analyzed.

- **Successes and Failures**: during the game, it was challenging to maintain the students' attention on calculating the number of attempts because, at various moments, they would make moves without tallying the beans. To address this issue, tutor students were assigned to accompany and assist their peers during the initial plays, ensuring they understood the rules of the game and did not forget to count the number of attempts. Also, some students reported difficulties in understanding the game rules. This activity underwent restructuring, featuring a new theme and adaptations to the materials and methodology used. The Treasure Hunt, as it was called, took place in 2015.

4.2 Report from 2015

In 2015, three activities were implemented in three fifth-grade elementary school classes: two classes from a peripheral school and one class from a central school.

Activity - Treasure Hunt (TH)

- **Materials**: game boards containing two groups of islands: at the top, the player's islands (identified by letters and numbers), and at the bottom, the enemy's islands (only identified by letters). One large game board for the teacher, mounted on a foam board for demonstration to the students, as well as multiple game boards in A4 paper size for the students, affixed by clips to a cardboard folded in half (separating the player's islands from the enemy's islands), pens, and supporting cards where students can record the number of the island on which the treasure was hidden as well as the number of islands visited to find the treasure. Additionally, small squares made of black cardboard measuring 6cm x 6cm are provided, along with pins to secure the squares on the foam board. Both were utilized to demonstrate the rules of the game by marking the islands visited on the teacher's board.
- **Motivation and Methodology**: The students were invited to participate in a treasure hunt game where the objective was to find the hidden treasure with the fewest number of attempts. Therefore, students were encouraged to employ the most effective search strategies to succeed in the game. In the first meeting, linear search is introduced alongside the rules of the game. Students engage with the topic through gameplay, with the teacher and students taking turns playing against each other. Strategies for playing the game are discussed, along with best and worst-case scenarios. During the second meeting, binary search is introduced. Initially, students play against the teacher, and then they are divided into pairs to play against each other. At the conclusion, linear and binary search strategies are compared in the context of winning the game. In the third meeting, a different map is utilized to apply the concept of a hash function. Once again, students first play against the teacher and then against each other. Finally, the three search methods are compared, and their applications in different contexts are discussed. During the final meeting, a test comprising questions based on the treasure hunt game is presented to the students.
- **Successes and Failures**: students appeared motivated to participate in the tasks, especially when playing against each other. This time, there were no issues with understanding the activity, as had occurred with the first version of this activity (Battleship).

Activity - Face to Face Game (FF)

- **Materials**: students were provided with a collection of cards containing character faces with various characteristics, as well as a board where the cards could be placed upright in front of them.
- **Motivation and Methodology**: students were invited to participate in a game where the goal was to identify a hidden character through questions related to its attributes/characteristics. By analyzing the characteristics of all possible characters using the techniques presented in the meetings, students were encouraged to uncover the hidden character with the fewest number of questions. In the first meeting, students are introduced to important concepts in data collection and classification, such as population, sampling, constants, variables, and frequency. Following this, students receive a set of cards and analyze the characteristics of the characters depicted on them. Subsequently, a game is played where students sit in a circle, each with a card attached to their forehead. Taking turns, students ask questions about their characters and attempt to guess who the character on their forehead is. During the second class, students are prompted to identify characteristics of the characters that are relevant to identifying them. They are divided into groups and tasked with producing a list of characteristics that would assist in winning the game. The results proposed by the groups are then analyzed with the entire class. In the subsequent meeting, students learn how to organize the data collected from the characters into tables and bar graphs. In the following two sessions, the data collected in tables during the previous session is analyzed, aiming to demonstrate the difficulty of analyzing unorganized data. In the sixth class, students are divided into pairs and play the game against each other, attempting to identify the chosen character with the fewest number of questions. Finally, the teacher reviews with the entire class which characteristics are the most decisive to be used in the game. The last meeting is dedicated to a final test where students answer questions about concepts presented throughout the entire activity.
- **Successes and Failures**: students seemed motivated to participate in the tasks, especially when playing against each other. There were no difficulties in understanding the game and its rules. Some students encountered difficulty in organizing graphs that represented information from multiple variables, but this issue was addressed during the meetings.

Activity - Algorithms (A)

- **Materials**: instruction sheets for making origami, printed game boards, a kit containing a set of printed algorithmic instructions, post-it notes, and larger versions of the materials to be used on the blackboard.
- **Motivation and Methodology**: Students were engaged in a game with the goal of constructing an algorithm to make a character find the right path in a maze. In the first meeting, students were introduced to the concept of algorithms as a sequence of steps to achieve an objective, demonstrated through origami-making. During the second meeting, students received boards containing mazes and a set of cards containing instructions such as *begin*, *end*, *go forward*, *turn left*, and *turn right*. Their objective was to organize a sequence of

instructions to guide a character through the correct path in the maze. In the subsequent class, students were given new instructions such as *if/else* to avoid obstacles and *collect/use* to interact with items found in the maze. During the fourth class, the concept of *instruction cost* was introduced, prompting students to construct more efficient algorithms. In the following meetings, repetition was introduced, allowing students to repeat a single instruction multiple times instead of using multiple cards for the same instruction. The sixth meeting served to review all concepts introduced thus far by creating algorithms to solve three different mazes. Finally, in the last session, a test was administered where students had to solve exercises related to the topics covered in previous sessions.

- **Successes and Failures**: students seemed to enjoy the activities. However, it was noticed that some students encountered difficulty in writing algorithms during the final test without using the instruction cards that were available for gameplay in the meetings

4.3 Report from 2016

In 2016, the activities were implemented in two third-grade elementary school classes, one from a school near the rural area of the city and the other from a school in the periphery.

Activity - Introduction to Algorithms (IA)

- **Materials**: LEGO® Mindstorms® Robot, LEGO® Mindstorms® EV3 software (where high-level functions and abstractions were implemented to represent commands defined in the software), marked path blocks and instruction blocks.
- **Motivation and Methodology**: students are encouraged to devise solutions for the robot to reach pre-established destinations, while respecting pre-drawn paths. The methodology adopted in this activity varied according to the task developed. Initially, the collaborative elaboration method was employed, where active interaction between the teacher and students determined the language adopted in subsequent tasks. Group work methodology was then adopted for almost all tasks, always aiming to create a challenging context. Groups were tasked with assembling paths from basic block junctions and defining individual algorithms for the robot to traverse these paths. Subsequently, groups were challenged to compose paths and algorithms, assessing their feasibility and required modifications. Other challenges included the collaborative construction of valid paths (e.g., following path lines without overlapping blocks), identifying paths and defining algorithms with lower computational costs, and devising solutions with a reduced number of blocks. The proposed solutions were simulated based on the execution of the defined algorithms/programs. In the initial tasks, algorithms were defined using printed command blocks, and later, the EV3 software was utilized. The tasks involved fundamental concepts of algorithms, encompassing spatial movement instructions and control structures (such as repetition), as well as debugging and algorithm analysis (including cost evaluation). The evaluation of this activity was observational and qualitative. For each task, a project collaborator (student or professor) was assigned to observe a group of students (approximately 3-4) and complete an evaluation form for each student. This form assessed whether the student: identified the spatial references of the robot within the scenario; identified valid block connections; constructed

valid paths; suggested correct commands; accurately quantified the algorithm's cost; identified the shortest paths; used the software without difficulty; demonstrated participation (e.g., actively engaged or volunteered ideas); and cooperated with the group.

