

Educational robotics with interactive and environmental projects using “micro:bit” and “Nezha” in nine primary schools

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Abstract

This study evaluates the results of dynamic and innovative educational robotics activities in elementary schools, with 704 students in grades 4, 5, and 6 across nine schools in the City of Madrid. In 19 classrooms, students worked on projects using block-based coding and sensor-based educational robotics, developing their understanding of computational concepts and engaging in interdisciplinary and environmental educational tasks. The computational robotics test was used, applying a paired-samples t-test for the first dimension and a Wilcoxon signed-rank test for the second. In the post-test, students demonstrated improved understanding of computational concepts, particularly sequences, loops, sensors, and actuators. They learned how to assemble a robot, and they positively evaluated environmental and science projects. Other curricular areas showed lower scores and no significant improvements. The students felt that working with robotics made them more active and the class more engaging. In short, active implementation of dynamic, interdisciplinary, and environmental activities in elementary education is recommended. Manipulation, coding, and creativity in projects foster active learning of the content with enthusiasm and commitment.

Keywords: educational technology, elementary education, environmental education, programming, robotics

INTRODUCTION

In an environment characterized by constant technological advancements, students must not only navigate an increasingly digital world but also take an active role in its construction (De la Hoz et al., 2024; Gretter & Yadav, 2016). To this end, it is essential that the education system promotes the development of transversal and strategic competencies—known as 21st century skills—such as creativity, autonomy, collaboration, innovation, critical thinking, and problem-solving (Chalmers, 2018; Coşkun & Filiz, 2023; Seckel et al., 2021; Zhang et al., 2021). Carlborg et al. (2019) also include computational thinking among these competencies, arguing that its development should also be fostered by the education system (Jurado et al., 2020; Yadav et al., 2016).

Computational thinking is conceived as a set of advanced cognitive skills and attitudes that facilitate the resolution of real-world problems through problem

decomposition, pattern identification, and the creation of logical and sequential procedures (Misirli & Komis, 2023; Yang, 2024). In this sense, STEM-based learning (science, technology, engineering, and mathematics) acquires special importance, since it uses an interdisciplinary approach that integrates concepts linked to real-world situations and, moreover, significantly influences the development of computational thinking (Richardo et al., 2023).

Computational thinking can be developed in the lesson planning of any subject area (Sung et al., 2022). In fact, many countries are making changes to their primary and secondary education curricula (Carlborg et al., 2019) to incorporate this type of thinking explicitly. In this regard, the European digital competence framework for citizenship includes computational thinking within competence 3.4, “programming,” defining it as the ability to plan and develop instructions to solve problems using computer systems (European Commission, 2022). Digital competence is part of the

Contribution to the literature

- This study contributes to the literature by providing empirical evidence on the integration of educational robotics with environmental project-based learning in primary education.
- It expands current research by analyzing the combined use of micro:bit and Nezha kits to develop computational thinking and sustainability awareness simultaneously.
- The findings offer large-scale quantitative data from a substantial sample of elementary students, addressing a gap in studies with robust sample sizes. Moreover, the research highlights differential learning outcomes across curricular areas, clarifying where robotics-based interventions are most effective.

curriculum, which stipulates that, by the end of primary education, students should have begun to be able to use simple and sustainable digital solutions, such as block-based programming or educational robotics, to solve problems creatively.

Educational robotics, understood as the implementation of robots or robotic components in educational settings for didactic and pedagogical purposes (Trapero-González et al., 2024), has become established as an innovative and effective approach in primary education that is capable of integrating interdisciplinary content and fostering active learning (De la Hoz et al., 2024). Its theoretical foundation is framed within Papert’s (1980) constructionism, which is itself based on Piaget’s constructivism, and which promotes the active construction of knowledge by children through practical experience. By acting as manipulatives that offer immediate feedback, robots allow students to better understand abstract concepts and problem-solving processes (Ching & Hsu, 2023). In this way, by solving problems on their own, students “learn to learn,” become more motivated, and assume an active role in their own learning (Barradas et al., 2024).

Educational robotics is an effective teaching strategy for introducing computational thinking, as it requires students to learn to process tasks systematically and to develop instruction sequences for programming robots (Chalmers, 2018). This type of activity promotes learning in mathematics and science (Sáez-López et al., 2019), motivating students to apply their knowledge through play (Sung et al., 2023).

However, the potential of educational robotics is limited by technical difficulties (Chalmers, 2018), a lack of uniformity in methodologies and assessments (Trapero-González et al., 2024), inadequate teacher training (De la Hoz et al., 2024), both at the initial stage and during professional practice due to a lack of time, materials, and pedagogical support, and difficulties in integrating robotics with other subjects (Jurado et al., 2020).

