



From Programming to Action: Educational Robotics for the Development of Computational Thinking and Transversal Skills in Elementary School in Italy

Gabriele Letizia

Teacher and Electronic Engineer Primo Istituto Comprensivo A. Moro – P. Virgilio Marone, Italy

Email: scholar@primocomprensivofrancavilla.edu.it

Abstract

Educational robotics provides a particularly meaningful learning environment for introducing elementary school students to the principles of programming and computational thinking through concrete, collaborative, and problem-solving-oriented experiences. This paper describes a teaching experience carried out with a fourth-grade elementary school class as part of a workshop program aimed at developing skills in programming, robotics, and problem solving at Primo Istituto Comprensivo “A. Moro – P. Virgilio Marone” in Italy.

The program progressively guided the students from learning about the MicroBit board and visual block-based programming to using sensors, motors, and actuators, and finally to designing algorithms for line following and obstacle detection. The activities took place in the computer lab, alternating between individual work and small-group activities.

The methodological framework integrated active and experiential learning, a constructivist approach, problem solving, cooperative learning, the inductive method, and progressive scaffolding. The program was designed with a progression of increasing difficulty, in which each activity served as a prerequisite for the next. The observed results highlight a solid acquisition of the intended technical skills, a significant development in problem-decomposition and analysis abilities, and increasing autonomy during the debugging phase. Positive results also emerged in collaborative skills, peer communication, and error management. The experience confirms the potential of educational robotics as a teaching tool capable of making abstract concepts concrete and integrating digital, cognitive, and social-relational skills.

Keywords

educational robotics; elementary school; computational thinking; block-based programming; MicroBit; problem solving; cooperative learning; scaffolding.



1. Introduction

The integration of digital technologies in schools cannot be reduced to the mere use of devices or applications. Rather, the central issue concerns how these tools are incorporated into instructional design and used to promote meaningful cognitive processes.

From this perspective, educational robotics offers a particularly compelling environment because it allows the abstract dimension of programming to be linked to concrete, observable, and modifiable behavior. An algorithm is not confined to the screen: it produces a robot's movement, the lighting of an LED, a response to an obstacle, or the ability to autonomously follow a path.

This characteristic takes on particular significance in the development of computational thinking. Wing (2006) proposed computational thinking as a set of skills and attitudes useful for solving problems, designing systems, and understanding behavior, emphasizing its relevance far beyond the field of computer science. In elementary school, robotics can therefore provide a context in which concepts such as sequencing, conditionals, algorithms, debugging, and design can be explored through hands-on activity. A recent systematic review focused on educational robotics and computational thinking among young learners identified sequencing, conditionals, loops, debugging, and algorithmic thinking as the skills most frequently addressed in the interventions analyzed (Ching & Hsu, 2023).

The experience described in this article stems from the desire to use robotics as a tool to introduce elementary school students to computational thinking not understood exclusively as the ability to program, but as a way of analyzing, breaking down, and solving problems.

2. Methodology

The program draws its primary theoretical foundation from the constructivist approach developed by Papert (1980), according to which the use of computers can become particularly meaningful when it allows children to construct artifacts, develop ideas, and reflect on their own thought processes. *Mindstorms*, published in 1980 by Basic Books, is one of the seminal works in the development of this perspective. Educational robotics represents an evolution that is particularly consistent with this approach: the child is not merely a recipient of digital content but becomes the designer of a system capable of interacting with the environment.

The literature on educational robotics in elementary school highlights the role of robotics activities in the development of STEM skills, problem-solving, and active student participation (Tselegkaridis & Sapounidis, 2022). The systematic review conducted by the authors analyzed 36 studies on educational robotics and STEM in elementary school, also taking into account objectives, activities, tools, and assessment methods.

Robotics can therefore be interpreted as a learning environment in which students construct knowledge through interaction with a programmable device.

A second point of reference is Dewey's (1938) experiential perspective. Learning takes on meaning when experience is not viewed merely as doing, but becomes an opportunity for observation, reflection, and reworking. The book *Experience and Education*, published by Macmillan in 1938, is a classic text in experiential pedagogy. In robotics education, this dimension is particularly evident: the student programs the robot, observes the resulting behavior, identifies any discrepancies from the expected outcome, and modifies the program. The cycle of experience-observation-reflection-revision thus becomes an integral part of learning. Furthermore, robotics programming allows for the practical



application of certain fundamental elements of computational thinking. Students must break down a problem, identify a sequence of actions, recognize conditions, predict behaviors, and correct errors. The systematic review by Ching and Hsu (2023) confirms the centrality of these skills in educational robotics aimed at young learners and also highlights the widespread use of strategies such as collaborative learning, project-based learning, and embodied learning. In this sense, the robot serves as a mediating device between abstract reasoning and physical reality: the algorithm designed by the student becomes observable behavior.