- **Successes and Failures**: overall, students felt encouraged to interact and engage in the activity. The use of tangible materials facilitated the definition of algorithms, while group work encouraged interactions and collaborations to overcome challenges. Transitioning from defining algorithms with physical blocks to using the computer appeared to enhance understanding of solutions described in the software. Simulation of solutions proved crucial for identifying errors, particularly in spatial references and command usage. The primary difficulty observed was regarding spatial orientation, especially distinguishing between right and left. Additionally, students encountered challenges in defining algorithms without simultaneous simulation. When transitioning to the computer, path maps were printed on A4 sheets, along with a marker representing the robot. Some students struggled to orient themselves on the map without the aid of the marker.

4.4 Report from 2017

In 2017, activities were developed for a sixth-grade elementary school class from the periphery.

Activity - Sorting (S)

- **Materials**: boards and cards served as tangible teaching aids to illustrate the ordering criteria. Cards with numbers and letters, available in both teacher and student versions, were utilized for the selection sort. Additionally, cups containing various numbers and chairs corresponding to the number of students were employed, along with miniature ballots for quicksort simulations.

- **Motivation and Methodology**: this activity introduces two sorting algorithms, selection sort and quicksort, with the aim of presenting distinct strategies for sorting a data structure (such as a set, array, or list). It also encourages discussion based on the selected method, which directly influences the performance of the sorting algorithm. The initial tasks involved expository dialogues. Subsequently, the proposal delves into challenging/-experimental tasks, and in the final ones, students were encouraged to participate as actors in simulating sorting algorithms, using concrete data types (such as cards with letters and numbers, and cups) to represent abstract algorithm values. In the first meeting, students engaged in ordering words distributed in tables, revisiting basic concepts such as comparing sets described in increasing/decreasing order and exploring common ordering criteria in numeric and alphabetical sequences. In the second class, students simulated the selection sort algorithm through a game, where players should uncover a secret word hidden among the distributed set of cards, emphasizing the need to execute the algorithm to discover all the sorted letters. The third meeeting was dedicated to simulate the quicksort algorithm using cups containing numbers. Each student received a cup representing an element of the set to be sorted by the algorithm. In the subsequent class, students applied the concept of cost using additional comparisons in the quicksort algorithm. The class expands on the previous game, with students receiving toy money. Each time a student makes a comparison with the pivot, they must pay, highlighting that increased costs were associated with more comparisons. The last class comprised the final test.

- **Successes and Failures**: the materials and approach adopted facilitated comprehensive demonstrations of sorting algorithms and increased student engagement in the learning process. This task demonstrated the highest level of comprehension of sorting processes compared to the other instances. However, students encountered challenges in understanding the role of the pivot in the quicksort algorithm.

Activity - SoccerCraft (SC)

- **Materials**: a football field constructed from styrofoam, featuring horizontal and vertical lines segmenting it into squares. A ball and players of various ethnicities and genders (in a Minecraft-style design), adorned in uniforms representing the colors of the region's primary teams, printed on cardboard. Pins are utilized to fasten the players and ball onto the field. Additionally, exercise sheets presenting diverse scenarios (variations in player positions), aimed at devising various algorithms to achieve goal-scoring in the shortest possible time (fewer instructions).

- **Motivation and Methodology**: the entire activity is designed with the objective of scoring goals in a football game, which is the most practiced and widespread sport among Brazilian children, beloved by the majority of them. Players adopt a Minecraft-style aesthetic, i.e, inspired by the electronic game popular among children (Persson & Bergensten, 2011), which in recent years has topped the charts as one of the most played games worldwide (Newzoo International B.V., 2024). The proposed activity was divided into five meetings, implementing a strategy of incremental complexity. New concepts and rules were introduced in each meeting. From the first to the fourth class, the following were respectively presented: an introduction to the basic SoccerCraft module, basic commands (*run to the right*, *run to the left*, *run forward*, and *shoot on goal*), and the sequential structure; addition of the goalkeeper (positioned under the goalposts, occupying central, right, or left positions, unable to move or receive the ball), expansion of the field's size, and introduction of a new command (*run back*); four new commands (*touch back*, *touch forward*, *touch left*, and *touch right*), which enabled players to pass the ball between each other. The four fundamental rules of the game are as follows: (i) only the player with the ball can move; (ii) a player can only move exactly one space; (iii) no two players can occupy the same square; and (iv) a player can only score from inside the penalty area, with each movement taking one minute (a unit of time). In the fourth class, a game involving all students in the classroom was played. The student-players were divided into two teams, positioned symmetrically on the field. Each team possessed the ball and took turns making moves. The first team to score won the game. An evaluation was conducted during the final meeting.

- **Successes and Failures**: the vast majority of students actively engaged in the tasks and demonstrated motivation to participate in the challenges. However, three girls showed no interest in participating in the activity. Overall, everyone demonstrated a clear understanding in following the rules of the game and in formulating algorithms.

4.5 Report from 2018

In 2018, a third-year elementary school class from the periphery participated in the activities. In this year, the physical space of the classroom was extremely limited, hindering group work and proposed activities. Additionally, one student presented a medical report, necessitating the assignment of a dedicated volunteer to accompany him and attempt to involve him in the tasks, albeit sometimes unsuccessfully.

Activity - Comics (Co)

- **Materials**: complete and incomplete comic strips.
- **Motivation and Methodology**: students were motivated to engage in organizing and creating comics, as well as crafting stories inspired by comics. The introduction of concepts started with the organization and interpretation of comic sequences, where students initially shared their interpretations orally with the class. The activity encompassed both the partial and complete creation of comic sequences with narratives, done individually, in groups (to foster interaction and creativity in narrative description), and cooperatively (where each student contributes to a part of the story created by a peer, ensuring continuity and coherence). In the initial tasks, comics are represented solely by images. In some intermediate tasks, students have the freedom to choose the most suitable method for continuing the story, whether through text only, drawings and text (e.g., using speech bubbles), or solely through drawings. In the final tasks, students are encouraged to provide textual descriptions of the narratives. In all tasks, emphasis was placed on the sequence and dependencies between the scenes, ensuring clarity on how items in one scene, which relied on previous scenes, were introduced earlier in the story.
- **Successes and Failures**: the freedom provided by the assigned tasks, both in terms of organizing and describing the comics, cultivated creativity, resulting in the creation of numerous meaningful stories with varying arrangements of the same comics. The transition from visual to textual descriptions facilitated the development of narratives with coherent chaining and logical sequence.

Activity - Classification (Cl)

- **Materials**: kits consisting of various geometric shapes in different sizes and colors. Images are represented by composing full-size pieces using molds/templates.
- **Motivation and Methodology**: students were encouraged to swiftly compose images using geometric shapes of varying colors and sizes, challenging themselves to improve their completion time. For the presentation and discussion of different geometric shapes, as well as the exploration of various classification criteria (such as color, size, shape, or their combinations), a dialogical expository methodology was employed. Through experiments, it was concluded that employing appropriate classification criteria enhances the efficiency of the process. Various drawings served as models (e.g., figures composed of pieces of the same

geometric shape and color but different sizes, or figures composed of different shapes and colors but with all pieces of the same size), motivating students to recreate them. Through timed experiments, they recognized that organizing the pieces according to relevant criteria expedited the composition process. Some tasks focused on identifying appropriate criteria, including combinations thereof, based on the identification of common characteristics among different figures.

- **Successes and Failures**: students actively participated in the activity, demonstrating keen interest in assembling the figures and were motivated to improve their completion times through organizing the pieces. However, the limited space posed challenges in manipulating the pieces and hindered individual solution development.

4.6 Report from 2019

In 2019, the activities were applied to a fourth-year elementary school class from the periphery.

