# Evaluation of students' performance in the development of interactive robots with Arduino

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**Abstract**

Robotics and technology play an increasingly important role in human development, especially in education. This article presents the use of robotic prototype projects as a learning tool in higher education, with the aim of fostering creativity, logical thinking, robot programming, teamwork and problem solving. An experimental methodology was used through learning activities with the participation of 100 students, who were evaluated using rubrics and a quantitative analysis. The results show significant differences in student performance according to the group to which they belong, highlighting the influence of pedagogical strategies, prior skills and environmental conditions on learning. These differences indicate that students' ability to achieve the objectives may be related to factors such as the learning context and the strategies employed. In conclusion, robotics-based learning was well received by students, which identified difficulties in their interaction with Arduino and robotics. This research suggests the need to adapt and improve pedagogical interventions in the future in order to more effectively address barriers to learning and optimise students' skills development.

**Keywords**: Educational robotics, Arduino board, interactive robots.

## 1 Introductión

Robot-supported learning has established itself as a key tool for the development of students' technological competences (TC). Several studies have implemented robot-based activities, including curricula focused on robotic programming, to foster these skills. Despite progress in promoting TC through the use of robots, debates persist. Some argue that robots could have a neutral or even negative impact on student learning outcomes [1]. Computational thinking and programming in the formal educational context can be effectively promoted through the STEAM (Science, Technology, Engineering, Arts and Mathematics) approach. This methodological approach integrates the development of scientific, technological and artistic competences through collaborative and interdisciplinary projects, where each student takes an active role in achieving the proposed objectives. It is important to highlight that this approach has boosted the development of computational thinking, as it fosters cognitive skills and problem-solving processes that allow students to approach challenges from different perspectives and develop innovative solutions [2].

Interactive robots, from a constructivist learning perspective, foster a playful environment where students can construct new knowledge while being extrinsically motivated through skills related to robot creation and programming. Incorporating robotics in the classroom is a valuable educational resource that promotes learning through play and reinforces students' cognitive skills. In addition, educational robotics awakens students' interest by introducing innovative methods to teach traditional content, creating more engaging, dynamic and inclusive learning contexts [3].

In the study of Arduino technology, applied to robotics, it provides university students with new opportunities to explore the design and development of embedded systems. This approach encourages interaction between hardware and software, allowing the integration of sensors and actuators to create intelligent devices. Through hands-on projects with Arduino, students acquire key competencies in rapid prototyping and idea validation, essential skills for technological innovation. In addition, this learning stimulates creative thinking, improves technical problem solving and provides valuable experience in emerging technologies such as the Internet of Things (IoT), with applications across multiple industries.

In recent years, Arduino, a low-cost platform, has gained popularity as a prototyping tool, especially among hobbyists and in education. It is considered one of the most influential open source hardware platforms in the last decade. Its success is due to its focus on ease of use, low cost and the support of an active community. Arduino is a microcontroller designed for people with no engineering background, being a simple but powerful option, widely adopted by hobbyists around the world and used extensively in STEM education. Based on an open source model, Arduino encourages the sharing of designs, schematics and code examples between different communities [4].

In the same way, [5] The use of Arduino in upper secondary education enhances students' problem-solving, creativity and teamwork skills. In addition, it has been shown to promote the development of critical thinking and decision-making. Students who incorporate Arduino in their projects have the opportunity to experiment and learn hands-on, which facilitates a deeper understanding of theoretical concepts.

Nowadays, robotics plays an important role in the training of students in technological careers at a higher level, promoting the design, construction and programming of robotic prototypes in an intuitive and interactive way. This interdisciplinary approach combines areas such as mathematics, technology, science and engineering, facilitating the comprehensive learning of the use of hardware and software through Arduino technology. Through this method, students develop skills to create complex robots, strengthening their readiness to face the challenges of the modern technological environment. The growing incorporation of robotics and technology in education is revolutionising the way students approach learning, especially at higher levels. These tools not only enhance interest in and understanding of advanced concepts, but also promote the development of essential skills for today's work environment, with a particular emphasis on problem solving. As a transversal skill, problem solving is of key relevance in higher education and in the professions of the future, as it enables students to face complex, interdisciplinary challenges effectively and creatively.

