

STEAM and educational robotics in the development of statistical literacy

Vanda Santos^{1,2,3*} , Ana Silva¹ , Filipa Pinto^{1,2} , Marisa Maia Machado⁴ ,
Fernando Martins^{1,3,5} 

¹ Polytechnic University of Coimbra, Coimbra, PORTUGAL

² Research Center on Didactics and Technology in the Education of Trainers, University of Aveiro, Aveiro, PORTUGAL

³ inED – Centre for Research and Innovation in Education, Polytechnic University of Coimbra, Coimbra, PORTUGAL

⁴ Department of Education and Psychology, Research Center on Didactics and Technology in the Education of Trainers, University of Aveiro, Aveiro, PORTUGAL

⁵ SPRINT – Sport Physical Activity and Health Research & Innovation Center, Polytechnic University of Coimbra, Coimbra, PORTUGAL

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Abstract

In primary school, the teaching of mathematics and natural sciences should promote meaningful, context-based learning that enables students to apply knowledge in real-life situations. Interdisciplinary approaches such as STEAM foster 21st century competences through active and collaborative methodologies, while educational robotics (ER) supports the development of computational thinking and social skills. This study analyses the influence of a STEAM practice, incorporating ER on the development of statistical literacy and learning about ocean plastic pollution among 4th grade students. The research adopted a mixed-methods, interpretative action research design. Data were collected by the trainee teacher as participant researcher through performance tasks, field notes, photographs and audio recordings, later used to construct multimodal narratives. Findings reveal statistically significant improvements in global level of knowledge and global performance. The study concludes that steam practices incorporating ER and grounded in real-world problem-solving constitute an effective strategy for fostering statistical literacy.

Keywords: primary education, STEAM practice, educational robotics, statistical literacy

INTRODUCTION

In primary school, mathematics and natural sciences teaching should promote meaningful, real-life contextualized learning, enabling students to apply knowledge in everyday situations (Ministry of Education, 2021). The integration of different subject areas is essential, helping students connect mathematical concepts in concrete contexts (Perignat & Katz-Buonincontro, 2019; Silva et al., 2023a).

STEAM practices encourage 21st century competences through interdisciplinary, active, and collaborative learning (Amanova et al., 2025; Pires, 2024; Rafiq-uz-Zaman, 2025). Educational robotics (ER) further supports computational thinking and social skills, such as communication and cooperation (Bers,

2020), offering innovative experiences that connect students with technological and scientific contexts (Ragusa & Leung, 2023). Complementarily, Chaldi and Mantzanidou (2021) emphasize that the integration of STEAM practices and ER is essential for students to develop their knowledge and learning through engagement with a real problem in a productive and motivating learning environment.

In light of the above, the following research problem was defined: How can a STEAM practice, incorporating ER, contribute to the development of statistical literacy?

The need to promote meaningful and interdisciplinary educational experiences, as well as to address specific difficulties identified in the classroom context, underpinned the intervention developed within this study. It took the form of a STEAM practice

Contribution to the literature

- This study contributes to the literature by positioning statistical literacy as the central learning outcome of the intervention and by demonstrating how the implementation of a STEAM practice, incorporating ER, relates to the development of statistical literacy within a pedagogical context. Beyond its recognized motivational value, the study highlights the distinctive pedagogical contribution of ER.
- It connects statistical learning with real-world contexts, showing how interdisciplinary and problem-based practices can simultaneously enhance mathematical understanding and broaden contextual awareness.
- It introduces multimodal narratives (MN) as a methodological tool, offering an innovative way to capture and analyze students' learning processes. It extends existing literature by demonstrating the effectiveness of integrated STEAM and robotics interventions in promoting meaningful, context-based learning and measurable improvements in primary students' mathematical performance.

incorporating ER, focusing on the issue of plastic pollution in the oceans and the promotion of statistical literacy. In this study, a STEAM practice is understood as a set of three interdisciplinary sessions, the last divided into two moments, planned across three learning scenarios. These sessions articulated mathematics (organization, representation, and interpretation of data), environmental studies (ocean pollution), arts and engineering (design of an awareness-raising poster), and technology (SuperDoc robot) in solving real problems and producing a final awareness product.

Within this framework, the following research question was formulated: How does a STEAM practice, incorporating ER, influence the learning of statistical concepts among 4th grade primary school students?

To address the research question, we accomplished the general objective is to analyze the contribution of STEAM practice, incorporating ER, on promoting the learning of statistical concepts among 4th grade in primary school. Specifically, the study aims to assess students' level of knowledge (LK) in the different tasks before and after the pedagogical intervention, compare the evolution of the global level of knowledge (GLK) between the pre- and post-intervention phases, identify changes in the strategies used by students when solving the tasks, analyze the difficulties presented by students in the initial phase of task resolution, and examine, through the analysis of MN, the students' reasoning processes during task resolution.

THEORETICAL FOUNDATION

STEAM Practices

STEAM education is understood as an interdisciplinary or transdisciplinary approach integrating science, technology, engineering, arts/humanities, and mathematics within a common curricular framework, organized around real-world problems rather than isolated subjects (Perignat & Katz-Buonincontro, 2019; Quigley et al., 2020; Rodrigues-Silva & Alsina, 2023). STEAM practices represent the concrete

implementation of this approach through tasks or projects that integrate multiple areas and promote creativity (Perignat & Katz-Buonincontro, 2019; Quigley et al., 2020; Yim et al., 2025).

These practices foster active, collaborative, and meaningful learning, encouraging students to investigate and propose solutions to real problems (Pires, 2024; Quigley & Herro, 2016), while also helping to reduce gender inequalities by valuing diverse forms of expression (Kim & Bolger, 2016).

In the primary school, students' natural curiosity makes them particularly receptive to inquiry-based and interdisciplinary approaches, which promote contextualized learning and help address difficulties in subjects such as science and mathematics (Drake & Reid, 2018; Perignat & Katz-Buonincontro, 2019; Stylianidou et al., 2018). When centered on real-world problems, STEAM practices enhance authentic learning and support both curricular achievement and the development of social competences, such as cooperation and communication (Ferreira et al., 2024; Park et al., 2016).

Educational Robotics

ER plays an increasingly vital role in modern education, involving the use of programmable robots to engage students in meaningful and interactive learning experiences, which include construction, programming, and task exploration (Lu et al., 2025; Rojas et al., 2025; Silva et al., 2023b). ER helps students understand abstract concepts through concrete experiences, sparking curiosity and promoting computational thinking, creativity, and problem-solving (Gerosa et al., 2022; Silva et al., 2023a; Sullivan & Bers, 2017).

Its pedagogical value lies in integrating technology with active, interdisciplinary learning, creating motivating environments that enhance interest, persistence, and engagement in problem-solving (Chen et al., 2023; Ching & Hsu, 2024; Costa et al., 2022; Silva et al., 2023a). ER fosters computational thinking, cognitive skills, and social skills, such as creativity, reasoning, communication, and collaboration (Kerimbayev et al.

Table 1. Research sessions

Pre-intervention phase		Intervention phase			Post-intervention phase
Initial task	Session 1	Session 2	Session 3 – Part I	Session 3 – Part II	Final task
May 8	May 30	May 30	June 6	June 12	Jun 13

2023; Wing, 2006). Through hands-on tasks, students test hypotheses, solve problems, and refine solutions, mirroring authentic research processes, which in turn supports digital literacy and the development of 21st century competences (Gratani & Giannandrea, 2022; Lu et al., 2025).

Statistical Literacy

Statistical literacy is crucial in today's data-driven world, enabling individuals to comprehend, evaluate, and use statistical information in everyday contexts for active citizenship (Gal, 2002; Gomes et al., 2022). It is a key competence for the 21st century, helping individuals interpret data, make informed decisions, and critically engage with the world (Martins & Ponte, 2010; Martins et al., 2017; Ponte & Fonseca, 2001).

