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The Impact of Educational Robots as Learning Tools in Specific Technical Classes in Undergraduate Education

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***Abstract*—The use of mobile robots in the classroom has gained increasing attention in recent years due to their potential to enhance student engagement and facilitate personalized learning. This research presents the insertion of mobile robots as a hands-on learning experience in Control and Servomechanisms II and Signal Processing II classes. This work also addresses the challenges and limitations of using mobile robots in the classroom, including technical difficulties. The students were evaluated during the code implementation in the practical exercises. Besides, a form was provided to them in order to assess the impact of these robots as part of the pedagogical practice. From the students' positive feedback, it was possible to conclude that the mobile robots were well-accepted. Besides, the robots enhanced Control Systems classes and improved students' learning outcomes.**

***Index Terms*—Robotics, Project-based Learning, Control Systems, Signal Processing, Education.**

I. Introduction

Robotic tools have become increasingly popular in education over the past few years [1], [2]. One of the reasons is the benefits that robotics can offer to the classroom, such as bringing students to real-world applications and hands-on learning, among others [3]. Integrating robotics into education provides a multifaceted approach to pedagogy, revolutionizing how students engage with complex concepts and real-world applications. By incorporating robotic tools into learning environments, educators can bridge the gap between theoretical knowledge and practical implementation, fostering a dynamic and experiential learning journey. In this sense, in the last decades, several educational kits emerged in the market to help students with robotics projects in the classroom and even in scientific and technological initiation projects. However, a major problem with these kits is that, due to rapid technological advancement, educational kits can quickly become obsolete [4]. It is also important to highlight that these educational modules should encourage students' development in various fields [5].

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One of the objectives of this project is to describe the experience of introducing a few simple mobile robot tools. These robot tools are used as an educational practice to the theory of Control and Servomechanisms II, and Signal Processing II classes. Both classes are included in the curriculum of the Electronic Engineering course at CEFET-RJ. Hands-on activities can help expose students to robotics technology and provide them with opportunities to develop their skills and interests in this field [6]. Control Systems classes are an essential part of the educational system, and their effectiveness in teaching students can significantly impact their academic success. The use of technology in education has gained increasing attention in recent years, with mobile robots being one of the emerging tools in this field [7].

Mobile robotics stands out in the execution of many different tasks, such as cleaning, surveillance, verification, and human support [8], [9]. Despite the numerous publications and technological developments, several problems performed simply by humans are complex for robots [10]. Thus, the industry and the research area are sheltered from specialized labor. The introduction of robots in these two CEFET-RJ subjects has as one of the main objectives to allow students to improve their programming skills. This fact is crucial since programming languages are becoming increasingly important in various industries in today's technology-driven world.

According to [11], many undergraduates do not have any programming experience. They start learning programming in a single context before learning structure and style. This can lead to a negative programming habit, affecting the flexibility of learning another language in a different context. In this way, employing practices more connected to the current world could help motivate and improve programming skills, especially for engineering undergraduate students.

As stated by [12], mobile robots comprise several concepts that include different fields, such as algebra, probability, statistics, calculus, discrete mathematics, programming, or artificial intelligence [13]. These fields are present in Science, Tecnology, Enginnering and Mathematics (STEM) education programs [14], [15]. Thus, these robot kits can significantly impact STEM education in undergraduate programs by encouraging hands-on learning, developing problem-solving skills, fostering creativity and innovation, and improving teamwork. Therefore, this research explores the insertion of educational robots as learning tools for two classes in undergraduate education: (i) Control and Servomechanisms II; and (ii) Signal Processing II. In the first class, the students need to assemble the robot and program a classical PID so that the robot performs a specific task. In the second class, the robots will have on top of them an ArUco Marker so that the students will create an algorithm to track the robots using image processing. The main goals expected with this project can be summarized as:

- Developing practical skills in programming and assembly of the electronics components in the robots;
- Gaining hands-on experience in deploying algorithms in a robotic platform;
- Enhancing their problem-solving and critical thinking skills.