Research on the Use of Educational Robotics in Stem Education and Environmental Projects

Within the STEM competency framework, the areas most commonly addressed by research in educational

robotics are mathematics and technology, to the detriment of science and engineering (Trapero-González et al., 2024). According to Hsu et al. (2019) and Ching and Hsu (2023), the most frequently used approaches for developing computational thinking through educational robotics in schools are collaborative learning (e.g., Bers et al., 2019; Fanchamps et al., 2021) and project-based learning (e.g., Fanchamps et al., 2021; Papadakis & Kalogiannakis, 2019; Sáez-López et al., 2019).

Several studies have shown that Robotics Education effectively promotes digital literacy (Alonso-García et al., 2024), computational thinking, problem-solving skills and creativity (Barradas et al., 2024; Chalmers, 2018; Ching & Hsu, 2023; Freitas et al., 2024; Mwangi et al., 2022; Noh & Lee, 2020), teamwork, and social skills (Kanaki et al., 2025), and that it sparks interest in STEM subjects and careers (Ching & Hsu, 2023; Jurado et al., 2020; Mwangi et al., 2022), preparing students to assume an active role as producers and not just consumers of technologies (Papadakis & Kalogiannakis, 2019). Furthermore, when robotics is integrated with active methodologies such as problem-based learning (Bers et al., 2019; Sáez-López et al., 2016) and collaborative learning (Zhao et al., 2024), it improves students’ academic performance.

Educational institutions are currently seeking to promote learning and awareness about sustainability and environmental conservation from an early age, in line with the sustainable development goals (United Nations, 2015). In this context, educational robotics has enabled the implementation of various environmental projects while simultaneously developing computational thinking skills. Examples include activities using Bee-Bot to develop algorithmic thinking and environmental awareness in early childhood education (Kanaki et al., 2025); the “sustainable city” STEAM project that introduces primary school students to the challenges of climate change through robotics kits (Ruiz Vicente et al., 2020); the development for primary education of a mobile robot capable of recognizing food and displaying its ecological footprint (De Vasconcelos et al., 2022); and, in secondary education, the promotion of sustainable agricultural practices while developing digital skills and problem-solving abilities through the

implementation of the “automated garden” project (Freitas et al., 2024).

While the educational potential of micro:bit and Nezha has been widely documented, prior research has also identified several technical and pedagogical challenges associated with their implementation in elementary classrooms. Commonly reported issues include technical disruptions (e.g., unstable connections, sensor malfunction, or power limitations), uneven access to functional devices, and the risk of cognitive overload when learners are simultaneously required to manage programming, hardware assembly, and domain-specific content (Chalmers, 2018; Pedersen et al., 2020; Trapero-González et al., 2024). Acknowledging these constraints is essential to ensuring methodological rigor and interpretive validity.

The present study was deliberately designed to mitigate these challenges through a combination of technological simplification, pedagogical scaffolding, and instructional sequencing. First, the selection of micro:bit and Nezha was motivated not only by their educational affordances but also by their relative technical stability and low entry threshold. Both systems rely on visual block-based programming and plug-and-play hardware connections, which reduce configuration errors and troubleshooting demands compared to more complex platforms (e.g., Arduino-based robotics). Furthermore, the activities were designed to rely primarily on built-in or pre-tested external sensors, minimizing the likelihood of hardware failure during classroom sessions.

Goals

The main objective of this study was to evaluate the implementation of environmental projects using coding and educational robotics in the upper grades of primary education.

The specific objectives were:

- to analyze student learning and academic performance using educational robotics;
- to assess the feasibility of integrating environmental projects with educational robotics into the official elementary school curriculum;
- to analyze the acquisition of computational concepts and problem-solving skills in technology projects; and
- to interpret improvements in motivation, enthusiasm, enjoyment, and active learning approaches in a pedagogical process that uses programming and robotics activities in the classroom.

The research questions are:

RQ1. To what extent does the integration of educational robotics using micro:bit and Nezha kits improve elementary students’

understanding of core computational thinking concepts (e.g., sequences, loops, conditionals, sensors, and actuators)?

RQ2. How does participation in environmental project-based activities supported by educational robotics influence students’ learning outcomes in natural sciences and environmental education?

RQ3. What effects does the use of micro:bit and Nezha-based robotics projects have on students’ motivation, engagement, and perceived activeness in elementary classroom learning?

RQ4. How feasible is the curricular integration of educational robotics-supported environmental projects in elementary education, considering classroom implementation, interdisciplinary connections, and student perceptions?

MATERIALS AND METHODS

Participants

The study population consisted of primary school students aged 9 to 11, in the City of Madrid. These students attended nine public and private schools, and the study was conducted in a total of 19 classrooms across these nine schools, which voluntarily agreed to participate in the project.

Schools were selected based on their willingness to integrate educational robotics activities into their regular instructional schedule and their access to the required technological infrastructure. All students in the selected classrooms participated in the study as part of their regular curriculum. This approach ensured ecological validity by reflecting authentic classroom conditions. The sample was representative, non-probabilistic, and purposive. It comprised 47.7% female students and 52.3% male students, making it a representative sample of the schools. The mean age was 10.36 years.