Activity - Exchange (Ex)

- **Materials**: initially, the main materials were sets of the pick-up sticks game, an old game played with wooden or plastic sticks of different colors. During the first two meetings, the team facilitating the activities observed that students had difficulty understanding the exercises. Therefore, in the third session, the materials were replaced with sets of cards featuring pictures of animals at various stages of development.

- **Motivation and Methodology**: students were introduced to computing concepts through gameplay, initially with the pick-up-sticks game and later with sets of cards featuring animals. In the first meeting, students were introduced to the concept of data representation through various examples, such as TV channels represented by numbers, money bills representing values, and nicknames representing people. Following this introduction, students engaged in the pick-up sticks game. In this activity, plastic sticks of different colors were scattered on a table, and the objective was to pick up a stick without disturbing others. Each color was associated with different points, with the aim of accumulating the highest score. Throughout the meeting, students competed against each other in the game. The second meeting began with students playing the pick-up sticks game in different groups. They were instructed to retain the sticks they collected during the game. Subsequently, students were provided with goal cards specifying the desired quantity of sticks of certain colors. They were then invited to participate in a new game where, taking turns and adhering to specific rules, they traded sticks with one another in pursuit of achieving their individual goals. However, students encountered difficulties in comprehending the game and lacked motivation to participate. In the subsequent meeting, the same game was played, but instead of using plastic sticks, cards featuring pictures of animals were utilized. This modification resulted in improved student understanding and increased motivation to engage in the game. The final meeting was devoted to a test comprising questions related to the games played throughout the classes.

- **Successes and Failures**: as mentioned before, students lacked motivation to play the pick-up sticks game, especially during the final phase where they were required to trade sticks. However, when the same game was played using cards featuring animal pictures, they exhibited increased motivation and eagerness to participate in the activity.

Activity - Elementals RPG (E-RPG)

- **Materials**: sets of cards featuring the characters, inspired by well-known cartoon characters, larger versions of which were displayed on the blackboard to explain the game rules, game boards, and score sheets were provided to the students.
- **Motivation and Methodology**: the goal of the activity is to teach students basic algorithmic concepts (such as sequence, selection, and repetition) in addition to fostering pattern recognition, abstraction, and generalization, through a card-based RPG game inspired by the Pokémon®. In the first two sessions, a simplified version of the RPG game was introduced to the students. It was based on the rock-paper-scissors concept, but with cards representing elements such as water, fire, and plant. After explaining the characters and the game on the blackboard, students were provided with sets of cards and invited to play in pairs. Through the game's abstractions, concepts such as pattern recognition, abstraction, and selection were introduced to the students. In the third meeting, new elements such as strength and life points were incorporated into the characters on the cards. These additional attributes were utilized by instructors to discuss concepts such as selection and data/process abstraction. Expanding on the game in the fourth class, characters were given damage points, with each element-associated character having varying damage points. The instructor simulated battles between characters on the blackboard, and then the class was divided into two groups. Each group received a set of cards and was encouraged to strategize for playing against the other group. Battles between the two groups were played out on the blackboard, with concepts such as sequencing and selection discussed with the class. Noting that some students struggled with understanding how to apply damage points in sequences of rounds, the same game was revisited in the fifth meeting to reinforce comprehension. In the sixth class, the game was further expanded to include a game board. Students were tasked with devising strategies to navigate the board, engage in battles with characters, and form alliances until reaching the end, where all acquired characters had to confront a final villain. Each of the first six sessions concluded with exercises, and the final class was dedicated to a final test composed of questions related to the game and the exploration of computing concepts.
- **Successes and Failures**: students enjoyed the game, although some of them encountered difficulty understanding the rules of the more complex battles, needing an additional class to reinforce these rules.

5 Results

The students who participated in the project underwent two types of evaluation: (1) a test, administered before and after the development of all annual activities, referred to as pre- and post-tests, respectively, aimed at measuring students' average gains and testing their significance; and (2) an assessment of classroom performance for each developed activity (mentioned in the previous section). This section presents the results of the two forms of evaluation applied.

5.1 Pre- and Post-tests

Each year, on the first and last days of project development in the classroom, students underwent a test designed to assess concepts that would be covered in the activities. Administering the same test at these two junctures aimed to gauge whether the project activities could enhance students' performance in addressing these concepts. Consequently, the pre-test score indicates the student's initial proficiency regarding the computing concepts covered in the activity, while the student's gain in the post-test is calculated as the difference between their scores in the post- and pre-tests, which could be positive or negative. A negative gain value suggests that the student scored lower in the post-test compared to the pre-test, indicating a decline in performance. Conversely, a positive gain (improvement in performance) is attributed to the learning acquired through activity development. Considering that this situation indicates dependence between the samples, we opted for the Student's t-test for paired samples to test the statistical significance of the observed gain. The null hypothesis in this test posits that the mean gain (μ) of students does not differ from zero, expressed as $H_0 : \mu = 0$. In practical terms, this hypothesis suggests that the activity does not improve students' performance in the post-test. Since the paired t-test is a parametric test, we first verified the normality of the gain variable using the Shapiro-Wilk test. This test evaluates whether the variable values follow a normal distribution. When the normality assumption was rejected, we replaced the paired t-test with the Wilcoxon signed-rank test, the non-parametric equivalent. For all tests, we adopted a significance level of $\alpha = 0.05$.

Table 2 presents the means of students' pre-test and post-test scores, along with descriptions of gains and the results of significance testing for these gains, categorized by activity and year. Additionally, Figure 1 displays box plots illustrating the distribution of gains, categorized by activity and year. It's important to note that the number and nature of questions comprising the pre-test and post-test varied significantly across different years. Originally, the test was designed to provide a globally evaluation of all activities conducted throughout the year, without specific attention to maintaining balance in the distribution of questions related to each activity. However, starting from the second year, efforts were made to enhance this aspect and address other shortcomings of the test. Whenever any flaws, inadequacies, or insufficiencies in assessing understanding or application of concepts were identified, steps were taken to rectify them in subsequent years. The next section provides a discussion on the development of these tests. In this study, we opted to analyze the results separately for each activity within each year. Since the test was not initially intended for this purpose, this decision necessitated breaking down the test into subsets of questions corresponding to each activity. Consequently, activities were evaluated based on varying numbers of questions (nQ). Moreover, the number of students (n) assessed varied significantly across activities and years, which could also influence the outcomes of the significance test.

The box plots depicted in Figure 1 illustrate the distribution of values for the gain variable. In this graphical representation, the box encompasses 50% of the values, with the line inside representing the median, the x indicating the mean, and any points appearing at the extremes denoting outliers. The color of the box indicates the result of the Shapiro-Wilk normality test,

Table 2: Mean pre-test and post-test scores, description of gains, and results of significance testing for gains, by activity and year