The rest of this paper is divided as follows. Section II gives the methodology and the objectives outlined in the insertion of the prototypes in the cited subjects. Section III presents the results and the discussion for implementing this pedagogical practice. Finally, the concluding remarks are given in Section IV.

II. Methodology and Experimentation

The necessary instructions and information are given as worksheets and explanations so that the students can start programming the sensor readings and motors even with little programming knowledge. In order to enable the students to work with these robots, the project was composed of small tasks:

1) Assembly the robots with the necessary instruction;
2) Study the embedded electronics of the robots, including sensors and actuators;
3) Create a C language program to drive and control the robots. Note that this is a task for the students enrolled in the Control and Servomechanisms II classes.
4) Track the robot's path through an ArUco Marker placed on the top of the mobile robots. Note that this is a task for the students enrolled in the Signal Processing II classes.

Note that the ArUco markers are visual fiducial markers that can serve as essential tools for the hands-on exploration of mobile robots within the educational framework. Placed at the top of the robots, these markers enable students, particularly those enrolled in Signal Processing II classes, to delve into the practical applications of image processing. By tracking the robot's trajectory through these markers, students gain a tangible understanding of how sensor data and image processing algorithms interact to navigate and interpret their environment.

The following materials were used to assemble the robots: (i) One Arduino UNO board; (ii) One driver for the L298N engine; (iii) One structure for attaching sensors and wheels; (iv) Two DC motors with gearbox; (v) Two wheels for DC motor; (vi) One universal wheel; (vii) One 9V battery connector; (viii) One 9V battery; (ix) Connection jumpers; (x) Sensors; (xi) One mini protoboard; (xii) Screws.

The materials used to recognize and track ArUco Marker were (i) a Python 3 compiler, (ii) the OpenCV library, and (iii) a web camera.

A. Using the robots in Control and Servomechanisms II

In Control and Servomechanisms II classes, each team is formed by five students. Each team has the following objectives:

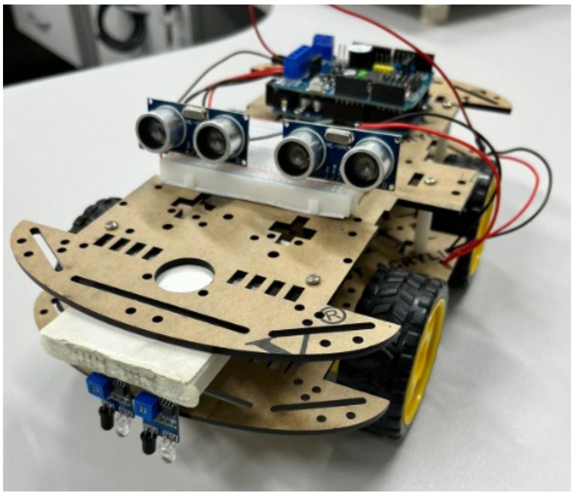
- **Team 1:** Line follower four-wheel robot
  Objective: Follow a line on the ground smoothly using two infrared sensors and implementing a PID controller to adjust the movement;
- **Team 2:** Object-following two-wheeled robot using ultrasonic sensors
  Objective: Follow an object smoothly using two ultrasonic sensors and implementing a motion adjustment PID controller;
- **Team 3:** Object tracking two-wheeled robot using infrared sensors
  Objective: Follow an object smoothly using two infrared sensors and implementing a PID controller for motion adjustment
- **Team 4:** Two-wheeled robot that avoids obstacles
  Objective: Avoid an obstacle using two ultrasonic sensors and implement a PID controller to adjust the movement.