No financial compensation, academic incentives, or material rewards were provided to students for their participation. Student assent was obtained implicitly through participation in regular classroom activities, which were fully aligned with the official curriculum and did not involve any procedures beyond standard educational practice. No personal identifying information was collected, and all data was anonymized prior to analysis.

Dimensions, Indicators, and Instruments

The dimensions, indicators, and various instruments (see **Table 1**) allow for data triangulation (Cohen et al., 2000). The different analyses and tests make it possible to determine and support the validity of the results and minimize error variance.

Table 1. Dimensions, indicators, and instruments

Dimension	Indicator	Instrument
1. Knowledge of computational concepts and robotics	Sequence, iteration (looping), conditional statements, & sensors	CRT, descriptive analysis, & student’s t-test
2. Active learning in curricular areas and the environment	Visual block programming and robotics and computational concepts application in curricular areas and the environment	Scale, descriptive analysis, & Wilcoxon test

For the first dimension, knowledge of computational concepts and robotics, the results of a 10-question test (the computational robotics test [CRT]) were analyzed using the student’s t-test. Pre-test and post-test scores were compared using a paired-samples t-test, with statistical significance defined as $p < 0.05$. The reliability calculated using Cronbach’s alpha coefficient yielded a value of 0.71 for this first dimension, which is considered acceptable (Hair et al., 1998).

To establish content validity, the CRT underwent a formal expert review process. A panel of 12 expert judges, all members of a competitive I+D+i research project and with recognized expertise in educational technology, computational thinking, and elementary education, independently evaluated each item. Experts assessed the relevance, clarity, and adequacy of the items in relation to the intended constructs and the target population.

Content validity was quantified using Aiken’s V coefficient, which yielded a value of $V = 0.69$, indicating an acceptable level of agreement among experts and supporting the adequacy of the items for measuring the targeted constructs. Items that received lower ratings were revised to improve clarity and alignment with instructional objectives, based on qualitative feedback provided by the experts. Moreover, internal consistency reliability was examined using Cronbach’s alpha, resulting in a coefficient of $\alpha = 0.74$, which is considered acceptable for an instrument assessing multiple related constructs in educational research.

In dimension 2, active learning in curricular areas and the Environment, the focus is on the results for the variables when applying the implementation of coding and robotics in environmental projects. Responses were collected using a 4-point Likert scale ranging from “strongly disagree” (1) to “strongly agree” (4). As a result of the ordinal nature of the data and its non-normal distribution, which was confirmed by the Shapiro-Wilk test, non-parametric analyses were performed. Specifically, the Wilcoxon test was used to compare responses ($p < 0.05$). This information allows us to determine if there were significant differences between the pre-test and post-test results for the intervention and practices with educational robotics.

Reliability, calculated through Cronbach’s alpha coefficient, gave an average of 0.78 on the scales for the second dimension, and the result was always higher

than 0.6, so this is considered acceptable (Hair et al., 1998).

Implementation

The project was carried out during the 2024-2025 academic year in 19 classrooms across nine schools. The sessions focused on building a series of environmental projects programmed on micro:bit using either the Nezha or the Maqueen kits.

Micro:bit is a low-cost, robust, and widely validated physical computing platform specifically designed for novice learners. Its integration of built-in sensors (e.g., temperature, light, accelerometer) and outputs enables students to directly observe and manipulate environmental variables, thereby supporting inquiry-based learning and the development of cause-effect reasoning in authentic ecological contexts. Moreover, its compatibility with MakeCode’s block-based programming environment reduces cognitive load and allows younger learners to focus on conceptual understanding rather than syntactic complexity.

The Nezha kit complements the micro:bit by providing a modular, sensor-rich robotics system that facilitates rapid assembly and reconfiguration without requiring advanced technical skills. Unlike more complex platforms (e.g., Arduino-based systems or advanced LEGO robotics kits), Nezha offers a simplified mechanical design and plug-and-play architecture, which minimizes setup time and technical barriers while preserving meaningful opportunities for experimentation with sensors, actuators, and control structures. This balance is particularly advantageous in elementary classrooms, where instructional time is limited and teacher expertise in robotics may vary.

Compared to alternative tools such as screen-based coding environments or pre-programmed educational robots (e.g., Bee-Bot), the micro:bit-Nezha combination offers a higher degree of flexibility and conceptual depth. Screen-only tools lack the tangible interaction necessary to link programming with real-world environmental phenomena, while closed robotic systems often constrain students’ agency by limiting customization and sensor integration. In contrast, micro:bit and Nezha support open-ended, project-based activities in which students design, build, and program functional prototypes (e.g., irrigation systems or environmental monitoring devices), fostering both computational thinking and environmental awareness.