Year	Activity[1]	n	nQ	Mean		Gain (difference)		Significance test	
				Pre-test	Post-test	Mean	Standard derivation	Statistic[2]	p-value
2013	BN	27	2	6.44	6.99	**0.56**	2.31	S=12.5	0.2803 ns
	CN	26	2	6.39	7.07	**0.58**	1.88	S=14.5	0.1465 ns
	SA	33	1	4.85	7.78	**2.93**	5.01	t=3.36	0.0020
	Bs	26	1	7.69	8.85	**1.15**	3.79	t=1.55	0.1337 ns
2014	BNm	43	4	7.69	8.85	**1.05**	2.69	t=2.57	0.0140
	CNm	41	3	4.58	8.31	**3.74**	2.75	t=8.70	< 0.0001
	SAm	45	1	7.16	7.91	**0.76**	5.04	S=49.5	0.2127 ns
2015	TH	60	2	2.67	5.95	**3.28**	3.18	t=7.99	< 0.0001
	FF	53	3	5.08	6.87	**1.79**	2.15	t=6.05	< 0.0001
	A	49	3	4.86	5.96	**1.10**	3.26	t=2.36	0.0222
2016	IA	20	5	6.41	8.17	**1.76**	2.70	t=2.92	0.0088
2017	S	8	1	3.75	7.5	**3.75**	7.44	S=4.5	0.3750 ns
	SC	10	4	2.00	3.00	**1.00**	3.76	t=0.84	0.4226 ns
2018	Co	16	5	3.00	4.50	**1.50**	2.97	t=2.02	0.0613 ns
	Cl	12	4	6.33	6.50	**0.17**	3.01	t=0.19	0.8514 ns
2019	Ex	22	3	7.88	8.19	**0.32**	2.26	S=2.0	0.9399 ns
	E-RPG	22	5	5.83	7.04	**1.22**	1.88	t=3.03	0.0064

Note: *n* - number of students; *nQ* - number of questions; *ns* - non-significant result, according to the statistical test;
[1]BN: Binary Numbers; CN: Coding with Numbers; SA: Sorting Algorithms; Bs: Battleship; BNm: Modified Binary Numbers; CNm: Modified Coding with Numbers; SAm: Modified Sorting Algorithms; TH: Treasure Hunt; FF: Face to Face Game; A: Algorithms; IA: Introduction to Algorithms; S: Sorting; SC: SoccerCraft; Co: Comics; Cl: Classification; Ex: Exchange; E-RPG: Elementals RPG.
[2]S: Wilcoxon signed-rank test; t: student's paired t-test.

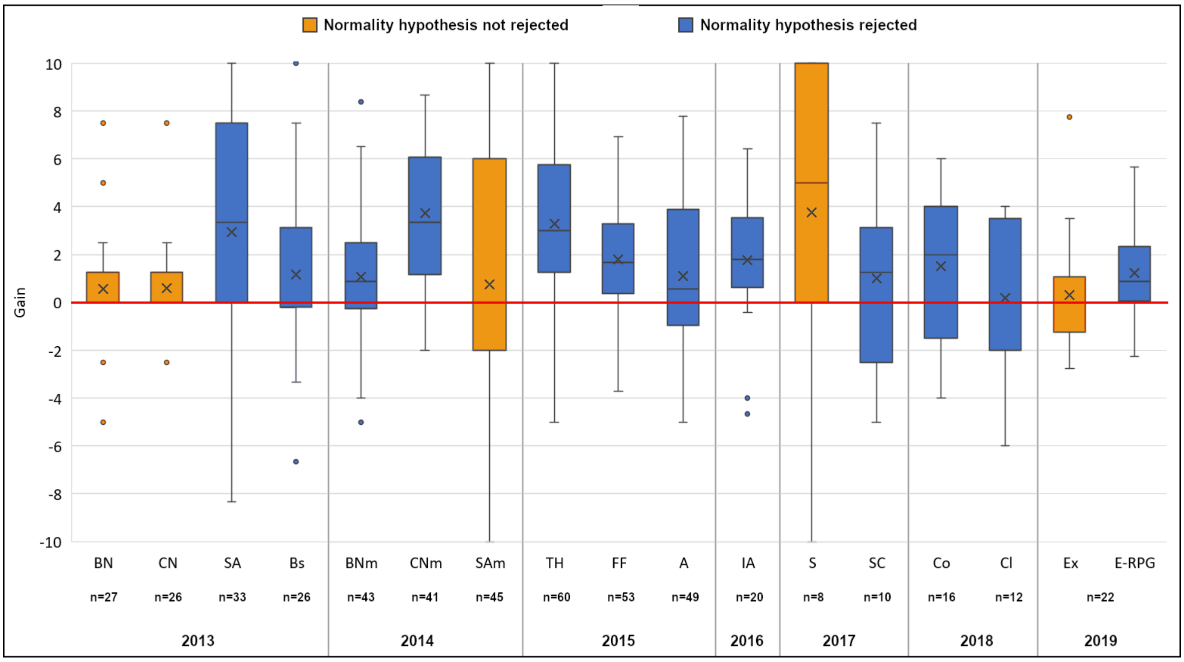

Figure 1: Distribution of the student gain variable by activity and results of the Shapiro-Wilk test, in the years 2013 to 2019.
Note: Gain = post-test score − pre-test score. x = average

specifically whether the hypothesis of normality for the gain variable was rejected or not. The normality hypothesis was rejected for five activities (BN-2013, CN-2013, SAm-2014, S-2017, and Ex-2019) and not rejected for all others.

In Table 2, alongside the averages of the pre- and post-tests, the average gain attained by students in each developed activity is highlighted. The statistical significance of this gain was verified using both the parametric paired Student's t-test and the non-parametric Wilcoxon signed-rank test, each with a significance level of $\alpha = 0.05$. Therefore, if the p-value is less than 0.05, the null hypothesis ($H_0 : \mu = 0$) is rejected, indicating that the average gain in the activity is significant; and the significance increases as the p-value decreases. Broadly, over the seven years of project execution, 16 activities were conducted in the classroom and evaluated through pre- and post-tests. However, only eight of them yielded significant average gains for the students. Notably, the activities Sorting Algorithms (2013), Coding with Numbers (2014), Treasure Hunt, and Face to Face Game (2015) exhibited the most substantial and statistically significant average gains, with respective values of 2.93 points ($p = 0.002$), 3.74 points, 3.28 points, and 1.79 points ($p < 0.0001$ for all three). Smaller yet still significant average gains were observed for the activities Binary Numbers (2014), Algorithms (2015), Introduction to Algorithms (2016), and Elementals RPG (2019). However, in other activities, students did not achieve significant average gains. It's worth noting that for the activity Comics (2018), the average gain of students (1.50 points) was very close to significance (p = 0.0613).

However, upon analyzing the students' averages in the pre-test and post-test, it's evident that in six of the eight activities where the average gain was nonsignificant, students had already achieved high averages in the pre-test. Conversely, for the activities SoccerCraft (2017) and Comics (2018), the opposite trend was observed, with both pre-test and post-test averages being very low. These results might be attributed to the inadequacy of the tests, which could have low sensitivity in detecting changes in student performance. The difficulty level of the questions may have been too easy in the former group and too challenging in the latter.

5.2 Assessment of student performance in the classroom

The method of assessing students in the classroom exhibited significant variation across different years and activities. These differences are due to specific characteristics of the activities, the grade levels involved (ranging from 3rd to 6th year), and adjustments made annually to enhance the assessment process. Generally, lists of exercises and written tests were employed to evaluate students' performance in the classroom. In 2013, students were assessed at the conclusion of each activity task using lists of exercises. Subsequently, in 2014 and 2015, evaluation shifted to end-of-activity written tests exclusively. In 2017, one activity (Sorting) was assessed through a single final test, while another (SoccerCraft) utilized lists of partial exercises at the end of each meeting. In 2018, assessments were conducted through a single final test for each activity. In 2019, evaluations reverted to assessing students at the end of each meeting. However, in 2016, a written form of evaluation was not feasible as not all students in the class (3rd year) were fully literate. Consequently, a qualitative evaluation method was adopted that year and thus will not be detailed in this work.