Building on Gal's (2002) framework, Martins et al. (2017) systematize the core knowledge of statistical literacy into five dimensions:

- (1) understanding the need for data and how it can be produced,
- (2) knowing the basics of descriptive statistics and data representation,
- (3) being able to read and interpret tables and charts,
- (4) having basic notions of probability, and
- (5) understanding how statistical conclusions or inferences are drawn.

The 4th grade of primary school in Portugal, statistical literacy is addressed under the topic "data and probability" (Ministry of Education, 2021), encompassing the formulation of statistical questions, data collection and organization, graphical representations, data analysis, communication and dissemination of studies, and probability (Rodrigues et al., 2025b). Recent studies show that exploratory teaching practices of primary school in Portugal foster statistical literacy by engaging students in full data investigation processes, including formulating questions, collecting data, and constructing graphical representations (Canavarro et al., 2012; Gomes et al., 2022; Rodrigues et al., 2025a; Silva et al., 2025).

Understanding the challenges students face in learning statistics is vital for teachers to design effective strategies. Common difficulties include reading and interpreting graphs, selecting inappropriate graph types, and understanding key concepts like mode and mean (Duque et al., 2015; Papeleira, 2023; Souza et al., 2021; Wu, 2004). Identifying these difficulties allows teachers to anticipate errors and create real-data tasks to support deeper learning.

MATERIALS AND METHODS

Study Design

This study is of a mixed nature (Creswell & Clark, 2018), interpretive (Amado, 2017), and action research design (Bogdan & Biklen, 2013). In this way, data collection and analysis used techniques and instruments characteristic of quantitative and qualitative research (Cohen et al., 2018). Qualitative data were used to interpret and explain the quantitative findings, through triangulation, providing a deeper understanding of the patterns and variations identified in the quantitative analysis (Amado, 2017). Qualitative data were systematically coded to identify recurrent categories and themes. These qualitative findings were then compared with the quantitative results to identify areas of convergence, complementarity, and divergence. This integration helped confirm, complement, and explain quantitative patterns and variations that were not fully evident from the quantitative analysis alone (Cohen et al., 2018).

Participants

This study was conducted with a class of 20 4th grade of primary school students in Portugal, comprising 11 boys and 9 girls, aged between 9 and 10 years. A third of the students received selective measures outlined in decree-law no. 54/2018 (Ministry of Education and Science, 2018). The data were during a teaching placement undertaken by a trainee teacher (TT) enrolled in an initial teacher education program at a higher education institution in Portugal. During the pedagogical intervention, the students worked in ten pairs. The implementation of the research had permission and parental approval obtained, as well as the consent of all students and educational entities involved. This study was conducted following the Declaration of Helsinki and approved by the Ethics Committee of Polytechnic Institute of Coimbra (reference: 101 CEIPC/2022 approved on June 24, 2022).

Data Collection

The data collection took place between May and June and spanned three phases: pre-intervention, intervention, and post-intervention (see Table 1).

Data collection and analysis were carried out through participant observation by the student teacher and responses of their worksheets completed by students. Based on the collected data, four MN were constructed, following the protocol of Lopes et al. (2018).

George's class decided to help local animal associations. To do this, they decided that each parent would donate a certain amount of money. The following table shows how much each student donated:										
Student	Ana	Bruno	Carolina	Eduardo	Francisco	Joao	Jorge	Leonor	Leonardo	Lia
Amount	15€	10€	20€	15€	25€	10€	5€	5€	5€	15€
Student	Maria	Manuel	Oscar	Patricia	Raquel	Rodrigo	Rui	Sara	Tiago	Xavier
Amount	20€	5€	20€	10€	5€	15€	10€	5€	15€	10€
1. After the donation, the students wanted to know how much money they had raised. Help them by representing the data in a bar chart. Using the data provided, construct a bar chart. Explain how you thought about constructing the chart.										
2. The teacher decided to donate the money raised equally to four associations. How much did he give to each one? Explain how you thought about it, using diagrams, drawings, or words.										
3. Which students were the most generous and the least generous? Explain your reasoning using diagrams, drawings, or words.										
4. How much did most students donate? What does this amount represent? Explain your reasoning using diagrams, drawings, or words.										
5. The students in the class got together again to discuss more issues related to this topic. Imagine that you are a student in this class and that you also participated in this fundraiser. What question would you ask based on the data presented?										

Figure 1. Pre-intervention phase (the authors' own elaboration)

At John's school, they decided to run an awareness campaign about litter in the school playgrounds. They proposed that each day, for 16 days, one class would collect and count the litter they found in the playground. The following table shows what was collected each day.								
Classes	1 st A	1 st B	1 st C	1 st D	2 nd A	2 nd B	2 nd C	2 nd D
Waste no	10	15	20	35	40	25	10	25
Classes	3 rd A	3 rd B	3 rd C	3 rd D	4 th A	4 th B	4 th C	4 th D
Waste no	30	40	10	20	25	45	25	25
1. The students want to organize the data using a bar chart. Help them by representing the data in a bar chart. What information can you see from this chart? Explain how you thought about constructing the chart.								
2. John's class decided to get together and wanted to know how much waste, on average, was collected by each class during recess. Can you help them? Explain how you thought about it, using diagrams, drawings, or words.								
3. Among the items collected by the classes, what was the largest and smallest amount of waste? Explain how you thought about it, using diagrams, drawings, or words.								
4. What was the most frequently collected item of waste by the classes? What does this number represent? Explain how you thought about it, using diagrams, drawings, or words.								
5. The students in the class got together again to discuss more issues related to this topic. Imagine that you are a student in this class and that you also want to participate in the discussion. What question would you ask based on the data presented?								

Figure 2. Post-intervention phase (the authors' own elaboration)

This study was conducted in accordance with the ethical principles set out in the Declaration of Helsinki, with the protection of participants' rights, privacy, and well-being maintained throughout the research.

Prior ethical approval was obtained from the Ethics Committee of the Polytechnic University of Coimbra (reference 101 CEIPC/2022, approved on June 24, 2022). All data were used exclusively for the purposes of this study. Written informed consent was obtained from all parents following the provision of clear information about the study, and authorization was granted by the school group. The anonymity and confidentiality of all participants were strictly safeguarded throughout the research.

In the pre- and post-intervention phases, initial and final tasks were administered (**Figure 1** and **Figure 2**), aimed at map students' difficulties in analyzing and processing data through the assessment of tasks. The initial and final tasks were constructed by the research

team. The first task involved constructing a bar chart, the second involved calculating the mean, the third and fourth involved identifying the minimum and maximum values and the mode, respectively and the fifth task involved formulating a statistical question related to the data presented.

The data collected from the pre- and post-intervention phases were analyzed using a criterion with four LK, taken from Freitas (2024), as shown in **Table 2**.

To carry out the analysis of the task resolutions in the pre- and post-intervention phases, descriptors were defined for each LK based on the specific objectives established for each task and adapted from the proposal by Freitas (2024). These criteria were validated by five independent researchers in the field of mathematics education. Feedback was collected and discussed by the research team, leading to refinements that improved the validity and reliability of the evaluation process.

Table 2. Criteria taken from Freitas (2024) for classifying the level of knowledge

Level 1	Level 2	Level 3	Level 4
The solution either does not demonstrate knowledge of the mathematical concepts involved or does not answer the question.	The solution demonstrates limited knowledge of the mathematical concepts involved and contains numerous inaccuracies.	The solution demonstrates some knowledge of the mathematical concepts involved and contains some inaccuracies.	The solution demonstrates a thorough understanding of the mathematical concepts involved in the task.