Robotics in the creation of higher-level projects is a key field that allows students to apply theoretical concepts in practical situations, integrating various disciplines such as engineering, computer science and applied sciences. Incorporating robotics into university projects provides opportunities for the development of advanced technical skills, such as programming, embedded systems design, automation and data analysis, all of which are essential in today's technological world. In addition, robotics fosters innovation, as students have the opportunity to design, build and programme robots to solve real problems, allowing them to face interdisciplinary challenges. This not only strengthens their understanding of technical areas, but also enhances teamwork, creativity and complex problem-solving skills [6].

In the educational context, Arduino has become a fundamental tool for hands-on learning in areas such as electronics, programming and robotics. Its accessibility and versatility allow students to explore complex concepts in an interactive way, promoting the development of technical skills and fostering creativity. In addition, the platform facilitates the integration of various disciplines, enabling students to tackle interdisciplinary projects ranging from problem solving to the creation of functional prototypes [7].

As well, learning through the use of Arduino in robotics is highly relevant for university students, as it promotes the development of fundamental practical and theoretical skills in various disciplines. Through Arduino projects, students acquire skills in programming, electronics and problem solving, strengthening their understanding in areas such as engineering, computer science and applied sciences [8]. Similarly, Arduino, characterised by its accessibility and flexibility, allows students to realise their ideas through tangible projects. This enhances their skills in design, electronic prototyping and exploration of key concepts such as the Internet of Things (IoT), automation and artificial intelligence, essential skills in today's technology careers [9].

Furthermore, integrating Arduino technology into academic activities favours the development of algorithmic and programming skills, as well as a solid foundation in electronics. Arduino is presented as a computer system that efficiently integrates hardware and software, facilitating the design and implementation of innovative solutions to real problems [10].

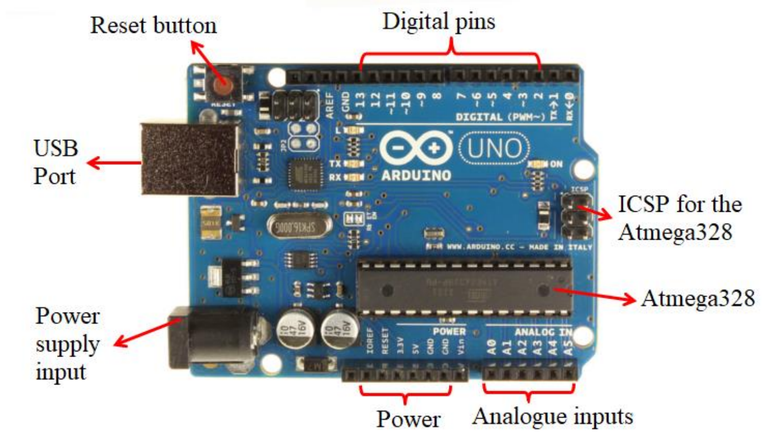


**Figure 1:** Arduino Uno R3 board schematic [11]

*Note*. In Figure 1, the arduino is a tool that enables robotics to create and control interactive prototypes through its ability to integrate sensors, actuators and other electronic components. As a rapid prototyping platform, it facilitates the development of robots that can respond to environmental stimuli, perform automated tasks and execute control processes. With the Arduino UNO, students and developers can implement robotics projects that include motor control, distance sensors, navigation systems, among others.[11]

## 2 Methodology

The research was developed experimentally using innovative electronic resources, such as robotic prototypes, in collaboration with students from a local private university. For this purpose, a sample of 100 students was selected, distributed in four groups of 25 members each. The selection was made by convenience sampling, chosen for practical reasons that allowed quick access to the students. The division into groups facilitated more efficient management and allowed for adequate supervision of activities, promoting balanced participation and encouraging teamwork within manageable groups.