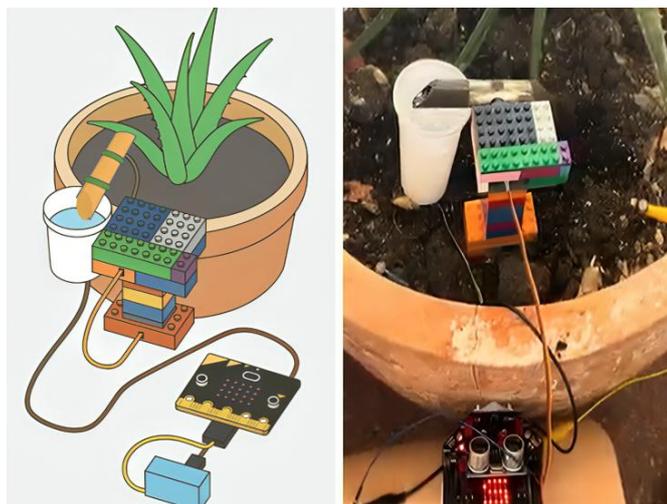


Figure 3. Automatic irrigation machine with servo and micro:bit (https://www.electfreaks.com/learn-en/microbit-kit/iot_kit/IOT_bit_case04.html)

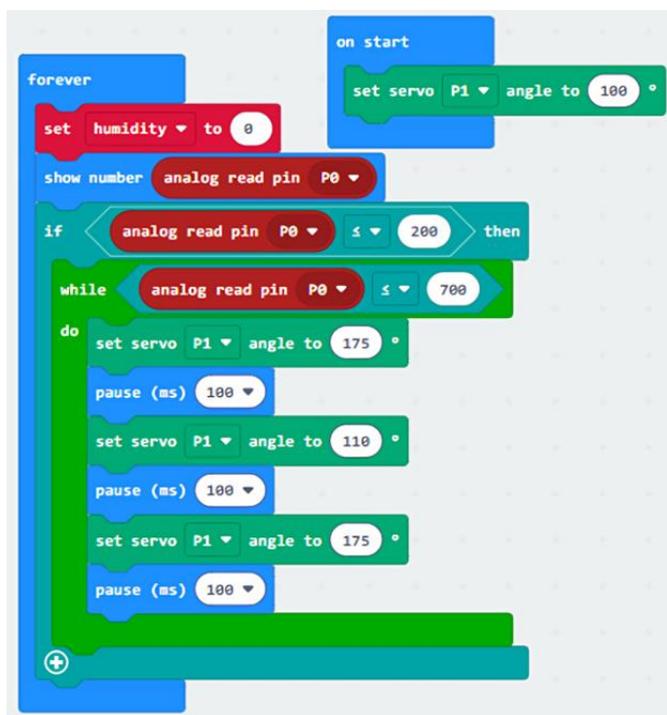


Figure 4. Visual block programming for “dispenser in the garden” (https://www.electfreaks.com/learn-en/microbit-kit/iot_kit/IOT_bit_case04.html)

The objectives of this activity were: to apply the basic principles of block programming to control sensors and actuators, to develop scientific thinking through the design, construction and testing of a technological prototype, to foster attitudes of cooperation, creativity and problem-solving in project-based work contexts, to promote ecological awareness and the responsible use of natural resources, especially water, and to use micro:bit and educational robotics as interdisciplinary learning tools.

These projects (see Appendix A for more detail) enhance problem-solving in code construction and

debugging, logical and analytical thinking, learning about how machines work, and an ecological and environmental vision related to the educational content.

RESULTS

Dimension 1. Knowledge of Computational Concepts and Robotics

For this dimension, an independent samples student’s t-test was applied to the results of the CRT. This 10-item test assesses the implementation of robotics and the acquisition of computational concepts. The means for the 704 students were compared, with a mean pre-test score of 5.6 points and a mean post-test score of 6.4 points. The study measured learning and whether the change was due to the intervention. The statistical analysis allowed us to verify whether there were significant improvements from working on these projects.

The result of the student’s t-test yielded a value ($t = 13.752$; $p = 0.001$) that allows us to conclude that there were significant improvements, indicating that the intervention improved the students’ ability to understand visual programming and robotics. The effect size was determined by a Cohen’s d of 0.518.

Dimension 2. Active Learning in Curricular Areas and the Environment

Descriptive analysis and statistical inference with the Wilcoxon test

Regarding the first scale, computational concepts and Robotics, it is noteworthy that approximately 42.2% of the subjects generated new ideas (1.1). However, there were no statistically significant improvements (p -value = 0.395), and the effect size was small. This suggests that the students did not feel that they had the autonomy or creativity necessary to generate new ideas with these approaches. Therefore, there is evidently a need for guidance and support from the teacher in these types of activities (see Table 2).

The students learned what a loop is (81.4%), the difference between sensors and actuators (93.6%), and how to assemble a robot (97%) (items 1.2, 1.3, and 1.4). This learning is demonstrated in the descriptive statistics after the intervention, with a very high percentage (agree + strongly agree) in all three variables. Statistically significant improvements (p -value below 0.05) were also observed in these three items. The effect size for item 1.2 is small, while for item 1.3 and item 1.4 it is very large.