Table 3. Descriptors of the level of knowledge by specific task objective

Task	Specific objectives	
Task1	LK	Represent the data using a simple bar chart, including the title, axis labels, auxiliary lines, and regular bars of absolute frequency.
		Describe the steps for constructing a simple bar graph, including data organization; identifying and labeling the axes; constructing bars using absolute frequencies and correct spacing; and adding a title.
	Level 1	It does not offer any solution or it offers a solution that is completely unrelated to the task.
	Level 2	Constructing a simple bar chart, however, with errors that reveal a lack of understanding of the rules for its construction: incorrect bars or incomplete data.
	Level 3	Create a simple bar chart, but without a title, axis labels, or auxiliary lines.
Task 2	Level 4	How to correctly construct a simple bar chart.
		Describes the four steps required to construct a simple bar chart.
	LK	Add the data.
		Perform the division to obtain the average.
	Level 1	It does not offer any solution or it offers a solution that is completely unrelated to the task.
Task 3	Level 2	Identify the data needed to perform the addition, but do not show the calculation.
		To demonstrate the intention to perform the division, although it contains many inaccuracies.
	Level 3	Present the addition highlighting errors in the calculation.
		Perform the division, although it contains some inaccuracies.
	Level 4	Perform the addition correctly.
Task 4		Perform the division correctly and obtain the average.
	LK	Reading and interpreting the data distribution: identifying the lowest value given by the least generous student, recognizing it as the minimum of the data set, and the highest value given by the most generous student, recognizing it as the maximum of the data set.
	Level 1	It does not offer any solution or it offers a solution that is completely unrelated to the task.
	Level 2	Present only the value given by the least generous student or the value given by the most generous student.
	Level 3	Recognize the value given by the least generous student as the minimum and maximum values of the dataset (without mentioning the words minimum and maximum).
Task 5	Level 4	Recognize the value given by the least generous student as the minimum and the value given by the most generous student as the maximum.
	LK	Reading and interpreting data distribution: identifying the most frequent value as the mode of a data set.
	Level 1	It does not present any resolution or presents a value that is completely unrelated to the task.
	Level 2	Incorrectly identifying the mode value.
	Level 3	Acknowledge the amount donated by the majority of students, without mentioning the word "mode."
Task 5	Level 4	Recognizing the amount donated by the majority of students as the mode value.
	LK	Develop a question using appropriate statistical vocabulary related to the data presented.
	Level 1	It does not present any issue or presents an issue that has nothing to do with the task.
	Level 2	To formulate a question with unclear data and lacking appropriate statistical vocabulary.
	Level 3	Develop a question related to the data, using statistically appropriate vocabulary.
Task 5	Level 4	Develop a question using appropriate statistical vocabulary related to the data.

Table 3 illustrates the specific descriptions adapted to the mathematical content of the tasks. The specific descriptions focused on three specific objectives for each task. The pairs were formed based on the results obtained in the pre-intervention phase. Following an analysis of the students' responses to the proposed tasks, each student was assigned an LK according to the predefined classification criteria. The pairs were then formed by matching students with similar LK, in

accordance with the principles of the zone of proximal development (ZPD) (Vygotsky, 1980).

The analysis of the students' proposed solutions was carried out based on the knowledge level descriptors for each specific objective defined for each task, as presented in **Table 3**. Initially, the median corresponding to each task was calculated. Subsequently, the median of the medians obtained was determined, thus allowing the identification of the LK of each student. Next, each student's performance was evaluated, assigning a

Table 4. Percentage values for each specific objective of each task

Tasks	Percentage values	LK	Objective 1	Objective 2
1	30%	1	0%	0%
		2	5%	3%
		3	15%	8%
		4	20%	10%
2	20%	1	0%	0%
		2	5%	5%
		3	7%	7%
		4	10%	10%
3	20%	1	0%	-
		2	5%	
		3	15%	
		4	20%	
4	15%	1	0%	-
		2	5%	
		3	10%	
		4	15%	
5	15%	1	0%	-
		2	5%	
		3	10%	
		4	15%	

percentage value to each defined knowledge descriptor previously presented for each task in the pre- and post-intervention phases (Table 4). To determine the students' global performance (GP), the percentage values obtained for each task were added together, organized into performance classes distributed across the intervals [0; 25[, [25; 50[, [50; 75[, and [75; 100].

Pedagogical Intervention

The intervention phase consisted of implementing a STEAM practice, structured in three sessions, the last of which was divided into two parts, planned using three learning scenarios, and articulated around the real problem of ocean pollution (Rodrigues-Silva & Alsina, 2023). The first session aimed to recognize plastic waste in the oceans as an environmental problem, learn how to organize data according to its common characteristics in relation to the main plastic pollutants in the oceans, and solve problematic situations involving the concept of angles using the SuperDoc robot. The second session aimed to identify and organize the main pollutants in the oceans as data to be processed, recognize how to construct a table of absolute frequencies and a bar chart, and analyze and interpret a bar chart. Part I and part II of the third session aimed to construct, analyze, and interpret bar graphs by calculating the mean, identifying the mode, minimum, and maximum of a bar graph, preparing statistical questions, and formulating conclusions about disposable plastic waste polluting the oceans, using statistical language. Each session followed the exploratory teaching model and was organized into four phases: introduction to the task, completion of the task, discussion of the task, and systematization of

mathematical learning (Canavarro et al., 2012). The sessions lasted approximately 80 minutes, and throughout the intervention, students worked in pairs organized according to the ZPD (Vygotsky, 1980). In the task introduction phase, the context and necessary materials were presented to the students, with the first session integrating the SuperDoc robot to promote computational thinking and the exploration of mathematical concepts (Silva et al., 2024; Wing, 2006). During the task in the sessions, the TT circulated around the room, adopting a work-and-walk-by approach, monitoring progress and asking questions to encourage students' reasoning (Domingos et al., 2020). The discussion and systematization phases allowed for the sharing of strategies and the formalization of statistical literacy concepts, such as data organization and interpretation (Martins et al., 2017; Ponte, 2017). Formative assessment was carried out continuously, using techniques such as the "exit ticket" to allow the researcher to adjust subsequent sessions according to the doubts identified (Lopes & Silva, 2020). A summary of the mathematical results obtained was made in the mathematical learning systematization phase. In this phase, the student teacher emphasized the importance of mathematical knowledge and worked on the difficulties identified out in the pre-intervention phase.

Data Analysis

Analysis of qualitative data

An exploratory content analysis was conducted on the qualitative data collected at three stages of the study: pre-intervention, during the intervention, and post-intervention. This type of analysis involves systematically examining participants' responses to identify significant information. By doing so, it allowed the researchers to track changes in participants' resolutions over time and to identify the specific challenges they faced when completing the tasks. This analysis provided evidence of both the learning progress and the difficulties experienced by participants throughout the intervention.

Analysis of quantitative data

The quantitative data were analyzed using descriptive statistics to characterize students' GLK and GP during the pre- and post-intervention phases. With regard to the GLK classification, level 1 and level 2 are considered as negative trends, and level 3 and level 4 as positive trends. Similarly, in the GP, the intervals [0; 25[and [25; 50[were interpreted as indicators of negative performance, while the intervals [50; 75[and [75; 100] were understood as indicators of positive performance.