The study adopted a quantitative approach, as it involved organising a specific number of students into defined groups, with the aim of evaluating and improving the learning process in robotics and electronics workshops. The projects focused on the use of programmable robots and low-cost components, providing a practical and accessible experience for the students.

The materials and student assessment are detailed below :

The learning process was complemented by detailed guides providing step-by-step instructions for circuit assembly and programming. In addition, recycled materials were incorporated, allowing students to use everyday objects such as cardboard boxes, plastic bottles, paper tubes and reused metal parts in the construction of their prototypes. This approach not only helped to reduce costs, but promoted sustainability and encouraged creativity by allowing students to adapt to various robot structures. Finally, the students carried out the programming of their prototypes using Arduino software and conducted test runs to verify the robot's functionality.

Student assessment was carried out using rubrics, providing specific criteria to evaluate student performance in each activity, including aspects such as accuracy in circuit design, logic of algorithms and potential impact on the creation of their robotic prototypes.

The research considered five stages proposed for the activities, Figure 2 describes a progressive learning scheme for the students, focused on the development and use of Arduino in technological projects:

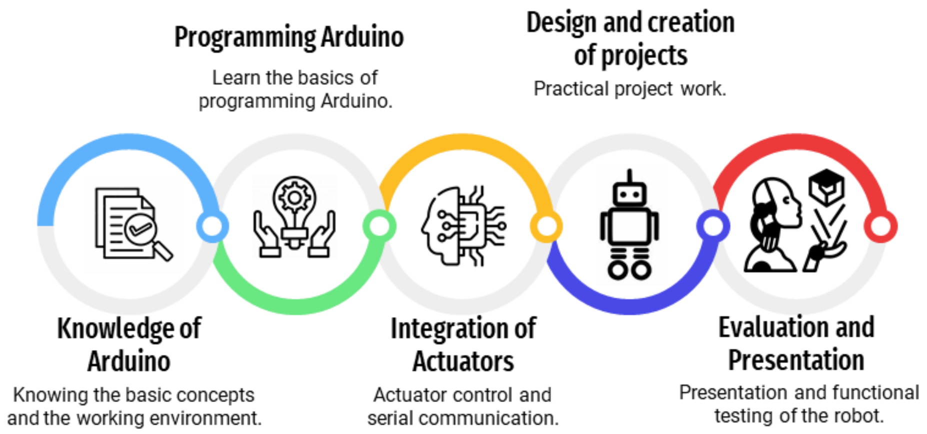


**Figure 2:** Proposed scheme: Stages of activities with arduino .

*Note*. In Figure 2, in the proposed scheme, the activity stages are organised into five key stages that guide the student from basic concepts to the implementation and presentation of functional projects. The **first stage, Arduino Knowledge**, focuses on becoming familiar with the fundamental concepts of this platform and its working environment, providing the necessary foundations to start its development. It also includes an understanding of the basic principles of electronics, allowing you to effectively integrate technical knowledge when working with Arduino. In the **second stage, Arduino Programming**, you acquire the skills to program using the Arduino software, focusing on learning the basics needed to control devices efficiently. Subsequently, the **third stage, Actuator Integration**, deals with the control of physical components such as motors, sensors, LEDs, among others, as well as serial communication, allowing hardware to be connected and managed in conjunction with the software. Once this knowledge has been acquired, the **fourth stage of Project Design and Creation** encourages students to develop practical projects, putting into practice everything they have learnt to create functional prototypes. Finally, in the **fifth stage of Evaluation and presentation**, a review of the operation of the project is carried out, ensuring that it meets the objectives set out, and it is presented, highlighting the results obtained.

This structured approach allows for an orderly progression in learning, taking users from the basics to the creation of advanced projects, promoting practical skills in technology and robotics.