2.1 Context and Objectives of the Experience.

The program was carried out with a fourth-grade elementary school class as part of the hands-on activities conducted in the computer lab.

Students worked both individually and in small groups, tackling activities that became progressively more complex.

The overall goal was to introduce the children to educational robotics and programming through a hands-on, meaningful, and progressive experience. The specific objectives were:

- to understand the difference between computers and robots;
- to learn about the structure and main functions of the MicroBit board;
- to acquire the fundamentals of visual block-based programming;
- to understand the relationship between input, processing, and output;
- to use sensors to gather information from the environment;
- control the robot's motors and movements;
- understand how conditional logic works;
- design simple line-following algorithms;
- use an ultrasonic sensor to detect obstacles;
- develop debugging strategies;
- break down complex problems into subproblems;
- develop independence in designing and testing solutions;
- foster collaboration, technical communication, and positive error management.

The objectives were therefore not exclusively technical or operational in nature, but also included cognitive and social-relational skills.

2.2 Tools and Learning Environment

The main technological component was the MicroBit board, used in combination with the Maqueen Lite educational robot. Programming was carried out using Microsoft MakeCode, a visual block-based programming environment that allows users to focus on the logic of the instructions while reducing, in the initial stages, the cognitive load associated with the syntax of a text-based language.

The tools enabled students to work with:

- 1.a LED matrix;
- 2.buttons A and B;
- 3.an accelerometer;



- 4.temperature sensor;
- 5.light sensor;
- 6.sound generator;
- 7.motors;
- 8.robot LEDs;
- 9.infrared sensors;
- 10.ultrasonic sonar sensor;
11. external servomotor.

The decision to use a programmable robot made it possible to establish a direct relationship between code and physical behavior.

2.3. Course Structure

The course was organized according to a progression of increasing difficulty.

2.3.1 The Digital Brain

The first phase introduced the distinction between computers and robots and allowed students to become familiar with the MicroBit. The LED matrix, block-based programming, and the board's main features were explored. Students experimented with the relationship between instructions and results, gradually understanding that the device executes the instructions it receives according to the programmed sequence.

2.3.2 The Robot's Senses

The second phase focused on the MicroBit's sensors. The accelerometer, temperature sensor, light sensor, and buttons were used to build simple interactive devices.

Using the metaphor of "senses" helped students understand the role of sensors within a robotic system. The robot was thus gradually interpreted as a system in which different components perform complementary functions: information acquisition, processing, and response.

2.3.3 Motors and Movement

The next phase involved integrating the MicroBit with the Maqueen Lite. The students experimented with moving forward, backward, and rotating, as well as controlling the robot's LEDs. The transition from programming on-screen output to controlling a physical object was a significant milestone: the code became immediately observable through movement.



2.3.4 Precision and Line Following

The next phase introduced infrared sensors and black-and-white contrast detection. The students designed line following algorithms using conditional structures. The activity helped them understand that the robot does not necessarily have to follow a completely predetermined sequence but can modify its behavior based on information received from the sensors.

2.3.5 Navigation and Obstacle Detection

The introduction of the ultrasonic sonar sensor made it possible to address the challenge of autonomous navigation. The robot had to detect the presence of an obstacle and, depending on the distance, decide whether to brake, steer, or continue. This task required the integration of detection, processing, and action, reinforcing the students' understanding of conditional structures.

2.3.6 Advanced Problem Solving

In the advanced phase, students worked on refining the algorithms. The goal was no longer simply to achieve functional behavior, but to improve its precision, stability, and effectiveness. Debugging became an integral part of the process: errors were interpreted as useful information for understanding the system's behavior. This approach is consistent with the literature on educational robotics, in which debugging is identified as one of the computational thinking skills frequently developed through robotics activities (Ching & Hsu, 2023).

2.3.7 ROBOMINDS and Final Test

The program concluded with the ROBOMINDS Grand Prix, a challenge on a mixed course in which students had to integrate the skills developed during the various phases. The test included elements of movement, line following, and obstacle detection. The final challenge served as a culmination of the program but also provided an opportunity to observe the skills acquired.