The paired-samples student's t-test was used after verifying its normality assumption (Field, 2018; Marôco, 2021). The normality of the dependent variables was

Table 5. Distribution of absolute (n) and relative frequencies (%) of LK

Tasks	Pre-intervention				Post-intervention			
	1	2	3	4	1	2	3	4
T1	90% (18)	10% (2)	0% (0)	0% (0)	0% (0)	20% (4)	50% (10)	30% (6)
T2	35% (7)	35% (7)	25% (5)	5% (1)	10% (2)	20% (4)	5% (1)	65% (13)
T3	25% (5)	50% (10)	25% (5)	0% (0)	5% (1)	20% (4)	50% (10)	25% (5)
T4	45% (9)	5% (1)	45% (9)	5% (1)	5% (1)	0% (0)	40% (8)	55% (11)
T5	50% (10)	15% (3)	25% (5)	10% (2)	10% (2)	0% (0)	40% (8)	50% (10)
GLK	50% (10)	35% (7)	15% (3)	0% (0)	5% (1)	0% (0)	60% (12)	35% (7)

Table 6. Descriptive statistics and pre- and post-intervention comparison in the GLK

	Mean	Standard deviation	t	p	d	Effect size
Pre-intervention	1.65	0.745	-11.573	0.001	2.588	Very high
Post-intervention	3.35	0.489				

assessed using the Shapiro-Wilk test (Field, 2018; Marôco, 2021). In cases where normality was not verified, the following condition was checked (Pestana & Gageiro, 2014; Tabachnick et al., 2021):

$$\left| \frac{\text{skewness coefficient}}{\text{standard error of the skewness coefficient}} \right| \leq 1.96. \quad (1)$$

The effect size associated with the student's t-test was calculated using Cohen's *d*, following (Marôco, 2021; Pallant, 2020): small ($d \leq 0.2$), medium ($0.2 < d \leq 0.5$), high ($0.5 < d \leq 1$) and very high ($d > 1$).

Statistical analysis was performed using IBM SPSS Statistics software (version 29, IBM USA), with a significance level of 5%.

RESULTS

Divided into three main sections, the first addresses the results related to LK, analyzing the students' progress on each individual task as well as their GLK. The second section focuses on GP, presenting the frequency distributions and conducting statistical analyses to determine significant differences between assessment points. The third section examines the qualitative findings, employing MN to illustrate students' problem-solving strategies, classroom dialogues, and the development of their reasoning. In all sections, the data are analyzed comparatively between the pre- and post-intervention phases.

Quantitative Results

Levels of knowledge

Table 5 presents the distribution of absolute and relative frequencies (%) of students' LK per task and the students' GLK, between the pre- and post-intervention phases. **Table 5** shows the students' LK evolution in all the tasks. Regarding task 1, it is observed that, in the pre-intervention phase, all students were at negative levels (90% at level 1 and 10% at level 2). In the post-intervention phase, it is found that most students are at level 3 and level 4 (50% and 30%, respectively). In task 2, it is observed that, in the pre-intervention phase, level 1

and level 2 concentrated 70% of the students. However, in the post-intervention phase, most students moved to the positive levels, with 80% of students at level 3 and level 4. Task 3 shows a similar trend. Initially, 75% of students are at level 1 and level 2, demonstrating limitations in identifying the minimum and maximum of a data set. After the intervention, this value drops to 25%, and 75% of students reach positive levels (50% at level 3 and 25% at level 4). Regarding task 4, in the pre-intervention phase, it is understood that half of the class is at negative levels and the other half at positive levels. In the post-intervention phase, it is observed that 95% of the students are at positive levels (40% at level 3 and 55% at level 4) and only one student remained at level 1. In task 5, before the intervention, most students were at level 1 and level 2 (50% and 15%, respectively). In the post-intervention phase, students are mostly distributed between level 3 (40%) and level 4 (50%). Analyzing the GLK, in the pre-intervention phase, negative levels account for 85% of students, while only 15% are at level 3 and none at level 4. In the post-intervention phase, 95% of students reach positive levels (60% at level 3 and 35% at level 4) and only one student is at level 1.

Table 6 allows us to highlight that there are statistically significant differences in the students' GLK between the pre-intervention phase and the post-intervention phase ($t [19] = -11.573$; $p = 0.001$; $d = 2.588$ [very large effect size]). It is observed that there is an improvement between the average value of the pre-intervention phase (1.65) and the post-intervention phase (3.35). This result shows that, initially, the students' performance was below level 2 and, after the intervention, it began to approach level 4, demonstrating that, considering the established criteria, this evolution indicates progress in the understanding of the treatment and analysis of statistical data.

Global performance

The comparison of the distribution of absolute and relative frequencies (%) of GP between the pre- and post-intervention phases is presented in **Table 7**, from which we can see that there have been improvements. In the

Table 7. Distribution of absolute and relative frequencies (%) of GP

	Pre-intervention	Post-intervention
[0; 25[	50% (10)	0% (0)
[25; 50[	35% (7)	10% (2)
[50; 75[	15% (3)	50% (10)
[75; 100]	0% (0)	40% (8)

pre-intervention phase, it was observed that half of the class (10 students) was in the lowest performance range. In addition to these, seven students (35%) were in the next range [25; 50[, also showing negative performance. Only three students achieved a performance above 50%. After the intervention, 90% of the class (18 students) showed positive performance levels. No students remained in the lowest performance range, and only two students (10%) remained in the range [25; 50[, corresponding to negative performance.

Table 8 shows statistically significant differences in the students' average GP results in all the tasks, with a high or a very high effect sizes across all tasks.

This positive development is evident in the strategies used by the students during the tasks carried out in the pre- and post-intervention phases, as shown below.

Qualitative Results

The observed improvement becomes especially visible when analyzing the strategies used by students in solving tasks before and after the intervention. Comparing the outputs allows us to identify, on the one hand, the difficulties manifested in the pre-intervention phase and, on the other hand, the strategies adopted in the post-intervention phase. To illustrate this evolution, some representations of the solutions produced by the students in the two phases will be presented below, which complement the quantitative results presented in **Table 5**, **Table 6**, **Table 7**, and **Table 8**. In this way, excerpts from MN will be presented, which describe in detail the students' reasoning and the researcher's actions, allowing for a deeper understanding of the factors that complement the positive quantitative results previously presented.

1.1. Os alunos pretendem organizar os dados através de um gráfico de barras. Ajuda-os, representando os dados num gráfico de barras. Que informação podes observar através desse gráfico? Explica como pensaste para construir o gráfico.

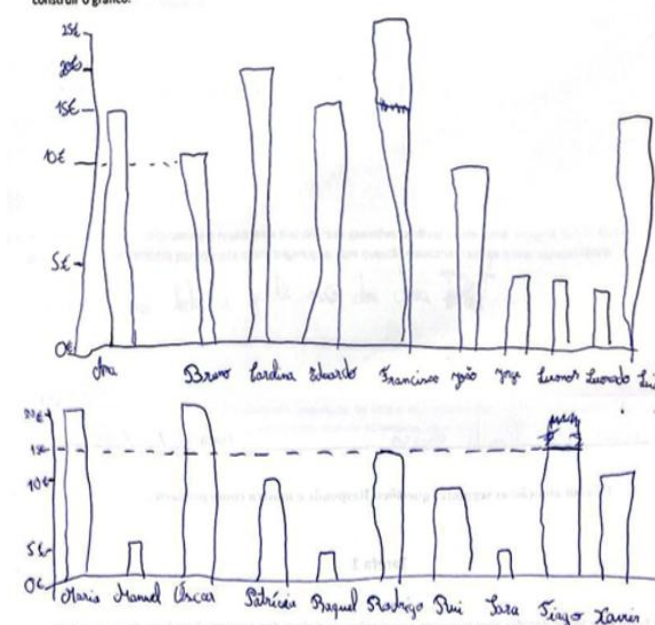


Figure 3. Student 20's proposed solution to task 1, in the pre-intervention phase (the authors' own elaboration)

Task 1

Pre-intervention phase: **Figure 3** shows student 20 solution to task 1 of the pre-intervention phase. In this task, the student demonstrated difficulties in understanding how to represent a bar graph, presenting incorrect bars, failing to identify the title and axis labels, and not providing a description of the steps involved in constructing a bar graph. Student 20 is at level 2 of objective 1 and level 1 of objective 2, relative to the LK of task 1.