Due to subjectivity, complexity, limited assessment tools, and time constraints, evaluating students' learning in robotics and programming can be challenging. Therefore, a combination of assessment tools was used to assess students' learning. The first assessment was through weekly meetings of the classes. In this sense, it was possible to verify and help the task execution. The second way to understand the student's progress was to give them small tasks to complete, as shown in Table I. The varying scores assigned to tasks within the evaluation process reflect the tasks' diverse complexities and learning outcomes. Fundamental tasks, like ”Reading the sensors and driving motors,” are weighted at 5 points, while more intricate challenges, such as ”Implementing the PID,” carry 10 points. Collaborative efforts receive 10 points for ”Accomplishing the group tasks,” and comprehensive understanding is assessed with 15 points for the ”Report” task. Encouraging creativity, the ”Extra features” task is worth 5 points. This well-rounded scoring approach accommodates different skill levels and underscores comprehensive assessment in robotics and programming education.

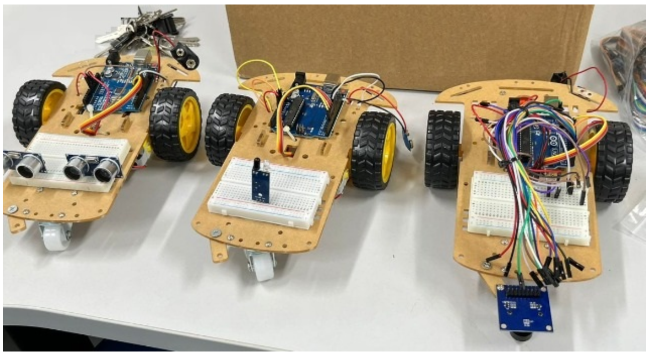
TABLE I
TASKS AND SCORE

Task	Score
Reading the sensors and driving motors	5 points
Implementing the PID	10 points
Accomplishing the group tasks	10 points
Report	15 points
Extra features	5 points

The assembled robots can be seen in Figure 1. Note that there are three robots with two wheels and one robot with four wheels. The students also formed teams and began to discuss the robots assembling and programming during the class of Control and Servomechanisms II, as shown in Figure 2.

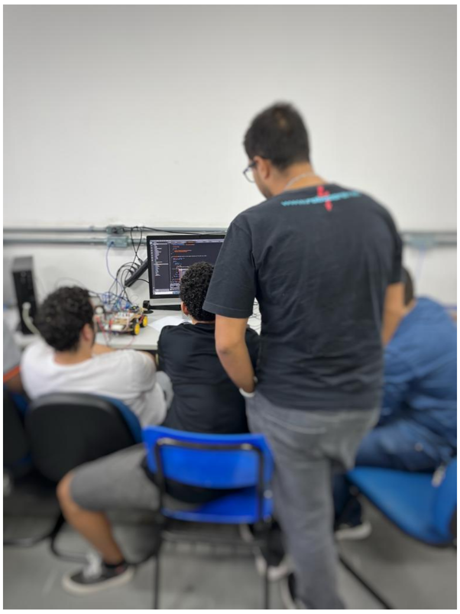


(a) Four wheels connected to a DC motor.



(b) Universal wheel and two wheels connected to a DC motor.

Fig. 1. Mobile robots.



(a)

(b)

Fig. 2. Students are discussing the robot assembling and programming - Control and Servomechanisms II class.

B. Using the robots in Signal Processing II

The built robots are still in the application phase in the Signal Processing II subject. This subject is dedicated to teaching image processing. Image processing, in turn, plays a crucial role in various robotics applications [16], [17]. In this sense, an effective way to enhance students' understanding and practical skills in this field is through engaging classroom exercises. The developed robots are used as a practical exercise to offer hands-on learning experiences.

The idea was to have the robots equipped with ArUco Markers, as shown in Figure 3. Currently, the students are still developing image-processing techniques for ArUco Marker detection. The students used OpenCV, an open-source computer vision library, to recognize ArUco Markers in videos they took from the robots.

ArUco Markers are a type of fiducial marker that consists of a black square with a white pattern inside. They can be used for pose estimation, camera calibration, and augmented reality applications. The students followed a tutorial explaining how to install OpenCV, detect ArUco Markers using the cv2.aruco module, and draw the detected markers on the original image [18].