With the aim of investigating whether specific school characteristics could influence student performance, the project was conducted in schools with diverse profiles in 2014 and 2015. In

2014, we worked with 4th-grade classes from three schools with distinct characteristics: a peripheral school (PS), a rural school (RS), and a central school (CS). In 2015, this endeavor was replicated with three 5th-grade classes: two classes from a peripheral school and one from a central school. The results, presented in Table 3, summarize student performance categorized by activity and school for the years 2014 and 2015. Alongside descriptive statistics of student performance (including minimum, maximum, mean, standard deviation, and coefficient of variation), confidence intervals for the mean are also provided at the 95% level.

Table 3: Descriptive measures for student performance, by activity and school, in 2014 and 2015, and confidence limits for the mean, at the 95% level

Year	Activity[1]	School[2]	n	Descriptive measures					Confidence limits (95%)	
				Minimum	Maximum	Mean	Standard derivation	CV (%)	Inferior	Superior
2014	BNm	CS	18	7.6	10.0	9.52	0.69	7.22	9.18	9.86
		RS	25	7.1	10.0	8.77	0.83	9.44	8.43	9.11
		PS	22	5.9	9.9	8.81	1.01	11.51	8.36	9.26
	CNm	CS	16	6.4	10.0	8.84	0.92	10.36	8.36	9.33
		RS	23	5.2	10.0	8.34	1.46	17.47	7.71	8.97
		PS	19	3.7	10.0	7.93	1.78	22.39	7.08	8.79
	SAm	CS	17	3.6	10.0	7.63	1.78	23.39	6.71	8.55
		RS	23	2.2	9.7	6.84	2.12	31.05	5.92	7.76
		PS	22	2.2	8.3	5.77	1.61	27.99	5.05	6.48
2015	TH	CS	24	0.0	8.5	5.11	2.26	44.19	4.16	6.07
		PS	56	0.0	10.0	5.16	3.21	62.13	4.30	6.02
	FF	CS	18	4.2	9.2	7.24	1.45	20.08	6.52	7.97
		PS	47	2.6	9.6	6.94	1.83	26.40	6.41	7.48
	A	CS	15	2.6	8.9	5.68	2.35	41.30	4.38	6.98
		PS	47	0.2	9.5	4.27	2.53	59.22	3.53	5.01

Note: *n* - number of students.

[1]BNm: Modified Binary Numbers; CNm: Modified Coding with Numbers; SAm: Modified Sorting Algorithms; TH: Treasure Hunt; FF: Face to Face Game; A: Algorithms.

[2]CS: Central school; RS: Rural school; PS: Peripheral school.

In 2014, the confidence intervals reveal that the mean performance of students in the activities Binary Numbers (9.5, 8.7, and 8.8) and Coding with Numbers (8.8, 8.3, and 7.9) did not show significant differences across the three schools. However, concerning the Sorting Algorithms activity, it was noted that the mean performance of students at the central school (7.6) did not differ significantly from that at the rural school (6.8), but was notably higher than that at the peripheral school (5.8). Moreover, it was observed that students demonstrated relatively consistent performance, both within and between schools, in the Binary Numbers activity (CV between 7.2% and 11.5%). Conversely, in the Coding with Numbers activity, student performance exhibited more variability within schools (CV between 10.4% and 22.4%). This variability was even more pronounced for the Sorting Algorithms activity (CV between 23.4% and 31.1%).

In 2015, it was observed that, for the three activities developed, mean performances did not exhibit significant differences between students at the central school and students at the peripheral school. However, for the Treasure Hunt and Algorithms activities, very high variation was observed within schools (with coefficients of variation between 41.3% and 62.1%) alongside very low mean performances (ranging between 4.3 and 5.7). Upon comparing schools, it was determined that in five out of the six activities implemented during the period (2014 to 2015), there was no significant effect of the school profile on student performance.

Table 4: Descriptive measures for student performance, by activity and year, and confidence limits for the mean, at the 95% level

Year	School year	Activity[1]	n	Descriptive measures					Confidence limits (95%)	
				Minimum	Maximum	Mean	Standard derivation	CV (%)	Inferior	Superior
2013	4º	BN	37	7.1	10.0	9.38	0.83	8.8	9.10	9.65
		CN	32	6.4	10.0	8.84	1.07	12.1	8.46	9.23
		SA	42	4.0	10.0	7.50	1.52	20.3	7.02	7.97
		Bs	32	6.0	10.0	9.54	0.86	9.0	9.23	9.85
2014	4º	BNm	65	5.9	10.0	8.99	0.91	10.1	8.77	9.22
		CNm	58	3.7	10.0	8.34	1.47	17.6	7.96	8.73
		SAm	62	2.2	10.0	6.68	1.98	29.7	6.17	7.18
2015	5º	TH	80	0.0	10.0	5.15	2.94	57.1	4.49	5.80
		FF	65	2.6	9.6	7.03	1.73	24.6	6.60	7.46
		A	62	0.2	9.5	4.61	2.54	55.1	3.97	5.26
2017	6º	S	17	0.5	9.2	4.88	3.06	62.8	3.30	6.45
		SC	15	1.4	9.8	7.03	2.64	37.6	5.56	8.49
2018	3º	Co	17	5.6	9.2	7.56	2.50	14.4	7.01	8.12
		Cl	13	0.0	10.0	6.46	1.09	38.7	4.95	7.97
2019	4º	Ex	22	2.0	10.0	7.36	2.17	29.5	6.40	8.33
		E-RPG	22	2.7	10.0	8.60	1.57	18.2	7.90	9.29

Note: *n* - number of students.

[1]BN: Binary Numbers; CN: Coding with Numbers; SA: Sorting Algorithms; Bs: Battleship; BNm: Modified Binary Numbers; CNm: Modified Coding with Numbers; SAm: Modified Sorting Algorithms; TH: Treasure Hunt; FF: Face to Face Game; A: Algorithms; IA: Introduction to Algorithms; S: Sorting; SC: SoccerCraft; Co: Comics; Cl: Classification; Ex: Exchange; E-RPG: Elementals RPG.

Table 4 provides an overview of the overall student performance (across one or more classes) by activity for each year. The activities in which students achieved the highest average performance were developed in 2013. In this year, the activities were implemented in two $4th$-year classes at a peripheral school, and the classes were collectively analyzed. The confidence intervals indicate that the means observed for the activities Battleship (9.5), Binary Numbers (9.4), and Coding with Numbers (8.8) did not exhibit significant differences from each other, but were higher than the mean observed for the activity Sorting Algorithms (7.5). Additionally, it is noted that students' performance in this latter activity was more heterogeneous (with a coefficient of variation of 20%) compared to the others, whose coefficients of variation ranged between 8.8% and 12.1%.

Three of the four activities developed in 2013 underwent modifications and were applied in 2014. Additionally, two more schools were included in the project this year, resulting in a considerable increase in the number of students compared to 2013. The results observed in 2014 closely mirrored those of the previous year. The average performances of students in the Binary Numbers (9.0) and Coding with Numbers (8.3) activities did not show significant differences from each other, but were significantly higher than the average for the Sorting Algorithms activity (6.7).

In terms of variation, student performances across all three activities were more heterogeneous compared to 2013. Once again, the highest coefficient of variation was observed for Sorting Algorithms (CV = 30%).

From 2016 onwards, the activities were conducted in only one class at the school with a peripheral profile, resulting in a drastic reduction in the number of students. This is because sources of financing have decreased significantly. In 2017, the SoccerCraft and Sorting activities were implemented in a 6th-grade class. Although the mean performance of students in the SoccerCraft activity (7.0) was higher than in the Sorting activity (4.9), the overlapping confidence intervals of these means suggest that the difference between them is not statistically significant. It is possible that the lack of significance in this difference between the means is due to the high variation in student performance observed in both activities (coefficients of variation of 64% and 38%, respectively).