During her presentation, the TT chose the example of student 1 and student 20 to project on the board. This example served as a basis for comparison with another graph constructed by student 7 and student 12. The differences between the two examples were analyzed, and the students were involved in reflecting on what they should do to construct a simple bar graph, as demonstrated in the excerpt from the second lesson:

Table 8. Descriptive statistics and pre-intervention and post-intervention comparison of GP

Tasks		Mean	Standard deviation	t	p	d	Effect size
T1	Pre-intervention	4.50	4.26	-10.66	0.001	2.382	Very high
	Post-intervention	16.85	5.72				
T2	Pre-intervention	10.30	8.10	-5.10	0.001	1.141	Very high
	Post-intervention	20.20	8.24				
T3	Pre-intervention	6.25	5.60	-4.22	0.001	0.943	High
	Post-intervention	13.50	6.09				
T4	Pre-intervention	5.50	5.36	-5.85	0.001	1.308	Very high
	Post-intervention	13.00	2.51				
T5	Pre-intervention	4.75	5.50	-6.61	0.001	1.477	Very high
	Post-intervention	12.75	2.42				
GP	Pre-intervention	31.30	17.46	-11.34	0.001	2.535	Very high
	Post-intervention	74.30	16.38				

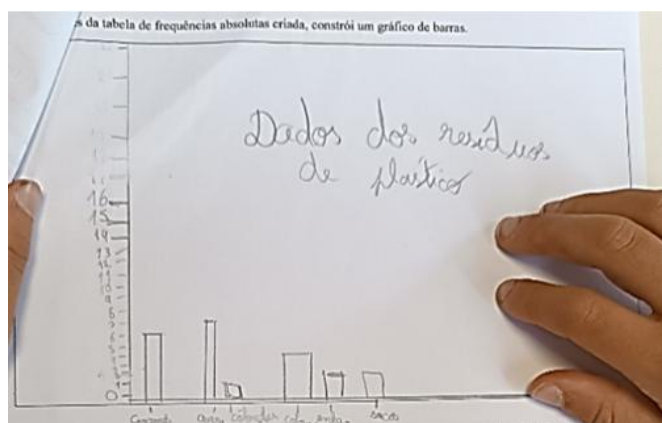


Figure 4. Task 2 completed by the student 1 and student 20 (the authors' own elaboration)

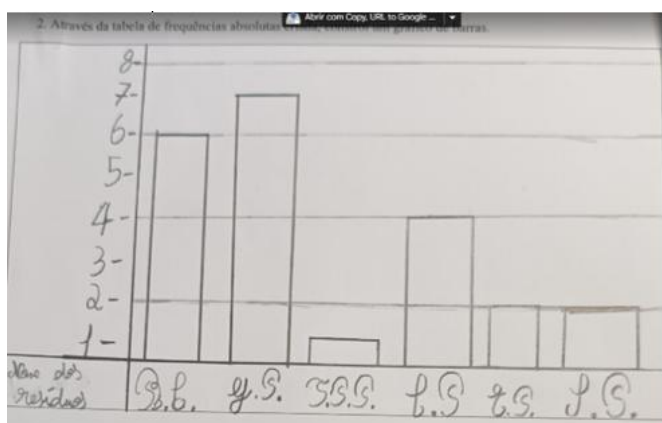


Figure 5. Task 2 completed by the student 7 and student 12 (the authors' own elaboration)

The students who were at the board sat down, and the TT projected the solution to task 2, performed by different pairs of students, onto the interactive whiteboard for 22 seconds (Figure 4 and Figure 5).

Teacher: What is the difference between these two graphs?

Post-intervention phase: In the post-intervention phase, student 20 (Figure 6) presented a solution demonstrating a more proficient understanding of graph representation and the types of elements involved, showing the construction of a simple bar graph with a title, axis labels, and auxiliary lines. In objective two, the student described all the steps, demonstrating that they organized the data – adjusting the scale to the number of students and not to the students' names – identified and labeled the axes, constructed bars, and added the title, placing them at level 4 according to the established criteria.

Task 2

Pre-intervention phase: In task 2, it was found that most students already demonstrated some understanding of what it means to perform an equitable

1.1. Os alunos pretendem organizar os dados através de um gráfico de barras. Ajuda-os, representando os dados num gráfico de barras. Que informação podes observar através desse gráfico? Explica como pensaste para construir o gráfico.



Figure 6. Student 20's proposed solution to task 1 in the post-intervention phase (the authors' own elaboration)

1.2. O professor decidiu doar o dinheiro angariado de forma equitativa pelas quatro associações. Quanto é que ele doou a cada uma? Explica como pensaste, usando esquemas, desenhos ou palavras.

240/4
= 60
R: Doar a cada uma 60€.

Figure 7. Student 4's proposed solution to task 2 in the pre-intervention phase (the authors' own elaboration)

division of data. However, difficulties persisted in explaining the reasoning underlying the procedures used. In several cases, students only presented the result of the division, without showing the steps that led to the values obtained, as exemplified in student 4's solution (Figure 7).

Other students simply added up the data presented in the task and formulated the final answer based on that calculation, as illustrated by student 15 (Figure 8).

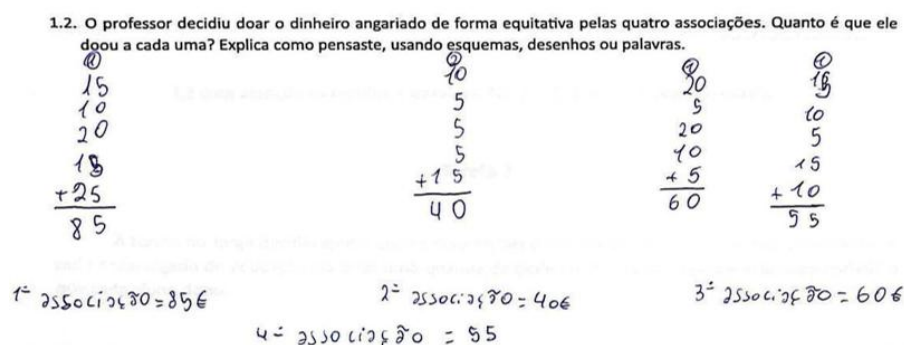


Figure 8. Student 15's proposed solution to task 2 in the pre-intervention phase (the authors' own elaboration)

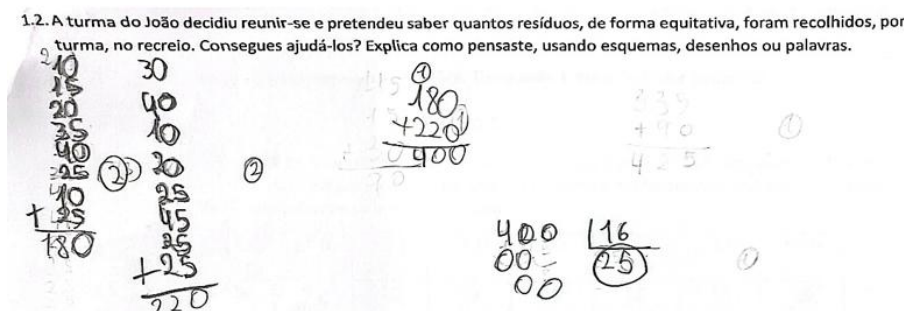


Figure 9. Student 15's proposed solution to task 2 in the post-intervention phase (the authors' own elaboration)

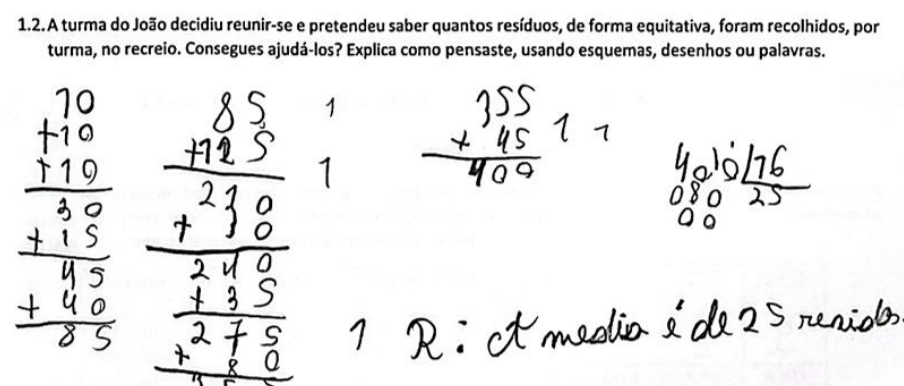


Figure 10. Student 4's proposed solution to task 2 in the post-intervention phase (the authors' own elaboration)

Post-intervention phase: In the post-intervention task, student 15 demonstrated a more developed solution and recognized the need to perform addition and division to obtain an equitable distribution of the data (Figure 9).