## 3 Results

Currently, the innovative projects in the workshop are in a learning phase, where the students have made significant progress. To ensure the successful implementation of these projects, a scheme of activities was designed to guide and organise the work of each group. This approach ensures that students follow a structured and efficient methodology throughout the development process. The scheme, summarised in Table 1, describes the assigned activities and key steps that students should follow at each stage of the project, promoting collaborative, practical and application-focused learning.

**Table 1.** Outline of the activity

| **Name of the activity:** Development of interactive robots with Arduino. | |
|---|---|
| Objectives | ▪ To facilitate the understanding and handling of the arduino board, integrating artificial intelligence concepts so that students can develop interactive and automated projects.<br>▪ To strengthen students' logic programming skills, promoting dynamic and structured learning, guided by the teacher, in order to achieve a deep and applied understanding of programming principles. |

| | |
|---|---|
| Materials | ▪ Arduino Uno R3 board, Sg-90 servo motors, HC-SR04 ultrasonic distance sensor, YL-83 rain sensor, Bluetooth HC-05.<br>▪ Recycling materials and painting tools. |
| Duration | 8 hours |
| Compentencies | ▪ Encouraging logical and computational thinking.<br>▪ Introduction to research and the development of creativity in technological projects.<br>▪ Acquisition of fundamental knowledge in electronics and its practical application.<br>▪ Promoting teamwork and the development of leadership skills.<br>▪ Strengthening complex and adaptive problem-solving skills.<br>▪ Integration of AI (artificial intelligence) basics and real projects. |
| Desarrollo de las actividades | **Basic knowledge:** Students become familiar with the fundamental concepts of electronics and programming, which serve as a necessary basis for their technical development with Arduino.<br><br>**Programming:** They acquire skills in the creation of algorithms, applying their knowledge to program in the Arduino software, understanding the logic behind the code.<br><br>**Actuator integration:** They learn to apply physical control by integrating electronic components, using actuators to bring their projects to life.<br><br>**Project design and creation:** Students apply the knowledge acquired in a practical environment, designing and building functional robotic prototypes.<br><br>**Evaluation and presentation:** They provide continuous testing of their code, adjust algorithms in real time, analyse common errors and optimise the robot's performance. Finally, they present their robotic prototype, demonstrating the process and results obtained. |
| Actividades complementarias | The student describes in detail the process of creation, design and programming of their project, explaining the decisions taken at each stage, the challenges faced and how they solved them. In addition, they present a clear view of the functionality of the prototype, highlighting the techniques and tools used during its development. |

During the development of the projects, significant progress was observed in the learning of the students, who effectively applied Arduino technology in the creation of robotic prototypes. Among the most outstanding projects were: a robot with moving joints (designed as a toy for children), a robotic hand (to help disabled people), a rain detector (to protect housewives' clothes), a smart trash can (to reduce pollution when disposing of solid waste), a safe (to prevent theft of objects), and a prototype of a smart home with Bluetooth connection, thus demonstrating the creativity and applicability of their ideas in real solutions.


**Figure 3:** Robotic prototypes developed by students

Table 2 presents the learning outcomes of the four groups, showing the number of students who completed the assigned activities. The assessment was carried out using the observation technique, applying three performance criteria: "They achieve without orientation", "achieved with minimal guidance" and "they achieve with difficulty and effort". In all groups, it is observed that most of the students successfully achieved the objectives of the activity, either without help or with minimal guidance.

**Table 2.** Data on the number of students, evaluation criterion

| Criteria | Group 1 | Group 2 | Group 3 | Group 4 |
|---|---|---|---|---|
| They achieve without orientation | 12 | 13 | 16 | 14 |
| Achieve with minimal guidance | 11 | 7 | 9 | 8 |
| They achieve with difficulty and effort | 2 | 5 | 0 | 3 |
| **Full** | **25** | **25** | **25** | **25** |

*Note.* Table 2 shows the performance of five groups of students, each consisting of 20 students, according to the level of help required to complete a task. The majority of students achieved the objective without help, with Group 5 being the most outstanding in this category. Some students in each group needed minimal help, especially in Group 3. In the category of considerable help, Group 2 had the highest number of students requiring significant support, while Group 3 had no students in this category. These results reflect different levels of autonomy in the groups, indicating areas where some students need additional support to achieve their learning objectives.

