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Low-cost educational robotics applied to physics teaching in Brazil

Marcos A M Souza[1] **and José R R Duarte**[2]

[1] Departamento de Física, Instituto Federal do Piauí, Parnaíba, Piauí 64215-000, Brazil
[2] Departamento de Física, Instituto Federal do Piauí, Teresina, Piauí 64000-040, Brazil

E-mail: msouza@ifpiparnaiba.edu.br and ricardo_duarte@ifpi.edu.br

Abstract
In this paper, we propose some of the strategies and methodologies for teaching high-school physics topics through an educational robotics show. This exhibition was part of a set of actions promoted by a Brazilian government program of incentive for teaching activities, whose primary focus is the training of teachers, the improvement of teaching in public schools, the dissemination of science, and the formation of new scientists and researchers. By means of workshops, banners and the prototyping of robotics, we were able to create a connection between the study areas and their surroundings, making learning meaningful and accessible for the students involved and contributing to their cognitive development.

1. Introduction

The contemporary process of the teaching and learning of physics that brings about elements based on modeling concrete objects with an emphasis on empirical methods dates back to ancient Greece. These methods of scientific investigation, which still serve today as guidelines in the scientific community, were popularized in the 16th century by the likes of Francis Bacon, William Gilbert and Galileo Galilei [1]. From this point of view, the importance of rescuing these aspects of physics teaching, often designated by many authors as the triad research–action–reflection, is vital [2]. In Brazil in particular, there are few public schools that have laboratories with the appropriate equipment to undertake practical classes. Therefore, students often say that the discipline is too far from reality, and the traditional concept of teaching using archaic and tedious methodology predominates. There can be an excessive routine of lectures and list of exercises that generally prioritize the memorization of mathematical formulas. Because of this misguided way of teaching, many students are driven to mechanically repeat the solutions of similar questions previously solved by the teachers, and this in general ends up not promoting the development of the practical and cognitive skills of the students.

In this paper, we reinforce the positive aspect of experimental activities in the process of teaching and learning physics in high school. This is the story of an exhibition of educational robotics in the public schools in the state of Piauí, in Parnaíba, Brazil. The activities were developed as part of the actions promoted by PIBID (Programa Institucional de Bolsas para Iniciaç ao a Docência), an institutional scholarship program for teaching initiation [3], and is an initiative of the Federal government of Brazil in partnership with the Federal Institute of Piauí (IFPI). The

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program is intended to stimulate, develop and improve the teaching skills of undergraduate students, with a medium- to long-term goal of the enhancement of the low-performing basic education of local public schools as evaluated by the Ministry of Education (MEC). In order to make future teachers become aware of both the actual conditions of a teachers' work environment and their obligations, the teaching initiation for most undergraduates takes place under the supervision of their own academic teacher, along with the supervision of the teachers that work in the school where the project is implemented.

All of the projects regarding the educational robotics developed so far have been brought into reality under the supervision and guidance of the authors of this article, and were only made possible due to the financial support of PIBID. Some of the experiments were made with recycled and low-cost materials, facilitating access for many high-school students, and the results obtained from these innovative activities have already resulted in two papers [4, 5].

The paper is organized as follows. In section 2, we consider the use of robotics in several contexts. Then, in section 3, we discuss the methodology used to build up an easy comprehension of the concepts involved in the field of robotics, as well as the educational motivation for the proposal and its role in the teaching of physics. Finally, the achievements and conclusions are presented, respectively, in sections 4 and 5.

2. Educational robotics

The robotics branch of science involves the study and development of educational and technological architectures that can be simple or complex systems based on logic programming which dynamically articulates through a mechanical automaton structure operated by means of integrated circuits and electro-hydraulic controls and tyres, resulting in what is popularly known as a robot.

Although a relatively new science, officially emerging in the 20th century, the history of robotics has its origins, just like physics, in ancient Greece. The search for the production efficiency and improved quality of manufactured products has always been one of the main reasons for mankind's interest in developing the robotics research field. For instance, the pneumatic automata is the remarkable piece of work of a Greek engineer from Alexandria, and is considered one of the first texts on the subject.