Student 4 (Figure 10) also demonstrated the same understanding of performing addition and division, which showed that he understood equitable sharing as the average of the data. Both students progressed from level 1 of knowledge to level 4 according to the established criteria.

The demonstration of this evolution is complemented by the following excerpt, which highlights the emphasis placed on equitable sharing to demonstrate how they could calculate the average.

Student 6: Okay. But I still need to do a calculation on the side (3-second pause). And then we have

here ... The problem says we have three classes of the fourth, fourth grade. No, it says four grades ...

Teacher: Yes, but I was mistaken.

Student 6: And ... then we have to divide by three!

Teacher: Why do we have to divide the money among how many classes?

Student 6: Across three classes.

Teacher: Exactly!

Student 6: So we divide by three (writes on the board).

Teacher: We don't want to divide the money by the number of people in the class! We want to divide the money among the three classes.

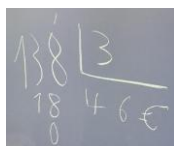


Figure 11. Division in the table made by student 6 (the authors' own elaboration)

[Student 6 performs the division for 34 seconds].

Student 6: Gives forty-six euros per class. The average donation of euros per class is forty-six euros (**Figure 11**).

Teacher: Very good! Did you understand?

Student 20: Yes.

Teacher: Why did he do that? Did you understand? (student 7 raised their hand) student 7 says.

Student 7: Why did you divide by three?

Student 6: I divided by three because that's the number of classes.

Teacher: Because we don't want to divide the number by the number of people. We want to divide by the number of classes that the problem states.

Student 6: In this case, it's divided among the three classes.

Teacher: Exactly (3-second pause).

Student 6: I'll honestly admit that I also made that mistake at first.

Teacher: Yes, but then we talked about it, didn't we? And we realized what the difference was. In other words, the average, in the end, corresponds to the equitable distribution, equitable, my friends!

Student 20: Same.

Teacher: Equal. Equitable means equal to, of all elements, that is, of all classes. (1 second pause) Did you understand?

Student 16: More or less.

Teacher: So, the average ... to calculate the average, what do we have to do? Add ... Add, no, sorry. Multiply all the elements, add them.

Student 6: Since this is a graph, since this is a graph where you need to multiply, but if it were a normal case you wouldn't need to.

Task 3

Pre-intervention phase: In the pre-intervention phase of task 3, most students were able to understand what the minimum and maximum values of a data set were, but they did not demonstrate that the largest value was the maximum of the data set and the smallest value was the minimum of the data set, as can be seen in student 7's solution (**Figure 12**).

Next, from the MN perspective, a part of the intervention is observed where the students called the TT to clarify a doubt and, in this way, understood the minimum and maximum values of the data they were analyzing on the worksheet.

Teacher: So what's bigger here?

Student 13: That's the best.

Student 7: This is it (pointing to the same bar in **Figure 12**).

Teacher: So ...

Student 7: This is the bare minimum.

Teacher: What is the biggest one?

Student 13: No. The biggest one is ten.

Teacher: Is ten the biggest?

Student 4: Ten? What are you talking about?!

Student 13: That's ten euros.

Student 7: Huh? It's the quantity!

Post-intervention phase: The same student, who in the pre-intervention phase (**Figure 13**) identified the most and least generous students but did not recognize

1.3. "De entre os alunos qual foi o mais generoso e o menos generoso? Explica como pensaste, usando esquemas, desenhos ou palavras."

*Eu pensei
Mais generoso - Francisco.
Menos generoso - Jorge, Leonor, Leonardo, Lara, Manuel e Raquel.
Pensei, e como na tabela dizia o que era um
dois eu vi o mais generoso / menos generoso.*

Figure 12. Student 7's proposed solution to task 3 in the pre-intervention phase (the authors' own elaboration)

1.3. De entre o que as turmas recolheram, qual foi o maior e o menor número de resíduos? Explica como pensaste, usando esquemas, desenhos ou palavras.

O maior número de desenhos é 45 e o menor é 15.

45 = mínimo 15 = máximo

Figure 13. Student 7's proposed solution to task 3 in the post-intervention phase (the authors' own elaboration)

1.4. Qual a quantidade dada pela maioria dos alunos? O que representa essa quantidade? Explica como pensaste, usando esquemas, desenhos ou palavras.

Dom 2 f5
porque juntei
tudo e represento
a igreja

Figure 14. Student 8's proposed solution to task 4 in the pre-intervention phase (the authors' own elaboration)

1.4. Qual a quantia doada pela maioria dos alunos? O que representa essa quantia? Explica como pensaste, usando esquemas, desenhos ou palavras.

S - representa $\frac{1}{5}$ do total. (total - 25)

Figure 15. Student 20's proposed solution to task 4 in the pre-intervention phase (the authors' own elaboration)

1.4. Qual o número de resíduos recolhidos mais frequentemente pelas turmas? O que representa esse número? Explica como pensaste, usando esquemas, desenhos ou palavras.

25 com 5 turnos que são 2. 2, 2, 2, 2, 2
7.º D. R.: 25 que representa 5 turnos.

Figure 16. Student 8's proposed solution to task 4 in the post-intervention phase (the authors' own elaboration)

these values as the maximum and minimum of the data set, and who participated in the discussion in the MN excerpt above, subsequently made this clarification in the post-intervention phase, demonstrating an improved understanding of the concepts involved.

Task 4

Pre-intervention phase: In student 8's proposed solution (Figure 14), we can see that he or she did not demonstrate knowledge of the mathematical concepts involved, placing them at level 1.

Other students demonstrated some understanding of the concept involved. Student 20 explained the mode he chose by identifying the amount most often donated but did not explain the concept represented by that amount (**Figure 15**). The student is at level 2 of knowledge in this task.

Post-intervention phase: In the post-intervention phase task, student 8 explained their reasoning and

provided a correct answer, placing them at knowledge level 4 (Figure 16).

More comprehensively, student 20 identified the concept being worked on and how it could be identified in the data being processed, placing them at level 4 of knowledge for this task (Figure 17).

The following excerpt from MN demonstrates the discussion of results, in which student 20 understands with his colleagues that the mode is identified in the data point with the highest absolute frequency (Afonso & Nunes, 2019).

Student 19: The mode is the number that repeats most often. In this data graph, it's a bar graph, and it's...

Teacher: In this case (helps to read what the students had written – **Figure 18**).

Student 19: And in this case, the mode is fi ... a ... is five!

1.4. Qual o número de resíduos recolhidos mais frequentemente pelas turmas? O que representa esse número? Explica como pensaste, usando esquemas, desenhos ou palavras.

A moda é de 25.
 Este número representa a mais frequente frequência absoluta.

Figure 17. Student 8's proposed solution to task 4 in the post-intervention phase (the authors' own elaboration)

1.1. Qual é a moda deste conjunto de dados? Explica como pensaste, usando esquemas, desenhos ou palavras.

3: A moda é o número que se repete mais vezes, neste gráfico de barras e neste caso a moda é 25.

Figure 18. Response to task 1.1 by student 17 and student 19 (the authors' own elaboration)

1.5. Os alunos da turma voltaram-se a reunir para discutir mais questões relativas a este tema. Imagina que és aluno desta turma e que também participaste nesta angariação. Que questão colocarias com os dados apresentados?