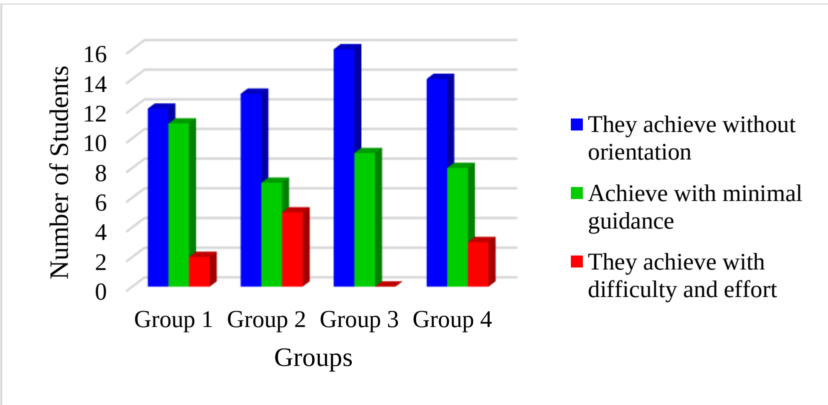


**Figure 4:** Result of the groups according to the level of activity

*Note*. Figure 4 shows results that reveal important differences in students' ability to achieve a goal according to the group to which they belong, highlighting the influence of applied strategies, prior skills or environmental conditions. Groups 2 and 3 demonstrate greater autonomy, suggesting that conditions in these groups favour independent learning. In contrast, in Group 1, students were able to achieve the goal without guidance, although a significant proportion required minimal guidance, while a small number experienced difficulties. Group 4 has a higher number of students requiring guidance or facing difficulties, indicating possible barriers or additional support needs.

These results underline the importance of customising pedagogical strategies and learning conditions to respond to the specific needs of each group. Implementing differentiated approaches could help to reduce difficulties in groups with less autonomy, while reinforcing the strengths of those with greater independence, thus fostering equitable and efficient progress for all students.

**Electronic circuits and programming**

In the development of the construction and programming of the circuits, some examples are presented:

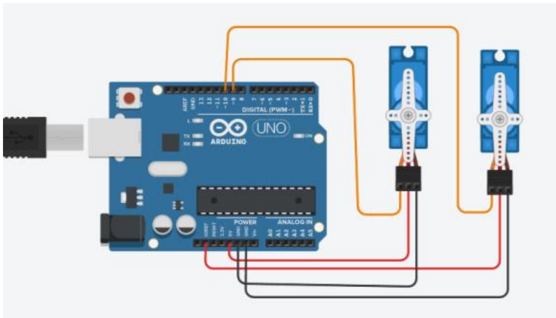


**Figure 5:** Circuit with servo motors, designed on Tinkercad platform.

*Note.* Figure 5 shows a basic configuration in which an Arduino Uno controls two servo motors. The servo motors are connected to the Arduino both for power and to receive the control signals needed to adjust their position. In summary, this circuit demonstrates a practical and simple design for controlling servo motors, ideal for learning motion control concepts with the Arduino or for integrating into more complex projects such as robotic arms or automated systems.