It is interesting to note that 93.3% of students enjoyed completing the environmental projects through programming (item 1.5), and that statistically significant improvements are obtained. The effect size is very large. Therefore, we interpret this as meaning that students

Table 2. Scales and items, descriptive analysis (%), and Wilcoxon test

Scales	Items	Percentage (%)				Wilcoxon	Effect size
		1	2	3	4		
1. Computational concepts	1. Programming robots gives me new ideas.	15.2	42.6	11.8	30.4	0.395	0.03
	2. I know what a “loop” is.	10.1	8.10	72.4	9.40	0.001	0.34
	3. I can build a robot from parts.	0.60	2.40	17.5	79.5	0.001	0.64
	4. I can distinguish between sensors and actuators.	0.90	5.50	18.2	75.4	0.001	0.61
	5. I enjoy doing environmental projects through programming.	0.70	5.40	15.9	78.0	.001	0.64
2. Areas and robotics	1. You learn a lot with robotics.	0.90	2.60	16.6	80.0	0.001	0.69
	2. You learn a lot of math with programming and robotics.	9.70	14.1	67.9	8.40	0.600	0.01
	3. Programming and robotics help you learn in natural sciences.	0.60	2.70	16.1	80.7	0.001	0.68
	4. Programming and robotics help you learn in social sciences.	9.80	10.7	70.2	9.40	0.844	0.00
	5. Programming and robotics allow you to learn about the environment.	0.90	5.30	17.6	76.3	0.001	0.67
	6. With programming and robotics, the class is more interesting.	0.90	2.60	17.6	79.0	0.001	0.72
	7. With programming and robotics, I feel more active and do more things.	0.90	2.60	17.9	78.7	.001	0.71

Note. 1: Totally disagree; 2: Disagree; 3: Agree; & 4: Totally agree

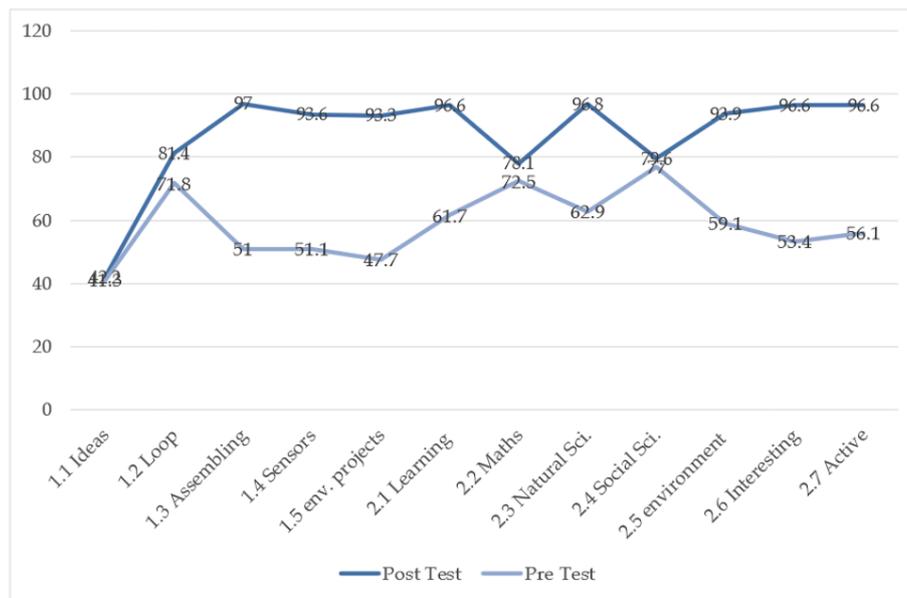


Figure 5. Descriptive values of the pre- to post-test results (Source: Author’s own elaboration)

appreciate these hands-on and motivating environmental projects.

For the second scale, active learning in curricular areas and the environment, 96.6% of the participants believed that one learns a great deal through robotics (2.1).

Regarding learning in natural sciences (2.3) and the environment (2.5), descriptive values above 90% were obtained, showing a statistically significant improvement and a large effect size for both items. This can be interpreted to mean that the intervention, which was heavily focused on ecological projects, has fostered this improvement.

Item 2.6 and item 2.7, which refer to robotics making the class more interesting and active, obtained descriptive values above 95%, with statistically significant improvements and a very large effect size, indicating general agreement among the sample regarding these variables.

Regarding mathematics (2.2) and social sciences (2.4), descriptive values were obtained above 75% of the sample, which is a good result, but they did not show statistically significant improvements, and the effect size was small for both variables. This suggests a highly positive assessment before the intervention, and the intervention did not improve those results (see **Figure 5**).

To calculate the effect size of the Wilcoxon test, the Z-statistic value obtained is used and applied to the formula $r = Z / \sqrt{N}$, where N is the total sample size. A value of 0.1 or below is considered small, 0.3 to show a medium effect, and 0.5 or above a large effect.