The term 'robot' was first mentioned in 1920 by the Czech Karel Kapec in a play entitled 'Rossum's universal robots', and was used again later, in 1950, by Isaac Asimov in his famous science-fiction book: *i, Robot*.

Over the past few years, there have been great advances in the robotics field, led by the necessity of the creation of a spatial program and the growth of the entertainment of Lego toys, and by the artificial intelligence program and the development of bipedal robots and exoskeletons for medical and military purposes.

A first attempt to classify robots can be carried out according to their application, kinematic chain and anatomy. In fact, the motion dynamics of a robot is described by means of more complex calculations [6], and a more specific approach would flee the scope of this work. However, physical concepts such as torque, linear and angular momentum, acceleration, force and speed can be investigated during the construction of prototypes. From this point of view, and with this motivation we showed the possibility of using robotics as a physics teaching tool, leaving the educator with the task of providing a simple description and making this accessible to students whenever possible.

From an educational point of view, the practical use of robotics is encouraging, and some of the main reasons for its use as a teaching tool are:

(i) it is an interdisciplinary science;
(ii) it develops logical thinking, entrepreneurship, leadership, creativity and psychomotor abilities;
(iii) it provides teaching technologies related to sustainability, which is part of new worldwide trends and science teaching;
(iv) it allows students to apply the theory learned in classrooms to prove the importance of science in modern society and in the manufacture of products that sustain life as we know it.

In addition, the use of simulations and computational modeling, which helps in the development of programming logic and in the subsequent process of the architecture of the robotics project, facilitates the building of relationships and

Figure 1. The figure on the left shows students demonstrating how to operate a robotic arm, while the one on the right shows a follower robot.

meanings, promotes constructivist learning [7–9], and may also:

(v) raise the level of the cognitive process, requiring students to think at a higher level and generalize concepts and relationships;
(vi) require students to refine their ideas more precisely;
(vii) provide opportunities for students to test their own cognitive models, detecting and correcting inconsistencies.

Once robotics is considered an interdisciplinary area, it is possible to investigate physics concepts involved in the construction of the projects developed in this article. Thus, we use the fascination that most young people have for robotics to encourage them to develop logical reasoning, problem solving and seek the understanding of various physical phenomena.

3. Applied methodology

PIBID has as a main objective the development of social and political teaching responsibilities, to provide the necessary assistance to facilitate the link between theory and practice, making the research a basic principle in education, and also stimulating the use of new information and communication technologies in the teaching–learning process. Thus, the main actions of the program are:

(1) physical demonstrations of experiments with simple, low-cost materials, providing students proof of the theory discussed in class;
(2) the organization of games, pranks and thematic competitions based on physics topics that increase students' curiosity and allow them to learn easily through play;
(3) the responsibility of choosing themes to be developed by means of workshops, drama, skits, exhibitions and seminars or short lectures.

From this perspective, we conducted an exhibition of educational robotics, which consisted of developing programming logic and architecture systems similar to the biomechanics of living beings and also building combat robots, crawler robots and automata systems for industrial use and for probing environments. All of this was achieved using only electronic scraps for the development of low-cost robots. Furthermore, during the exhibition, the following activities were also promoted: the demonstration of robotics projects and prototypes, the presentation of banners and videos, workshops and a competition between combat robots.

Because an educational robotics kit may have a high acquisition price, many schools in Brazil do not have the means to provide the necessary resources for students at elementary and high schools to acquire the materials to develop the activities we mention above. However, the use of electronic scraps [10, 11] offer a good alternative to build some prototypes.