In 2018, the Classification and Comics activities were introduced to a 3rd-year class. The average performances of students did not significantly differ between the activities (6.5 and 7.6, respectively). However, it is noteworthy that students' performance in the Comics activity was much more homogeneous (CV = 14%) compared to the Classification activity (CV = 39%). In the final year reported, 2019, the Exchange and Elementals RPG activities were implemented in a 4th-grade class. The students achieved a good mean performance in both activities: 7.4 for Exchange and 8.6 for Elementals RPG. These means did not differ statistically. Concerning variation, student performance was more homogeneous in the Elementals RPG activity (CV $=$ 18%) than in the Exchange activity (CV $=$ 30%).

5.3 Classroom performance versus post-test performance

The data analysis also encompassed comparing students' performance in classroom activities with their performance in corresponding post-tests. It's reasonable to assume that students who excel in the classroom will replicate their performance in the post-test. Thus, there was an expectation that these results would show a positive correlation. To test this hypothesis, a correlation analysis was conducted for each activity, examining the correlation between students' grades in the classroom and their grades in the post-test. Pearson's linear correlation coefficient (r) was calculated for each, and its significance was assessed using a t-test at a significance level of $\alpha = 0.05$. The findings of this analysis are summarized in Table 5.

It's notable that for over half of the activities analyzed, the linear correlation was not significant, with r ranging between -0.32 and 0.58. Even in cases where the correlation was significant ($p < 0.05$), the r values suggested a weak correlation between classroom performance and post-test scores. One activity of particular interest was the Exchange, which showed the highest correlation coefficient ($r = 0.66$). However, this value indicates only a moderate positive correlation.

The comparison between students' classroom performance and the gain (measured by the difference between post- and pre-test scores) also exposes some discrepancies. For instance, in 2013, across three activities (BN, CN, and Bs) where students excelled in the classroom, the mean gains were not significant. Conversely, in activities where students performed poorly in the classroom (TH and A, in 2015), the corresponding mean gains were highly significant. As mentioned earlier, these inconsistencies might stem from shortcomings or inadequacies in the tests' ability to measure student learning.

Table 5: Results of the correlation analysis between classroom performance and post-test scores, by activity and year

Year	Activity[1]	n	Pearson's linear correlation coefficient (r)	t-test	
				t	p-value
2013	BN	28	0.08	0.429	0.6716 ns
	CN	26	0.45	3.477	0.0207
	SA	34	0.16	0.903	0.3733 ns
	Bs	26	-0.13	-0.626	0.5370
2014	BNm	52	0.49	3.996	0.0002
	CNm	50	0.22	1.582	0.1203 ns
	SAm	53	0.23	1.713	0.0928 ns
2015	TH	62	0.41	3.494	0.0009
	FF	56	0.39	3.144	0.0027
	A	52	0.51	4.173	0.0001
2017	S	–	–	–	–
	SC	10	0.58	2.039	0.0758 ns
2018	Co	16	-0.11	-0.407	0.6905 ns
	Cl	12	-0.32	-1.071	0.3092 ns
2019	Ex	22	0.66	3.884	0.0009
	E-RPG	22	0.45	2.230	0.0374

Note: n - number of students; ns - non-significant result, according to the t-test ($\alpha = 0.05$).

[1]BN: Binary Numbers; CN: Coding with Numbers; SA: Sorting Algorithms; Bs: Battleship; BNm: Modified Binary Numbers; CNm: Modified Coding with Numbers; SAm: Modified Sorting Algorithms; TH: Treasure Hunt; FF: Face to Face Game; A: Algorithms; IA: Introduction to Algorithms; S: Sorting; SC: SoccerCraft; Co: Comics; Cl: Classification; Ex: Exchange; E-RPG: Elementals RPG.

6 Lessons Learned

One of the primary challenges we encountered revolved around evaluation. Throughout the reported years, we employed various strategies to design the pre-/post-tests, consistently striving to gauge any progress made. Upon scrutinizing the test questions, it becomes evident that they aimed to assess at least one of the following criteria: (i) Application of concepts/strategies introduced in the activities in alternative contexts: in such case, solutions to the questions necessitated the direct application of concepts and/or strategies from the activity but in a different scenario (for example, applying the binary search strategy to locate a specific card in a deck rather than within the context of a Battleship game); (ii) Application of concepts/strategies introduced in the activities within the same context as presented in the classroom: solutions to these questions demanded the direct application of concepts and/or strategies introduced in the activity while maintaining the same thematic context; (iii) Employment of skills developed in the activity in different contexts: solutions to these questions required utilizing competencies acquired after mastering the introduced concepts/strategies (for instance, applying code/decode techniques in alternative contexts); (iv) Utilization of skills correlated with those employed in the activity in different contexts: solutions to these questions demanded employing competences typically associated with those developed in the activity (such as relating to coding).

Table 6 correlates the number of pre- and post-test questions per activity with a description of the assessed criteria. Shaded rows indicate a significant gain in the corresponding activity. We have concluded that attempting to assess general skill gains within short timeframes is not practical. Rather, the focus should be on evaluating the ability to apply the concepts covered in

Table 6: Number of Pre-/Post-Test Questions per Activity Associated with the Evaluated Criteria

Year	Activity[1]	Application of concepts/strategies introduced in the activity in another context	Application of concepts/strategies introduced in the activity in the same context	Skills employed in the activity in another context	Skills correlated with those employed in the activity in another context
2013	BN			1	1
	CN			2	
	SA			1	
	Bs	1			
2014	BNm			3	1
	CNm		1	2	
	SAm	1			
2015	TH	2			
	FF	1	2		
	A	3			
2016	IA	5			
2017	S				
	SC			4	
2018	Co		1	2	2
	Cl		2		2
2019	Ex	3			
	E-RPG		5		

[1]BN: Binary Numbers; CN: Coding with Numbers; SA: Sorting Algorithms; Bs: Battleship; BNm: Modified Binary Numbers; CNm: Modified Coding with Numbers; SAm: Modified Sorting Algorithms; TH: Treasure Hunt; FF: Face to Face Game; A: Algorithms; IA: Introduction to Algorithms; S: Sorting; SC: SoccerCraft; Co: Comics; Cl: Classification; Ex: Exchange; E-RPG: Elementals RPG.

the activities. We believe that the most effective strategy for preparing the pre-/post-test involves presenting the concepts in different contexts and at increasing levels of difficulty. This approach helps avoid overly simplistic questions that may already yield correct answers in the pre-test, thus hindering the accurate measurement of progress. As the test should include a variety of questions with differing levels of difficulty, its administration must be meticulously planned to ensure completion within the allotted time, typically around one hour. Reading together with the class proves particularly beneficial, especially for students lacking reading fluency, as it fosters collective progress, particularly among younger learners. However, it's worth noting that this strategy may pose challenges for older students.

Regarding tangible materials, bulky and/or heavy kits are best produced and stored in schools. Establishing partnerships with arts classes can be a fruitful strategy when feasible and appropriate. We've observed that the most practical material for transportation isn't always the most suitable. For instance, bottles were found to be much more effective than stickers for teaching sorting algorithms. Tangible materials with minimal abstraction tend to be most effective for younger children, typically up to 10-12 years old.