DISCUSSION AND CONCLUSIONS

This study highlights some interesting findings regarding the use of robotics in primary education, including the learning of computational concepts, project development and problem-solving skills, and the possibility of coding and learning curricular content through innovative and environmental activities. Integrated planning, with simple and feasible projects, appropriately sequenced and structured, fosters effective work with environmental projects, natural science content, robotics, computational concepts, and problem-solving.

Several precedents and studies analyzing the possibilities of visual block programming in educational contexts can be considered, and these show positive results like those found in our study (Lu et al., 2025; Maya et al., 2015; Mwangi et al., 2022; Ouyang & Xu, 2024).

Based on the study results and considering the information from the two dimensions and the statistical tests analyzed, the following conclusions can be drawn:

1. Students improved their understanding of computational concepts and the technological concepts related to robotics (e.g., sensors and actuators) because of the study intervention. Although the average score obtained was modest (6.4), indicating the difficulty of the content for the participants, statistically significant improvements in learning were evident after the intervention. Therefore, we conclude that an active approach to technological projects improves the ability to tackle projects by solving problems, facilitates the understanding of computational concepts, and promotes the implementation of educational robotics with an environmental perspective (dimension 1).
2. Most students (81.4%) learned the concept of a computational loop by applying this knowledge in their projects. They could also understand and distinguish between the operation of sensors and actuators in their practical exercises (93.6%), and almost all of them could assemble a robot (97%). These variables (1.2, 1.3, 1.4) show statistically significant improvements. Furthermore, most of the children (93.3%) reported enjoying carrying out these environmental technology projects (1.5).
3. On the other hand, the sample shows more modest values for the survey item about generating new ideas (42.2%), and there were no statistically significant improvements (item 1.1).

Therefore, autonomy and creativity in these types of activities are areas for improvement. In this regard, teacher guidance in these activities is considered essential, and future reflection is needed on designing more open-ended activities focused on refining and solving problems to improve this variable related to autonomy and creativity. The results for item 2.2 and item 2.4, which refer to work in the areas of mathematics and social sciences, are also considered improvable. It can be concluded that there is no statistically significant improvement, and the results obtained are modest because the projects are more focused on the environment.

4. Regarding natural sciences and the environment (2.3 and 2.5), there are high descriptive values and significant improvements, indicating that the students found the learning in these subjects and areas satisfactory. Furthermore, the students affirmed that they learned a great deal about robotics (2.1), resulting in a positive outcome and attitude.
5. The students demonstrated, with relevant values and significant improvements, that these approaches kept them working more actively and that they found the approach more interesting (2.6 and 2.7). Therefore, with a selection and sequencing of content, adjusted to the students' prior knowledge and progress, appropriate implementation is feasible, especially in the natural sciences and with environmental projects.

The study concludes that the high scores and significant improvements demonstrate that integrating programming and robotics into classroom environmental projects fosters active learning that is engaging for students. This approach helps them learn computational concepts and problem-solving skills, and develop curricular content, particularly in the natural sciences.

We must consider the possibilities in other curricular areas and the autonomy of students in these complex projects, as well as their capacity to generate new ideas. Ultimately, we should strive to enhance student autonomy and creativity, given the room for improvement in these areas. This will allow us to develop more open-ended interventions in the future, focusing on refining and implementing multiple solutions.

Based on the results of this study, an active approach using environmental technology projects in the natural sciences is considered feasible. This approach fosters integrated, hands-on, and active learning, working with subject content through projects and a motivating and enthusiastic perspective.

While the results indicate an overall improvement in students' achievement, a closer examination reveals

notable differences in learning outcomes across computational concepts and subject-area integrations. These differences can be explained by pedagogical, cognitive, and instructional design factors inherent to the intervention.

Computational concepts such as sequences, loops, and the distinction between sensors and actuators showed significant learning gains because they were explicitly taught, repeatedly practiced, and directly operationalized through hands-on robotics tasks. These concepts were embedded in concrete actions with immediate and observable feedback (e.g., a motor activating in response to a sensor), which aligns with constructionist and experiential learning theories. The tangible nature of these activities reduced abstraction and allowed students to iteratively test, debug, and refine their understanding, thereby reinforcing conceptual learning.

In contrast, subject-area integrations, particularly in mathematics and social sciences, did not yield equally strong or statistically significant improvements. One plausible explanation is that these domains were addressed implicitly rather than as explicit learning targets. While mathematical reasoning (e.g., counting iterations, and setting thresholds) and social science concepts (e.g., agricultural organization or community practices) were present in the activities, they were not systematically foregrounded through explicit instruction, assessment, or reflection. As a result, students may have perceived these connections as peripheral rather than central to the learning experience.