Eu com os dados ~~colocaria~~ representando colocaria a seguinte questão: Porque é que alguns alunos só levaram 5€?

Figure 19. Student 19's proposed solution to task 5 in the pre-intervention phase (the authors' own elaboration)

Teacher: Is it number five what?

Student 17: Euros.

Student 19: It's fi ...

Teacher: Euros.

Student 19: Five euros.

Teacher: Why isn't it, why isn't it nine?

Student 20: Nine?

Teacher: Why isn't it nine?

Student 20: Because five is ... the ... the ... absolute frequency.

Teacher: Is five an absolute frequency?

Student 7: No!

Teacher: Or is nine the absolute frequency?

Student 20: It's nine!

Teacher: Ah! (student 7 raised their hand). Yes, student 7.

Student 7: It's not nine, so uh, it's not, that's what repeats, the number of times.

Teacher: The number of times it's repeated, very good! In other words, what's the frequency? (3-second pause) What's the frequency? If it's the number of times it's repeated, what's the frequency?

Student 19: Absolute.

Teacher: Absolutely, exactly.

Task 5

Pre-intervention phase: In the pre-intervention phase, student 19's proposed solution indicated a limited understanding of the requested mathematical concept; specifically, the student was unable to formulate a statistical question based on the data available for analysis (Figure 19). The student presented a question from their own point of view, which placed them at level 1 of the established knowledge level classification criteria.

Post-intervention phase: Student 19, in the post-intervention phase, demonstrated understanding of what was being asked and asked a question related to a concept worked on during the intervention (Figure 20).

1.5. Os alunos da turma voltaram-se a reunir para discutir mais questões relativas a este tema. Imagina que és aluno desta turma e que também queres participar na discussão. Que questão colocarias com os dados apresentados?

Qual é o modo?

Figure 20. Student 20's proposed solution to task 5 in the post-intervention phase (the authors' own elaboration)



Figure 21. Group 4 exploring the robot's commands using the cards (the authors' own elaboration)

Intervention phase

In the present study, the improvements observed in GLK, GP, may be associated with the implementation of STEAM practices, with ER being used only to a limited extent. Nevertheless, ER may have contributed to these improvements for several reasons:

- a. Due to the mobilizing effect of ER in the first session, where student engagement and enthusiasm were observed during the exploration of the SuperDoc robot, leading to persistence in solving subsequent tasks, this is consistent with studies that point to ER as a promoter of motivation and active student involvement (Bers, 2020; Silva et al., 2023a). The following MN illustrates the involvement of a group of students and their active role in constructing solutions to the task and programming the robot:

Student 10: Put it there student 15 (asked to write on the worksheet). One, two, three (clicked and counted the robot's commands simultaneously).

Student 15: No, that's not how it works!

Student 10: Yes, yes.

Student 15: No, it's not!

Student 10: Yes, yes, put it like this! (2-second pause) That's it, yes!

Student 15: Student 20, student 20, is it like this here or with this arrow like this? (with the orange card indicating a step forward or the yellow card indicating a step back).

Student 20: It's the other one.

Student 10: Like this (with the yellow card indicating a step back - **Figure 21**) (7-second pause).

Student 20: Something's wrong (they couldn't get the robot to follow the direction they wanted) (5-second pause).

Student 10: Put it upside down (6-second pause).

Teacher: Have they registered yet? They have to register!

Student 20: Na ... na 1 ... na 1 ... is it like this or is it ... po ... can we walk on the plastic?

Teacher: In group 1, they can take whichever route they prefer, as long as ... as long as it's from the source to the mouth (for 22 seconds, TT left the group and went to group 1).

Student 20: Ok ... one, two, three, four, five, six (counts the squares on the rug).

Student 10: Do you want me to write that down? (referring to the worksheet).

Student 20: Yes. Six in front.

Student 10: Should I put the arrows like I did?

Student 20: No. Six in front, then ... a quarter turn to the left and then one in front.

- b. By integrating different disciplinary areas around a real problem, identified by the students themselves - ocean pollution - the intervention gave meaning to the work carried out. The organization and analysis of data on plastic waste ceased to be an abstract task and became something concrete: raising awareness for a



Figure 22. Idea implemented by student 14 (the authors' own elaboration)



Figure 23. Mural created by the class (the authors' own elaboration)

change in behavior, situating statistical tasks within a significant problem (Vásquez et al., 2023). The articulation between mathematics, environmental studies, ER, and environmental citizenship is in line with the literature that describes STEAM practices as promoters of contextualized and meaningful learning (Pires, 2024; Wu et al., 2022). In this study, students who worked with real data were able to construct awareness messages, as shown in the following excerpt from MN, which made learning authentic and gave meaning to the tasks performed.

Teacher: Very well. So what did we want to do with all this? Who can tell me what we want to do with all this? (student 6 raised their hand) Tell me, student 6.

Student 6: Motivate people not to pollute.

Teacher: Good. Motivating people not to pollute. Oh student 5 (calls attention because the student is talking). So ... why was this the idea for the bottom part? Student 14? It was your idea (Figure 22).

Student 14: It's to demonstrate that there's a lot of plastic in the ocean.

Teacher: Very good. Look, and tell me something, what about this graph? Why did we make it?

Student 14: To demonstrate the largest quantity of plastic ...

Teacher: Say it, with your hand in the air! Say it (to student 7, who had raised their hand in the air).

Student 7: It's to show that each type of waste is more polluting. The larger the quantity of each type of waste.

Cooperating Teacher: Okay. Compare the residues.

Student 7: That there is more of one and less of the other.

Teacher: Very good. So, what are the types of waste we have described here? Do you remember? Student 20 says.

Student 19: It's cigarette butts, plastic bags, cutlery and straws, uhm, plastic bottles, plastic cotton swabs and packaging.

- c. Due to the productivity of the proposed tasks, students engaged in learning statistics: organizing real data, constructing simple tables and bar graphs, conducting statistical analyses, and formulating statistical questions. In the last session, they created an awareness poster with slogans, images, and prevention messages, as demonstrated in the following excerpt from the MN. This structure aligns with STEAM practices and the exploratory teaching model, which values research, creation, and communication of results (Gomes et al., 2022; Wu et al., 2022).

Teacher: What did we want to do with this? (Figure 23).

Student 20: Show ... (student 16 interrupts).

2.2. Que questão colocarias com os dados apresentados?
 Com os dados apresentados eu colocaria as seguintes questões:
 Qual é a moda da gráfica? Qual é o mínimo da gráfica de barras?

Figure 24. Questions asked by student 7 and student 12 (the authors' own elaboration)

Student 16: Show people that polluting is bad.

Student 20: That's bad.

Teacher: To our planet.

Student 14: Influencing people to ... pollute

Teacher: Yes, to pollute less. Or not to pollute at all!

Student 14: Yes, to pollute less, to recycle ...

Student 20: And pollution is no joke!

Teacher: And pollution is no joke, very good!

Student 20: And so as not to unlearn!

Teacher: (Student 11 raised their hand) Say ...

Student 11: And warn people not to ... that it could get worse if we continue like this.

Teacher: Very good!

- d. By promoting moments of collaboration and the development of transversal skills, such as communication, critical thinking, and creativity. When working in groups, students demonstrated the ability to make collective decisions, justify arguments, and integrate different contributions, evidencing a positive development of skills (Perignat & Katz-Buonincontro, 2019; Pires, 2024). The analyses of the MN show moments in which students question their own choices, compare solutions, and refine their productions, revealing a process of shared reflection in the tasks performed. The following excerpt shows the communication and collaboration work between the pair of student 7 and student 12 in the second session.

[Student 7 read the statement for 6 seconds].

Student 7: What's the trend? It's good!

[For 1 minute and 5 seconds, the pair of students began writing the answer to the item].

Student 7: What is the mode? (read what he had written)

Student 12: The question's trend ...