Students demonstrate greater engagement with activities when they're motivated by the subject. We encountered cases where simply changing the theme, such as transitioning from color patterns to animal evolutions, resulted in increased engagement and comprehension of the concepts taught. However, spending too much time on the same type of activity can lead to demotivation. Planning challenges with incremental difficulty is a strategy to sustain interest. Games and competitions consistently foster engagement. Presenting concepts in short, incremental sessions interspersed with dynamic and practical tasks appears to be the most effective approach.

The layout and available space within the classroom significantly influence task development. It's crucial to consider available locations for carrying out activities before planning the dynamics, and adjustments should be made as needed. A teacher who is familiar with the students aids in classroom management, and depending on the proposed methodology, having more collaborators can assist in clarifying doubts and optimizing activity progress.

Over the years, we encountered different student profiles and categorized the schools as central, peripheral, or rural. Rural students were usually the most motivated, with highly engaged teachers. Some peripheral classes showed similar interest, while central ones were the least motivated.

Table 9 in Appendix C presents a summary of the main lessons learned throughout the development of this report.

7 Final Remarks

This article presents an experience report on teaching some fundamentals of Computer Science to students from the third to sixth grade in Elementary School. It explores three key areas of investigation: the factors influencing the feasibility and effectiveness of introducing computing concepts at this educational level, the benefits and challenges of implementing unplugged computing methodologies, and the existence of statistically significant gains in the evaluation of the activities conducted.

Observations of student behavior and engagement, along with descriptive measures of performance across activities, reveal that the integration of computational learning in elementary school is both feasible and effective. Key factors contributing to the success of the proposed methodologies include careful class planning that takes into account the physical environment and the prioritization of engaging, playful activities. The related activities were inspired by topics thought to be of interest to students and incorporated challenges or competitions. This experience successfully achieved two key objectives: (i) The effective integration of various members and diverse target audiences — including the academic communities (professors, undergraduate, master's, and doctoral students) from the Federal University of Pelotas Computing courses — throughout all stages of activity development, from modeling to structuring, organization, and evaluation. Additionally, the active participation of the school community (students from 3rd to 6th grade, pedagogues, and teachers) as the primary agents in executing the activities further highlights their role as key contributors in disseminating the results. (ii) A diverse set of proposed activities designed to explore key computing concepts—such as algorithms, information, coding, data representation, classification, generalization, abstraction, decomposition, and pattern recognition. Additionally, the report details the application of various evaluation methods during the study period, drawing on assessments and experiences from previous results.

Regarding the second research topic, several benefits can be highlighted when integrating computer science education into the elementary school curriculum using unplugged methodologies. First, the proposed activities can be easily replicated, independent of the costs associated with technological development. Additionally, these activities integrate seamlessly with the resources typically available in school classrooms. The procedures adopted can also complement traditional lecture-based instruction by providing clear motivations and introducing challenges or games that enhance student involvement. It is important to note that student engagement has consistently been closely linked to the themes used to contextualize the content, and that the use of concrete materials, minimizing abstraction, significantly aids in the understanding of computer science concepts at the targeted grade levels.

In the third contribution of the report, the statistical analysis of the developed activities enabled the comparison of various strategies for creating pre- and post-tests. Over short periods, it is the accurate application of concepts (rather than the development of skills) that can be effectively measured. The most effective strategy proved to be the development of tests featuring short, direct questions with incremental levels of difficulty. These tests involved applying the computing concepts in contexts different from those explored in the classroom.

Based on the analyzed related works, it can be observed that most efforts to introduce computing concepts primarily focus on programming logic and algorithmic thinking. In our project, while we included activities involving programming logic, we also aimed to diversify the addressed concepts by placing a strong emphasis on the organization and representation of information. Another significant observation from the related works was the type of evaluation employed, which predominantly relied on questionnaires to measure motivation and acceptance of the activities. Few studies assessed knowledge gain, with some utilizing self-assessments, and none incorporating statistical analysis of the learning outcomes.

Limitations and Future Directions

This study presents promising results, yet it faces limitations. One issue lies in the assessment design: using the same instrument for both pre- and post-tests may have introduced familiarity bias, potentially inflating learning gains. Although efforts were made to refine the tests for better alignment with the content taught, future iterations should adopt isomorphic test versions to enhance validity and reduce recognition effects.

Replicability also poses a challenge in contexts lacking the support infrastructure provided by the project. Despite comprehensive teaching materials, some activities depend on a multidisciplinary team - comprising faculty and trained undergraduate students - which may not be available in all schools. Relying on a single teacher can present organizational and pedagogical obstacles. The project's sustainability is equally tied to the training of in-service teachers. Lasting impact requires not only conceptual understanding but also mastery of instructional strategies tailored to diverse educational settings. Without ongoing professional development, there is a risk of reduced fidelity and effectiveness in implementation.

To address these issues, future work should prioritize three key areas: (1) the development of parallel assessment tools to ensure more accurate measurement of learning; (2) the design of simplified methodologies for single-teacher contexts, including practical classroom guidelines; and (3) robust teacher training programs that integrate both technical content and adaptable pedagogical approaches. In this context, a central challenge is promoting effective teacher engagement in both plugged and unplugged computing activities within Brazilian Basic Education. By aligning with the BNCC and focusing on equitable access, especially in underrepresented areas such as data structures and problem-solving, the project aims to foster meaningful and inclusive computing education. Future assessments will also incorporate broader indicators—such as student interest, engagement, and perceived challenges—to guide refinements and ensure relevance across diverse learning environments.

Acknowledgements

Our special thanks to the Municipal Education Department of Pelotass, as well as the Pro-Rectory of Extension and Culture and the Pro-Rectory of Research and Postgraduate Studies of Federal University of Pelotas, whose support made this work possible.

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A Structure of Brazil's Education System

Table 7 presents the structure of Brazil's education system.

Table 7: Structure of Brazil's Education System. FONTE: OECD, 2021

ISCED 2011	**Starting age**	**Administrative unit (primarily responsability)**	**Grade/Year**	**Education programme**
4	18	Federal government and states		Technical course (*curso técnico de nível subsequente*)
3	15	States	Grade 3	Upper secondary education (*ensino médio*)
			Grade 2	
			Grade 1	
2	11	Municipalities and States	Year 9	Lower secondary education (*anos finais do ensino fundamental*)
			Year 8	
			Year 7	
			Year 6	
1	6	Municipalities	Year 5	Primary education (*anos iniciais do ensino fundamental*)
			Year 4	
			Year 3	
			Year 2	
			Year 1	
0	4	Municipalities		Pre-school (*pré-escola*)
	0			Early childhood education development (*creches*)

B Summary Table of Related Work

Table 8 summarizes the related works by identifying the computing-related content and concepts addressed in the proposed activities, target audience, methodologies used in the interventions, assessment methods for analyzing the project results, and the training area for individuals involved in the preparation and implementation of activities.