Additionally, the environmental and natural science content benefited from a high degree of conceptual alignment with robotics tasks. Environmental phenomena such as soil moisture, light, and temperature naturally lend themselves to sensor-based monitoring and automated responses, making the integration intuitive and cognitively coherent. This alignment facilitated meaningful learning by enabling students to directly observe cause-effect relationships within authentic ecological contexts.

From a cognitive perspective, the limited gains in some subject areas may also reflect cognitive load constraints. As students simultaneously engaged with programming, hardware assembly, and environmental problem-solving, their attentional resources were primarily allocated to mastering computational and technological challenges. Without targeted scaffolding, this may have limited deeper engagement with secondary curricular domains.

Findings suggest that instructional intentionality plays a decisive role in interdisciplinary integration. Domains in which learning objectives were clearly articulated, scaffolded, and assessed showed stronger outcomes than those addressed incidentally. This underscores the need for future interventions to design

robotics-based activities with explicit, balanced learning goals across all intended subject areas, supported by dedicated reflection and assessment strategies.

There is evidence highlighting the effectiveness and benefits of implementing visual block programming in areas framed within the current curriculum (Brennan & Resnick, 2012) and interactions that support reflection (Kolodner et al., 2003; Papert, 1980). Several studies have found positive results related to attitudes toward computer science and information technology (Lambert & Guiffre, 2009).

Several studies (Kastner-Hauler et al., 2022); Maya et al., 2015) agree on the importance of acquiring basic programming and robotics concepts in elementary education, with interventions achieving significant improvements. The researchers concur that an active pedagogical approach that incorporates robotics (Sáez-López et al., 2019) is needed to understand computational concepts in different curricular areas and to develop innovative educational practices.

In elementary education, several studies agree on the benefits for learning and interaction and the motivating nature of these approaches (Chevalier et al., 2022; Giannakoulas & Xinogalos, 2024; Maya et al., 2015; Noh & Lee, 2020; Rich et al., 2022; Wei et al., 2021; Wong, 2024; Wu, 2021).

Recent studies show positive results for both approaches (block-based programming, Sáez-López et al., 2016) and educational robotics in primary schools, increasing participation, improving certain science-related skills, and fostering positive attitudes toward learning. Block-based coding (MakeCode in this study) is usually implemented through projects that allow for iterative construction, sometimes combined with physical computing (micro:bit in this research).

This reinforces the manipulative component and the connection to real-world phenomena, promoting integrated learning. Kastner-Hauler et al. (2022) demonstrated that combining visual coding and physical devices in primary schools significantly enhances computational thinking skills and conceptual understanding, coinciding with the results of this work.

Both robotics and block coding generate increases in motivation, interest, and participation in the classroom. The immediate feedback and playful nature of these activities improve students' attention and enjoyment, promoting persistence in the face of challenges. We agree with Ouyang and Xu (2024) in their meta-analysis that educational robotics has a moderate positive effect on motivation and attitudes toward learning in science, although these authors found greater improvements in technology and engineering. We also agree with Pedersen et al. (2020) that the benefits depend on the quality of the instructional design.

We concur with Lu et al. (2025) regarding improvements in motivation and experiential learning.

However, some studies have suggested that this increase in motivation may be partly due to a novelty effect when interventions are brief (Pedersen et al., 2020).

Several studies have demonstrated that integrating programming and robotics into science units leads to significant improvements in students’ conceptual understanding. Kastner-Hauler et al. (2022) showed that physical programming tasks (using devices) contribute positively to the development of scientific problem-solving skills. According to the same authors, direct interaction with physical objects enhances the understanding of cause-and-effect relationships and fosters scientific thinking by allowing students to experience and visualize phenomena in a tangible way.

Similarly, Ouyang and Xu (2024) have pointed out that the most sustained effects are observed in longer-term programs with continuous monitoring, in contrast to one-off interventions, which tend to generate temporary or superficial improvements.

Regarding the applicability of each approach, if the main objective is to introduce computational thinking and problem-solving, block coding is more accessible and flexible for students aged between 6 and 10 years old (Kastner-Hauler et al., 2022).

However, recent literature indicates that combining the two approaches—block coding and robotics or physical computing—offers the greatest benefits, as it allows for the abstraction of programming to be united with the concrete manipulation of physical objects (Lu et al., 2025; Ouyang & Xu, 2024).

On the other hand, there are some risks and limitations in implementing these methodologies. Pedersen et al. (2020) warned of the tendency to focus excessively on the technological device without clear curricular integration or well-defined learning objectives.

The literature agrees on a series of recommendations to optimize the impact of these methods: design teaching units that are in line with science curriculum objectives, extend interventions to avoid the novelty effect (Ouyang & Xu, 2024), and investigate the differentiated effects according to the type of robot, the age of the students, and the level of pedagogical support (Kastner-Hauler et al., 2022).

Future research should build on the present findings by addressing the pedagogical and methodological factors that constrained learning outcomes in certain subject areas. Studies should investigate instructional designs that explicitly integrate disciplinary learning objectives, particularly in mathematics and social sciences, within robotics-based projects. Experimental or quasi-experimental designs comparing explicit versus implicit integration strategies would help clarify the conditions under which interdisciplinary learning is most effective.