They also experimented with different parameters and settings to improve the detection accuracy and robustness of the detection and tracking algorithm. The ArUco Marker on the robot's top requires algorithms such as thresholding, contour detection, morphological filters, and image subtraction to identify the marker's position and orientation in each frame. The tracking is achieved by comparing consecutive frames and estimating the marker's displacement, velocity, and orientation. The choice for ArUco Markers is due to the reason that they are widely used in computer vision for visual tracking and pose estimation [9].

III. Results and Discussions

A lot of benefits emerge with this type of tool. As an example, this kind of robot can be used to facilitate group work. The students need to interact with each other to find solutions, both for programming and assembling. While using mobile robots in the classroom has many potential benefits, some challenges and limitations must be addressed. The cost of purchasing and maintaining mobile robots can be a barrier for some schools. Technical difficulties, such as connectivity issues or malfunctions, can also be a concern. Privacy concerns

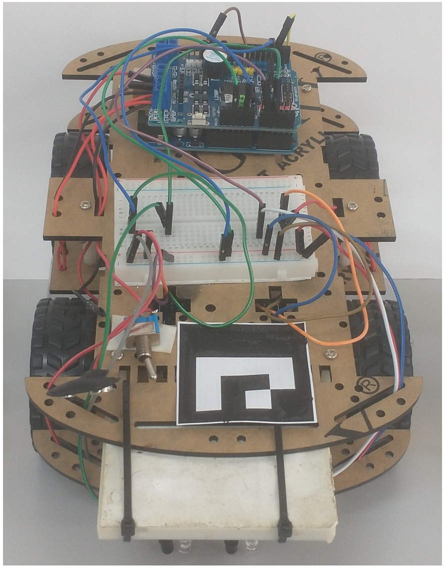


Fig. 3. ArUco Marker placed on the top of the prototype robot.

may also arise if mobile robots have cameras or other sensors that collect students' data.

A. Prototype costs

Intending to reproduce this work, Table II presents the total cost of the electronic components used in the final prototype, including all the sensors. However, it is necessary to note that wires and screws were not considered. Figure 4 presents the final built prototypes.

TABLE II
APPROXIMATE VALUE FOR PROTOTYPE CONSTRUCTION

Item	Price [R$]
Arduino UNO	100,00
Robot chassis with DC motors and wheels	80,00
Driver for the L298N engine	27,90
Sensors	32,00
9V battery	13,00
9V battery connector	4,00
Mini protoboard	15,00
Total	***271,90***

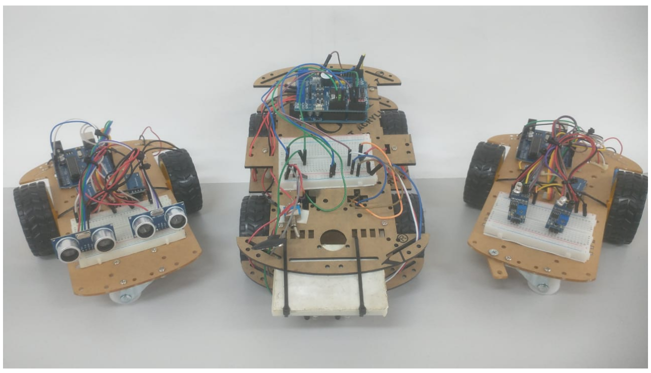


Fig. 4. Assembled final prototypes.