Table 8: Summary of works addressing activities that focus on computing concepts proposed for basic education in Brazil

Paper[1]	Computing Concepts	Target audience	Methodologies and Tools	Assessment methods	Involved areas
[1]	Programming Logic	Students from Primary through Upper Secondary Education	Scratch Platform	–	B.Sc in Computer Science
[2]	Database	Primary and lower secondary education teachers	Unplugged Computing	Pre- and post-questionnaire on knowledge of careers in Computing	B.Sc in Computer Engineering; B.Sc in Information Systems
[3]	Theory on Computational Thinking Pillars; Algorithmic Thinking; Tool Usage (Digital Literacy)	Year 7 Students	Constructivism	Questionnaire on activity satisfaction	B.Ed in Computer Science Education

[4]	Programming Logic	Year 4, Year 6 and Year 9 Students; Grade 1 and Grade 2 teachers	Problem-solving Approach; Unplugged Computing	–	Multidisciplinary (Education and Computer Science)
[5]	Binary Encoding; Error Detection in Data Transmission	–	Unplugged Computing	Informal survey on interest in Computing	B.Sc in Computer Engineering
[6]	Diverse Computing Concepts from CS Unplugged[2]; Programming Logic	Year 6 Students	Constructivism; Unplugged Computing	Informal survey of students' interest and acceptance of the activities	B.Ed in Computer Science Education; B.Ed in Pedagogy
[7]	Programming Logic	Students from Year 6 to Year 9	CodeCombat Game	Pre- and post-tests of mathematical logic; Observational assessment of students' acceptance and interest in the game	–
[8]	Binary Numbers; Information Compression, Algorithmic Thinking	Grade 1 Students	Expository Classes; Unplugged Computing; LightBot Puzzle Game	Observational assessment of students' interest in the activities	B.Ed in Computer Science Education
[9]	Binary Numbers; Error Detection; Algorithmic Thinking; Algorithm Optimization; Sorting; Propositional Logic	Students aged 15 to 18	Unplugged Computing	Content knowledge and interest assessment questionnaires	B.Ed in Computer Science Education
[10]	Programming Logic	Year 4 Students	Scratch Platform	Questionnaires to assess memory retention, preferences, and the impact of learning programming on academic performance	B.Ed in Computer Science Education

[11]	Programming Logic	–	Scratch Platform	Questionnaires to assess interest, activity difficulty, contribution to problem-solving skills, and the importance of programming for future careers	B.Sc in Computer Science; B.Sc in Civil Engineering
[12]	Programming Logic	Year 2 Students	Code.org Activities	Questionnaires to assess the game's quality, motivation, and learning promotion; Observational assessment to support data analysis; Practical hardware test	B.Ed in Computer Science Education
[13]	Algorithmic Thinking; Programming Logic	Year 6 and Year 7 Students	Expository Classes; Project-based Learning; Maker Learning	Questionnaires to assess interest, teamwork, and activity difficulty	B.Ed in Computer Science Education
[14]	Programming Logic	Year 6 and Year 7 Students	Online Expository Classes; Code.org Activities	Questionnaires to assess students' familiarity with games and programming, activity difficulty, and perceived learning importance	B.Ed in Computer Science Education

[15]	Programming Logic	Year 8 and Year 9 Students	Expository Classes; Project-based Learning	Assessment through practical and theoretical tasks, a multiple-choice test, and implementation; Interest and satisfaction evaluated via questionnaire, observation, and discussion circle	–
[16]	Programming Logic; Software Engineering; User Experience	Year 5 Students; Year 8 and Year 9 Students	Expository Classes; Games; Experimentation; Problem-solving Approach	Pre- and post-questionnaire to assess knowledge of computing; Theoretical content test; Performance evaluation based on developed apps; Self-assessment questionnaire on enjoyment; Questionnaires after each class on learning ease; Final questionnaire on interest in further learning	MSc in Computer Science; BA in Graphic Design
[17]	Logical reasoning; Programming Logic	Students aged 11 to 14	OBI Simulated Exams; Quizzes; Physical Activities; Computational Robotics	Interview to collect students' feedback on the course	–
[18]	Introduction to AI; Machine Learning for Object Detection; Ethical Implications and Impacts of AI	Upper Secondary Education Students	Online Expository Classes; Active Methodologies for Project-based Learning	–	B.Sc in Information Systems

[19]	Programming Logic	Year 8 Students	Gamification; Unplugged Computing	Pre-activity questionnaire to assess students' knowledge of Computing; Test on the content covered in class; Final questionnaire to evaluate the project	B.Ed in Computer Science Education
[20]	Programming Logic	Early Childhood Education Development and Pre-school Students	Computational Robotics	Observational assessment to identify student success or challenges during activities; Evaluation of the execution time for each activity	B.Sc in Computer Science; Neuroscience
[21]	Logical reasoning; Programming Logic	Year 5 Students	Unplugged Computing; Blockly Game; Code.org Activities; Scratch Platform	Pre- and post-tests on logical reasoning; Verbal questionnaire on tool preferences	B.Ed in Informatics
[22]	Programming Logic	Year 6 Students	Scratch Platform	Pre- and post-tests on fractions knowledge; Questionnaire to assess students' perceived learning importance	MSc in Mathematics
[23]	Logical reasoning; Programming Logic	Students aged 5 to 13	Gamification; Unplugged Computing; Code.org Activities; AlgoRun Game; Coding School and Grasshopper Platforms	Observational assessment to identify game progress; Questionnaire to assess activity difficulty; Test on logical reasoning	–

[24]	Sorting algorithms; Network devices; Technology's impact on nature	Year 6 Students	Tangential learning; Games	Observational assessment of students' interest; Questionnaires to assess user experience, interests, difficulties, and tangential learning	–
Our work	Sorting and search algorithms; Collection, organization, abstraction, representation, encoding and analysis of data/information; Algorithms and simulation; Debugging; Analysis (cost); Pattern Recognition; (Efficient) Classification; Decomposition; Generalization; Abstraction	From Year 3 to Year 6 Students	Unplugged Computing; Playful Approach; Expository Classes; Guessing Games; (RPG) Board Games; Code.org Activities; LEGO Mindstorms® Robot and EV3 software; Visual Storytelling	Pre- and post-tests on logical reasoning, skills development, and/or computing concepts; Exercises and written tests on computing concepts; Observational assessment of students' performance	Multidisciplinary (Computer Science, Computer Engineering, Statistics and Education)

[1] [1] de Santana Oliveira et al., 2020; [2] Amador et al., 2021; [3] Torcatte et al., 2017; [4] Barata et al., 2023; [5] A. P. Ferreira and Lucchese, 2020; [6] Queiroz et al., 2016; [7] Pires and Prates, 2019; [8] V. Silva et al., 2016; [9] N. Santos et al., 2023; [10] da Silva Bisneta, 2019; [11] Franzen et al., 2022; [12] W. P. de Oliveira, 2018; [13] do Nascimento, 2019; [14] Widthauper, 2020; [15] J. B. Santos and Lima, 2020; [16] Pinheiro, 2019; [17] T. de Oliveira et al., 2017; [18] Gonçalves, 2022; [19] Aguiar and Menezes, 2019; [20] de Lima, 2017; [21] de Farias Pimenta, 2019; [22] Black, 2024; [23] Brito de Oliveira et al., 2023; [24] Junior et al., 2023.

[2] CS Unplugged: An enrichment and extension programme for primary-aged students (Bell et al., 2015).

C Summary of Lessons Learned

Table 9 presents a summary of the main lessons learned throughout the development of this report.

Table 9: Summary of lessons learned throughout the project

Theme	Lesson Learned
Evaluation Design	Assessing broad skill development in short timeframes is unfeasible; focus should be on applying concepts across varied contexts and difficulty levels.
Test Implementation	Questions must be diversified and manageable within the timeframe; reading aloud helps younger or less fluent students.
Material Use	Simpler and tangible objects work better for younger learners; heavier materials should be produced and stored at school to ease use and avoid transport issues.
Student Engagement	Motivation increases with relatable themes and short, progressive challenges; repetitive activities decrease interest.
Methodology	Short theoretical inputs followed by practical tasks are more effective; games and competitions improve engagement.
Classroom Logistics	Space layout affects activity success; knowing the students and having extra support facilitates management.
School Profiles	Rural students show greater motivation and participation; central urban schools tend to be less engaged.