Future work should explore longer-term and longitudinal interventions to examine whether sustained exposure to educational robotics reduces cognitive load over time and allows students to transfer computational skills more effectively to non-technical domains. Such designs would also help disentangle short-term novelty effects from durable learning gains. Future studies should consider incorporating comparison groups or mixed-method approaches, combining quantitative measures with classroom observations and student interviews, to deepen understanding of how students experience interdisciplinary robotics projects and why certain learning pathways are more successful than others.

Our contribution aligns with most of the key findings regarding improvements in motivation, manipulation and coding of materials, enthusiasm, activity, and iteration, as well as the need for depth and clarity in pedagogical design (which we detail in this paper). We also agree with the advantages of simplicity and visual block-based programming, and the benefits of manipulation highlighted by various authors.

In short, we recommend the implementation of coding and robotics in the design and development of elementary school curricula, integrated with the content of the natural sciences area and with environmental projects, using sequenced, simple, and appropriate activities, and considering students’ needs. Active implementation fosters motivation, enthusiasm, and problem-solving skills, and sparks students’ interest and curiosity.

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AI statement: The authors stated that generative AI tools were used exclusively to improve linguistic quality. All scientific content, interpretations, and conclusions were produced and validated by the authors.

Declaration of interest: No conflict of interest is declared by the authors.

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APPENDIX A: INSTRUCTIONAL SEQUENCE AND LESSON PLANS

This annex provides a detailed description of the instructional sequence implemented during the intervention. The activities were integrated into the regular curriculum of grades 4, 5, and 6 and followed a progressive, scaffolded design grounded in constructionist and project-based learning principles. While all grades addressed the same core concepts, task complexity and autonomy were differentiated according to students’ developmental stages. The instructional sequence progressively increased in complexity while maintaining coherence across grade levels. Programming concepts, robotics construction, and environmental applications were integrated in a manner that supported active learning, reduced cognitive overload, and ensured feasibility within regular classroom practice.

General Structure

The intervention consisted of six instructional sessions of 60 minutes each. Each session followed a common pedagogical structure: conceptual introduction, guided exploration, hands-on construction and programming, and reflection or debugging. Activities combined block-based programming (MakeCode), physical computing (micro:bit), and educational robotics (Nezha and Maqueen kits).

Session 1. Introduction to Programming and Physical Computing

Objectives

Introduce basic programming concepts (sequences and input/output) and familiarize students with the micro:bit board and programming environment.

Activities

Students explored the micro:bit components (LED matrix, buttons, and sensors) and created simple programs to display symbols or messages. Emphasis was placed on understanding linear sequences and immediate program feedback.

Differentiation

Grade 4: Simple sequential programs with predefined blocks.

Grade 5-grade 6: Event-based programs using button inputs.

Session 2. Sensors and Environmental Variables

Objectives

Understand the function of sensors and relate sensor data to environmental phenomena.

Activities

Students programmed the micro:bit to read temperature and light values and discussed their relevance to environmental contexts such as plant growth and energy use.

Differentiation

Grade 4: Single-sensor use with fixed thresholds.

Grade 5-grade 6: Comparison of sensor readings and basic data interpretation.

Session 3. Robotics Assembly and Actuator Control

Objectives

Assemble a basic robotic structure and control actuators (motors or servos) through programming.

Activities

Using Nezha or Maqueen kits, students assembled robots and programmed basic movements or actuator responses linked to micro:bit outputs.

Differentiation

Grade 4: Semi-guided assembly and predefined movement sequences.

Grade 5-grade 6: Modification of structures and experimentation with movement patterns.

Session 4. Conditional Logic and Automated Responses

Objectives

Introduce conditional statements (“if-then”) and apply logic to automated environmental actions.

Activities

Students programmed conditional behaviors, such as activating a servo when a sensor detected low soil moisture or specific light levels.

Differentiation

Grade 4: Single-condition logic.

Grade 5-grade 6: Compound conditions and nested logic with teacher scaffolding.

Session 5. Development of Environmental Projects

Objectives

Integrate programming, robotics, and environmental knowledge and foster collaboration and problem-solving.

Activities

In small groups, students designed and built functional environmental prototypes (e.g., automatic irrigation systems). They tested, debugged, and refined their projects iteratively.

Differentiation

Grade 4: Focus on achieving correct functionality.

Grade 5-grade 6: Emphasis on optimization, efficiency, and justification of design decisions.

Session 6. Presentation and Reflection

Objectives

Communicate project outcomes and reflect on learning processes and sustainability concepts.

Activities

Students presented their projects, explained how sensors and programming supported environmental goals, and discussed challenges and improvements.

Differentiation

Grade 4: Guided oral reflections.

Grade 5-grade 6: Structured written or diagram-based explanations.

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