B. Evaluation form

After the practical classes with the robots, a form was developed to collect feedback from students about the pedagogical practice done in the classroom. The questions contained in this form are:

1) What is your programming skill level?
(Low, Average, Good, Excellent)
2) What is your skill level in hardware and electronic components?
(Low, Average, Good, Excellent)
3) Does the application of a robot as a practical part help you to understand the subject?
(Yes, No, Prefer not to answer)
4) Does the work being given in a group helps you to interact with other students in the class?
(Yes, No, Prefer not to answer)
5) How can the inclusion of robots in the discipline contribute to the professional training of students?
(Allows the practical application of theoretical concepts, Favors the development of technical skills, Promotes teamwork, All above)
6) In your opinion, what is the impact of the use of robots in the discipline?
(Improves the quality of teaching, It makes no difference in the learning process, Difficult due to technical part)
7) Did the use of robots in the course makes the learning process more interesting and motivating?
(Yes, No, Prefer not to answer)
8) What could be improved in relation to practice? (Suggestions)

Even if 25 students were currently enrolled in the course, only six students answered the form. For questions 3, 4, and 7, the students responded positively (Yes). For question 5, five students answered "All above," and one answered, "Allows the practical application of theoretical concepts." For question 6, five students answered, "Improves the quality of teaching," and one answered, "Difficult due to the technical part." Figures 5-8 give the rest of the answers collected employing the form.

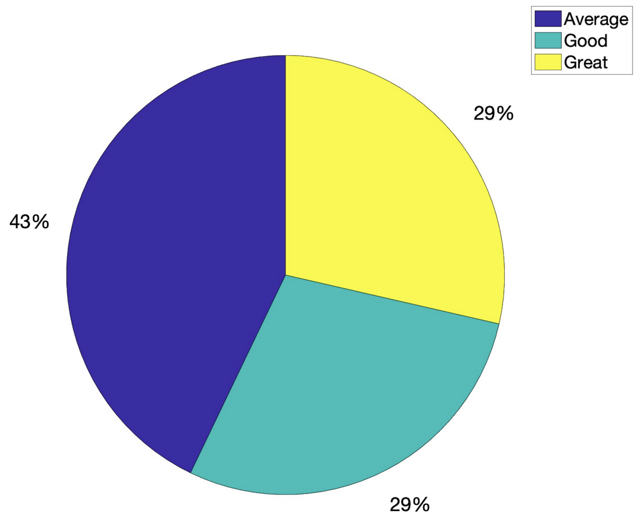


Fig. 5. Answer for question 1: "What is your programming skill level?"

For the last question, "What could be improved in relation to practice? (Suggestions)", students were invited to respond freely with suggestions for improvements. Most comments concerned the need for more time to work on the robot. Other suggestions were to use LiPo batteries to not depend on the

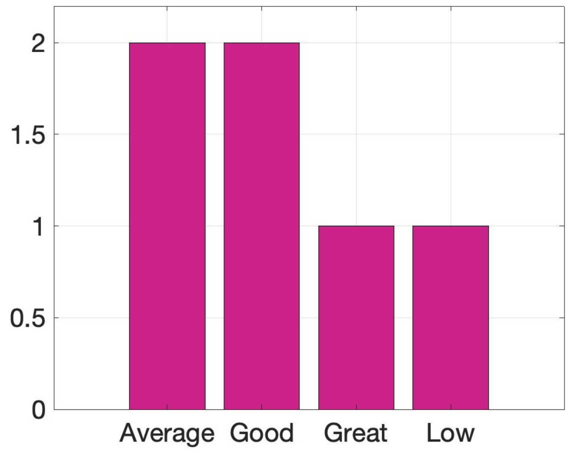


Fig. 6. Answer for question 2: "What is your skill level in hardware and electronic components?"

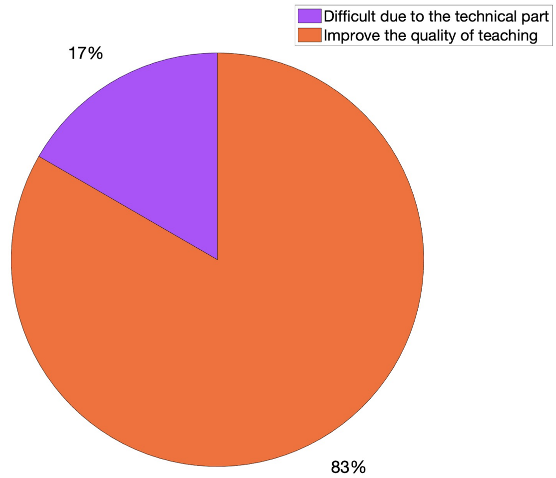


Fig. 8. Answer for question 6: "Did the use of robots in the course makes the learning process more interesting and motivating?"