3. Methodological Framework

The program adopted an active, experiential, and student-centered instructional approach. This methodological choice is supported primarily by the literature on active learning. Prince (2004), in a review of the research, highlights generally positive, though not uniform, support for the characteristic elements of active, collaborative, cooperative, and problem-based learning.

- *Learning by Doing and Experiential Learning*

Each concept was introduced through a concrete situation. Knowledge of sensors, motors, and logical conditions was built through direct experimentation. Practical experience served as the starting point for the subsequent formalization of the concepts. This approach is linked to the conception of educational experience developed by Dewey (1938) and to Papert's (1980) constructivist perspective.

- *Problem Solving*

The activities were structured as problems. Students had to identify the desired behavior of the robot, formulate a strategy, translate it into instructions, verify the result, and make adjustments to the



program. The general model follows the problem-solving tradition described by Pólya (1945): understand the problem, devise a plan, implement it, and review the result.

In the robotics lab, this process takes the following form:

problem → hypothesis → algorithm → test → observation → debugging → revision.

- *Cooperative Learning*

Working in small groups fostered collaboration and peer communication. The design of the activities allowed students to take on different roles related to programming, assembly, observation, and verification. The choice of cooperative learning is consistent with the literature on cooperative learning developed by Johnson, Johnson, and Holubec (1998), who systematized the principles and practices of cooperative learning. In research on educational robotics for young learners as well, collaborative learning ranks among the most widely used instructional strategies (Ching & Hsu, 2023).

- *Inductive Method*

The fundamental concepts of robotics were derived from experience. The students observed the robot's behavior, formulated hypotheses, and subsequently generalized the patterns they identified. This approach is consistent with the inductive approaches described by Prince and Felder (2006), in which learning begins with observations, concrete examples, or problems and subsequently leads to the formalization of concepts. In the course, for example, the concept of a condition was not presented exclusively as a syntactic structure, but emerged from the need to make the robot react to different situations.

- *Progressive Scaffolding*

The course was structured according to a gradual progression:

Each phase drew on previously acquired skills while introducing a new element of complexity. The concept of scaffolding is classically referenced in the work of Wood, Bruner, and Ross (1976), which analyzes the role of tutoring in supporting children as they solve problems.

MicroBit → sensors → motors → line following → obstacle detection → advanced problem solving.

Throughout the process, the teacher's support was gradually reduced as the students became familiar with the tools and procedures.

3. Results and Discussion

The experience was evaluated through observation of lab activities, the projects created, student behavior during individual and collaborative work, and the final assessment. The results were analyzed across four dimensions: technical and digital skills, computational thinking, collaborative skills, and autonomy.

All students achieved a good command of the MakeCode environment and were able to program the MicroBit independently. The vast majority of the group successfully developed line-following and obstacle-detection algorithms. The students demonstrated a concrete understanding of the role of sensors and the relationship between detected information and the robot's behavior.



This result is particularly significant when compared to the literature, which identifies educational robotics as an environment conducive to the development of sequencing, conditionals, debugging, and algorithmic thinking (Ching & Hsu, 2023).

Cognitively, the students developed the ability to break down a complex problem into simpler subproblems.

They gradually became capable of:

- identify relevant variables;
- formulate hypotheses;
- design sequences of instructions;
- use conditions;
- systematically test solutions;
- interpret errors;
- modify the code based on the results.

The advanced problem-solving session showed that the students had acquired not only operational procedures but also a working method. This result is consistent with studies that identify educational robotics as a concrete context for the development of computational thinking (Ching & Hsu, 2023; Bers et al., 2014).

In terms of cross-curricular skills, a significant development in collaboration skills was observed. Working in small groups required students to explain their own hypotheses, listen to those of their peers, compare strategies, and make shared decisions.

A growing ability to use technical language to describe problems and solutions also emerged.

The literature on educational robotics highlights precisely the importance of the collaborative and social dimensions associated with robotics activities (Ching & Hsu, 2023).

A particularly significant finding concerned autonomy: when faced with unexpected robot behavior, students gradually learned not to turn immediately to the teacher, but to consult with group members, analyze the code, and formulate hypotheses. Errors were gradually reinterpreted as a natural part of the design process. This aspect is particularly consistent with the concept of debugging as a component of computational thinking, which is frequently present in educational robotics activities (Ching & Hsu, 2023).