Student 7: Mode of the graph.

Student 12: From question two. From the graph in question two.

Student 7: This is just an example of what the mode is.

[For 14 seconds, student 7 wrote the question on worksheet].

Student 7: It's ... (for 2 seconds, the pair looked at the graph and tried to figure out the mode) Seven!

Student 12: It's plastic bottles, seven of them!

Student 7: And now ask another question. Just ask a question that can be answered based on this (graph).

Student 12: Ah, which one is the least?

Student 7: Ah, what's the minority?

Student 12: Yes.

Student 7: What is the minimum value of the graph? What is the minimum value of the bar graph? (**Figure 24**).

DISCUSSION

The purpose of this study was to analyze the impact of STEAM practice, incorporating ER, on promoting the learning of statistical concepts among 4th grade in primary school.

Regarding the development of statistical literacy, in the pre-intervention phase, students showed difficulties in recognizing all the fundamental elements of a simple bar graph, in organizing data, and in understanding and interpreting basic concepts of statistical analysis (mean, mode, minimum, and maximum of a data set) (Gomes et al., 2022; Papeleira, 2023; Souza et al., 2021). These difficulties directly influenced the resolution of the proposed tasks, in line with studies that indicate that students face conceptual and procedural obstacles at the

beginning of learning statistical literacy (Duque et al., 2015; Silva et al., 2022).

The previously identified difficulties continued to emerge during the intervention phase, requiring the researcher to orchestrate instruments tailored to the students' emerging needs. The guiding questions posed throughout the sessions promoted reflection among the students on their own strategies, allowing them to reconsider procedures and overcome identified obstacles (Rodrigues et al., 2025b). Simultaneously, moments of reflection on the tasks played a structuring role in deepening learning, providing a space for sharing and analyzing the different tasks, contributing to a mediated conceptual deepening among peers (Bessa & Fontaine, 2002; Ponte, 2020). It is important to highlight that it was the students who showed interest in calculating the average during the sessions and were able to learn the concept and its calculation, as was the case with Silva et al. (2022).

The results regarding the students' LK, analyzed by objective and by task, in the pre- and post-intervention phases, suggest an improvement in the tasks towards positive levels. In task 1, although most students improved in constructing the graph, it was observed that, regarding the objective of describing the steps in constructing the graph, half of the class remained at level 2. This suggests the need to strengthen students' understanding and explanation of the procedural stages involved in graph construction, particularly the selection and organization of data and the appropriate use of all graph components, as highlighted by Curcio (1987) and Pontes and Guimarães (2021).

The GLK results show a significant improvement in positive levels between the pre- and post-intervention phases. Analyzing the GLK average, we understand that only one student remained at level 1, while the others progressed to level 3 and level 4, suggesting an improvement in the construction of simple bar graphs and the analysis of statistical data. There is evidence of improved understanding of how to construct a bar graph and its respective elements in task 1, and strong evidence of how to calculate the mean and identify the mode, minimum, and maximum (tasks 2, 3, and 4), as well as in formulating statistical questions using the interpreted data in task 5.

Regarding the GP, this corroborates the trend of improvement, with 85% of students at negative levels in the pre-intervention phase and 90% of students showing positive levels of GP in the post-intervention phase.

The ER – in this case, solving a problem involving angles with the SuperDoc robot – functioned primarily as a motivating artifact, framing the issue of plastic waste and understanding the reality of the environment. The MN show that students discussed approaches, negotiated, and corrected programming errors, revealing resilience, curiosity, and collaboration. This

initial involvement developed persistence for subsequent statistical work, even though the robot was not used again in later tasks. Thus, in this study, the main contribution of ER lies in the motivational dimension and the activation of aspects of computational thinking. This type of integration is consistent with what the literature describes as a predominantly motivational use of technological artefacts and ER, in which the emphasis is placed on introducing and enriching learning activities rather than on exploiting their epistemic potential to support the construction of mathematical knowledge (Clemente & Rosário, 2023; Silva et al., 2024). In light of these studies, it is recognized that the potential of RE is broader and could have been explored in direct conjunction with statistics.

The intervention, designed within STEAM learning scenarios, integrated mathematics, environmental studies, technological artifacts, visual arts, and environmental citizenship into a real-world problem – ocean pollution. The organization and analysis of data on plastic waste, the construction of simple bar graphs, the calculation and identification of statistical measures, and the creation of an awareness poster, created an authentic learning context in which students attributed meaning to the statistical tasks performed and understood the social relevance of what they were studying, consolidating their self- and others' awareness of environmental problems. Several studies have shown that STEAM practices in a school context, including in the first cycle of basic education, promote deeper, interdisciplinary, and socially meaningful learning by integrating different curriculum areas through engagement with authentic real-world problems (Ferreira et al., 2024; Herro & Quigley, 2016; Park et al., 2016; Perignat & Katz-Buonincontro, 2019; Pires, 2024; Wu et al., 2022).

The instrumental orchestration of the sessions played a key role throughout the intervention, allowing the selection of artifacts used, such as SuperDoc robot, according to the emerging needs observed in the class. The applied "work-and-walk-by" dynamic fostered autonomy and active learning, allowing for close and tailored monitoring (Costa et al, 2022; Domingos et al, 2020; Freitas, 2024).

Overall, the results indicate that the intervention had a positive impact on students' statistical learning. The integrated use of a STEAM-based approach incorporating ER, together with the exploration of authentic environmental issues, contributed to more meaningful learning.

CONCLUSION

This study aimed to answer the following research question: What is the impact of a STEAM practice, incorporating ER, on promoting learning of statistical concepts among 4th grade in the primary school?

The results reveal that a STEAM practice, incorporating ER, promotes learning about statistical concepts, such as the construction, analysis and interpretation of bar graphs, the calculation of the mean, the identification of the mode, the minimum and the maximum of a data set, and the formulation of statistical questions using a data set.

The results obtained demonstrate progress in student learning regarding data organization, representation, and interpretation, the construction of simple bar graphs, and the calculation of elementary statistical measures. The comparison between the pre- and post-intervention phases shows a consistent shift from predominantly negative to positive levels of student knowledge, revealing significant conceptual and procedural development. This improvement is corroborated by student work and excerpts from the MN, which reveal greater rigor in their solutions and an increased ability to justify them.

The ER – in this case, solving a problem involving the concept of angles using the SuperDoc robot – played a primarily motivating and problem-framing role, helping to create curiosity and engagement in the first session. The connection between the robotics component, STEAM areas, statistical content, and the issue of ocean pollution allowed for the contextualization of mathematical content within concrete and meaningful challenges, promoting deeper learning. The researcher's encouragement, combined with the use of guiding questions, peer collaboration, and moments of collective discussion, fostered processes of continuous reflection, confrontation of ideas, and joint construction of learning, fundamental for consolidating statistical literacy.

This study has some limitations that should be considered when interpreting the findings. The sample was small and comprised only 4th grade primary school students from a single school, limiting the generalizability of the results. Furthermore, ER was incorporated only in the initial part of the intervention, rather than being used throughout the entire STEAM practice. This limited use of ER should be considered when interpreting its contribution to students' learning and the development of statistical literacy.

Future research should include students from different year groups to enable comparisons of the development of students' skills across primary education. It should also explore more comprehensive STEAM practices by incorporating additional prototyping and implementation phases for alternative solutions and by integrating ER across multiple sessions, rather than a single session, to further support the development of critical and creative thinking. We propose the inclusion of statistical tasks, encompassing other types of graphs, allowing students to develop the ability to select the statistical representation most appropriate to their needs.

This study concludes that the implementation of a STEAM practice, incorporating ER promotes learning about statistical concepts among 4th grade in the primary school. The articulation between content, technology, and real-world issues (such as ocean pollution) promoted active, contextualized learning aligned with current guidelines for teaching natural sciences and mathematics.

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