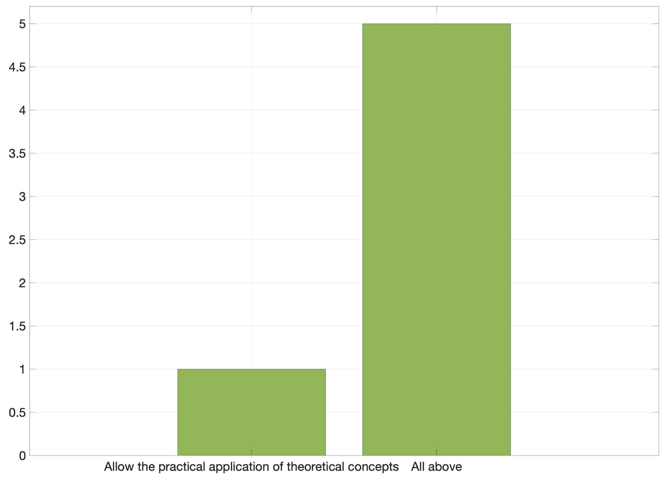


Fig. 7. Answer for question 5: "In your opinion, what is the impact of the use of robots in the discipline?"

bench source when dynamically testing the robot, and to put the students to assemble the robot. All comments are valid to improve this practice in further classes. It is important to note that the form does not contain the response of the entire class. However, from the answers obtained, it is possible to verify that the pedagogical practice adopted is well-received and valued by the students. Positive feedback demonstrates that students are satisfied and appreciate the teaching methods.

C. *Possible applications in other classes*

The methodology of this work consisted of developing a mobile robotic platform for experimental tests. The main objective is the possibility of being used in practical classes, such as the use presented in Control and Servomechanisms II and Signal Processing II classes.

The communication and control interfaces are user-friendly and compatible with industry standards. This approach allows students to experience electronic components that are simple and easy to understand. The main idea is that students can develop the necessary skills and acquire knowledge to reinforce the concepts and practices that are usually required by the industry. Currently, the control technique is used in several engineering problems due to its importance in the industry.

Thus, the prototypes can be selected for practices in the most diverse disciplines. Table III presents some fields where the prototypes can be applied.

TABLE III
POSSIBLE APPLICATIONS OF THE PROTOTYPE IN OTHER CLASSES.

Classes in CEFET-RJ	Possible Topics
Control and Servomechanisms I	Controllers and system modeling
Signal Processing I	Signal sampling and digital signal processing
Electronic Instrumentation	Measure speed and position
Microcontrollers I e II	Microcontroller programming
Digital Systems	Applications and read sensors

IV. CONCLUSIONS AND FUTURE WORK

Using mobile robots in the classroom can enhance Control Systems classes and significantly improve students' learning outcomes. Mobile robots are important in STEM due to the possibility of providing an engaging and hands-on way for students to learn and apply key concepts in science, technology, engineering, and mathematics. Students can develop critical problem-solving, communication, collaboration skills, creativity, and innovation by working with mobile robots. The obtained results showed that these kits are an effective tool for promoting STEM education. However, some challenges and limitations must be addressed, such as costs and technical difficulties. Further research is needed to fully understand mobile robots' impact on Control Systems classes and develop best practices for their use in the classroom.

The study incorporated a feedback form to gather insights from students regarding the pedagogical approach employed during the practical robotics classes. This form contained a series of questions addressing aspects like programming and hardware skills, the impact of robotics applications, the effectiveness of group work, and the overall influence of robotics on the learning experience. However, for future improvement, a more robust and systematic approach to feedback collection could be considered. Implementing a well-structured pedagogical assessment tool, possibly involving pre- and post-course evaluations

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