The work atmosphere remained consistently positive, characterized by enthusiasm, curiosity, and active participation.

The ability to immediately observe the results of their decisions served as a key motivational factor.



The final challenge also introduced a competitive element that remained within the context of positive competition among the groups. During the ROBOMINDS Grand Prix, the robots demonstrated significant levels of autonomy and precision, considering the students' grade level and the introductory nature of the experience.

At the end of the challenge, a guided reflection session was held: each team discussed the difficulties they faced, the strategies they adopted, and the progress they made.

The results of the experience suggest that the educational value of robotics does not lie exclusively in the acquisition of technical skills. The robot functioned as a cognitive mediator, making the relationship between thought, algorithm, and behavior visible. When the robot fails to follow a line correctly, misinterprets an obstacle, or performs an unexpected rotation, the error takes on a concrete dimension. The student can observe the result, compare it with the expected outcome, and seek an explanation. This feature makes the integration of experiential learning, problem-solving, and debugging particularly effective. Robotics also allows for the creation of an environment in which the child can take an active role in the construction of knowledge, in line with Papert's (1980) constructivist perspective.

Another point of interest concerns the collaborative aspect. Group work was not merely an organizational approach but also served as a cognitive resource: discussing a solution, comparing two algorithms, and explaining to a classmate why the robot behaves in a certain way requires students to rethink their own ideas. The available literature generally supports the relevance of such approaches. Systematic reviews on educational robotics in elementary school, in fact, reveal a significant variety of activities, tools, and objectives, confirming the widespread use of robotics as a setting for STEM and problem-solving activities (Tselegkaridis & Sapounidis, 2022).

4. Conclusion

The experience described highlights how educational robotics can serve as an effective learning environment for elementary school when integrated into a progressive and methodologically sound instructional design. The use of MicroBit and Maqueen Lite allowed students to gradually progress from understanding simple instructions to designing autonomous behaviors based on interaction with the environment.

However, the main outcome of this experience is not merely the ability to program a robot.

The most significant educational value lies in the development of a design-oriented and reflective mindset: understanding a problem, breaking it down, formulating a hypothesis, transforming it into an algorithm, verifying the result, identifying the error, and modifying the solution. Educational robotics thus brings computational thinking to life and, at the same time, offers opportunities to develop autonomy, collaboration, communication, perseverance, and the ability to deal positively with errors. From this perspective, the robot is not merely the object of learning but becomes a tool through which to learn.

Future developments could include the introduction of systematic tools for assessing computational thinking, the use of observational rubrics, and the collection of pre- and post-intervention data, thereby supplementing the qualitative evidence already gathered with quantitative indicators.



Ultimately, experience suggests that the transition from programming robots to programming the mind constitutes one of the most pedagogically interesting aspects of educational robotics in elementary school.

References

1. Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry*, 17(2), 89–100. <https://doi.org/10.1111/j.1469-7610.1976.tb00381.x>
2. Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, 72, 145–157. <https://doi.org/10.1016/j.compedu.2013.10.020>
3. Ching, Y.-H., & Hsu, Y.-C. (2023). Educational robotics for developing computational thinking in young learners: A systematic review. *TechTrends*. <https://doi.org/10.1007/s11528-023-00841-1>
4. Dewey, J. (1938). *Experience and Education*. Macmillan.
5. Johnson, D. W., Johnson, R. T., & Holubec, E. J. (1998). *Cooperation in the Classroom* (7th ed.). Interaction Book Company.
6. Papert, S. (1980). *Mindstorms: Children, Computers, and Powerful Ideas*. Basic Books.
7. Pólya, G. (1945). *How to Solve It: A New Aspect of Mathematical Method*. Princeton University Press. <https://doi.org/10.2307/j.ctvc773pk> JSTOR
8. Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, 93(3), 223–231. <https://doi.org/10.1002/j.2168-9830.2004.tb00809.x>
9. Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education*, 95(2), 123–138. <https://doi.org/10.1002/j.21689830.2006.tb00884.x>
10. Tselegkaridis, S., & Sapounidis, T. (2022). Exploring the features of educational robotics and STEM research in primary education: A systematic literature review. *Education Sciences*, 12(5), 305. <https://doi.org/10.3390/educsci12050305>
11. Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, 49(3), 33–35. <https://doi.org/10.1145/1118178.1118215>
12. Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry*, 17(2), 89–100. <https://doi.org/10.1111/j.1469-7610.1976.tb00381.x>