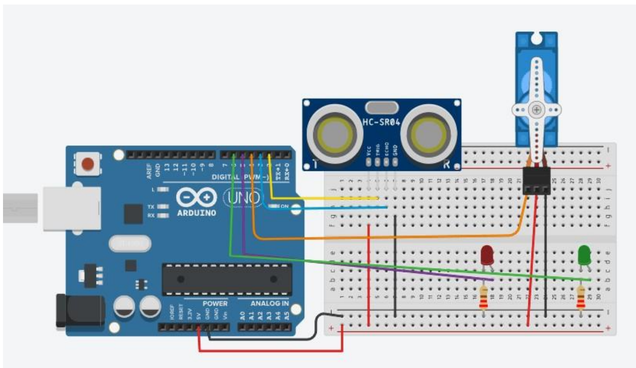


**Figura 6:** Ultratrasonic sensor circuit, designed on the Tinkercad platform.

*Note.* Figure 6 shows a circuit composed of two servomotors and an ultrasonic sensor controlled by an Arduino UNO. The ultrasonic sensor detects the proximity of an object at a given distance and, if detected, activates the movement of the servomotors, rotating them at an angle of 180°. In addition, a green LED lights up to indicate that the object has been detected. Otherwise, if no object is detected, the servomotors return to their initial 0° position and a red LED lights up to indicate that no object has been detected. This setup combines measurement, visual control and mechanical motion, making it a practical example of integrating multiple components into a single project.

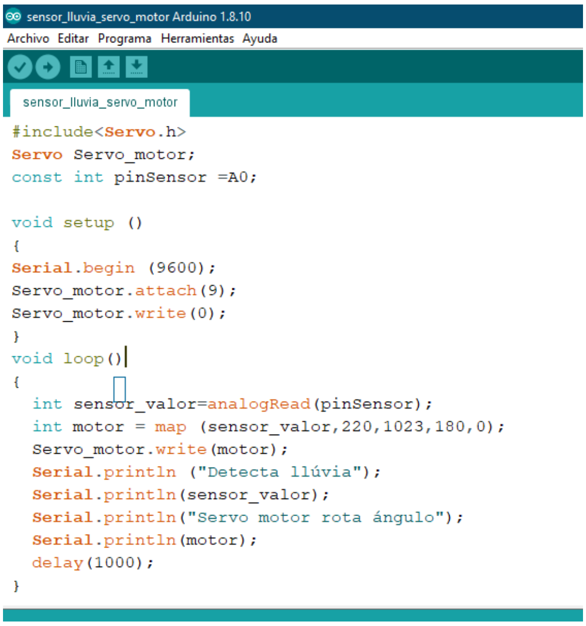


**Figura 7:** Presented code to control a servo motor with FC-37 rain sensor, arduino software.

*Note.* Figure 7 shows the code presented for the control of a servomotor based on the readings of an analogue sensor, using the rain sensor. This system was part of the automated projects, where the students demonstrated the closing of a lid, shutter or protection system against specific environmental conditions. The code is a simple and functional basis combining sensors and actuators for automation. However, its accuracy depends on proper sensor calibration (adjusting the minimum and maximum values in the mapping). In addition, a robust power supply should be considered if the servo motor requires more power than the Arduino can supply.

## 5 Conclusions

The use of Arduino technology and robotics in higher education has generated a growing interest among engineering students and teachers, who value the incorporation of these tools in academic training, as they enhance fundamental skills such as logical thinking, creativity and innovation. These skills are essential in the modern educational environment and in the context of Industry 4.0.

The results reveal notable differences in the students' ability to achieve the objectives according to the groups, which could be influenced by factors such as learning conditions, previous skills or strategies adopted. Groups 2 and 3 stand out for their greater autonomy, while Group 4 requires more intensive guidance, facing greater difficulties. This suggests the need to tailor pedagogical interventions and supports in a personalised way to meet the specific needs of each group and maximise learning opportunities and success for all students.

In future work, it is envisaged to continue advancing this approach, not only to identify and overcome challenges related to learning emerging technologies, such as artificial intelligence, but also to apply robotics to solve social problems. Continuous assessment, together with the adaptation of pedagogical strategies, will be key to ensure that all students achieve optimal performance and progressively develop greater autonomy in their robotics projects, thus facilitating their academic and professional growth.

Finally, the research gave students a practical understanding of key concepts such as automation, resource optimisation and sustainable development. These projects gave them a comprehensive and up-to-date view of the applications of technology in real-world contexts, preparing them to face contemporary challenges with innovative solutions.

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