The main focus of the activities reported in this paper was to relate robotics with physics. The students who developed the prototypes had the opportunity to work on physics topics such as electricity and electronics, with an emphasis on building electrical circuits. The concepts of kinematics and dynamics were studied through the movement and interaction of the robot with the environment. Modern physics, for instance, could be worked out from the photoelectric effect that governs the operation of the light sensors (phototransistors), which also provide a way

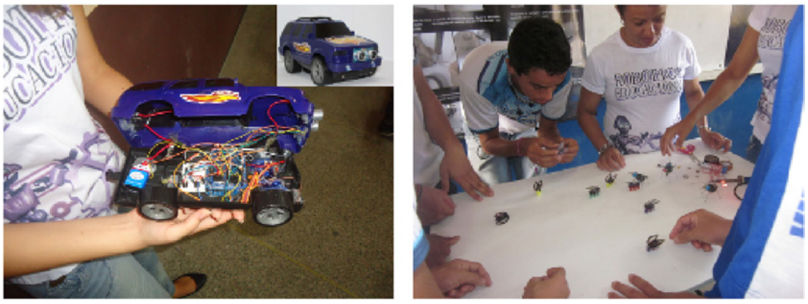

Figure 2. The left figure shows a robotic car with an ultrasonic sensor and Arduino micro-controller, while the right one shows an assembly plant where insect robots are built.

to describe the propagation of electromagnetic waves. The ultrasonic sensors of the robots, on the other hand, allowed the students to learn about the dispersion of sound waves.

Due to the large number of prototypes built, a detailed description of each project is not possible. However, we will briefly describe some of the robots that were developed, and we will provide the references that guided us in the construction and development of the projects discussed here.

In figure 1, we have as an example the display of a robotic arm [12], built of wood, whose joints are driven by motors used in an automotive power window. The central control sits at the base and allows the arm to rotate 360°, move vertically and horizontally, open and close the jaws, and the latter works from a 6 V dc motor. Through this prototype it was possible to explain concepts such as force, torque and levers. The follower robot [13] follows the black track by using phototransistors positioned at the bottom of the chassis. It is constructed with plastic wheels supporting the chassis made of a printed circuit board and is coated with a transparent mould for Easter eggs. Both projects do not require any programming.

On the other hand, by means of the intelligent control and free educational robotics systems, the use of Arduino plates also provides a cheap alternative to build efficient robots with simplified programming that is easy to teach, and that also have a practical purpose. The Arduino is a platform for electronic prototyping, architectured with a micro-controller Atmel AVR single board, embedded support for input/output, standard programming language C/C + +, and a board that can transmit or receive data through a channel using a computer or other electronic devices [14, 15].

Figure 3. A biped robot.

Figure 2 illustrates two extremes. We have a robotic car [16] with an ultrasonic sensor and Arduino microcontroller, where the function of the sensor is to prevent the car from colliding with obstacles, and works like sonar, sending and receiving sound waves to detect objects. The insect robot [17, 18] assembly workshop allowed students to interact with the activity. Being guided by PIBID fellows, they could build a small insect endowed with incessant movement using the vibrate function on mobile phones, toothbrushes, batteries and wires. To improve the presentation of the project, the students added wings to the robotic insects.

In figure 3, we show the functioning of a biped robot [19]. This was built using two servo motors as the driving source, and is controlled

Figure 4. The left figure shows students explaining the construction of the fighting robots, while the right one shows a competition between different robotic prototypes.

by a satellite dish receiver and mounted on a wooden frame. The legs are made of aluminium bars fixed by screws onto the feet, which are also made of wood. Using Newton's laws and frictional force concepts, PIBID fellows explain that the robot can walk on various surfaces and make reclining lateral movements, simulating dance.

Figure 4 shows the students at the school field interacting with the PIBID fellows via a combat robot [20] competition. These robots have a wooden or acrylic frame, and plastic wheels made with CD. Movement was made possible by 6 V dc motors connected to a control connected to circuits mounted on the chassis. During this competition, physics topics such as dynamics and electricity were investigated.

In table 1, we can find a list of the prototypes and robotics projects developed by undergraduate students that were used to teach physics topics to high-school students. Some of the projects were taken and adapted from websites, and some from manuals. The educational robotics exhibition lasted one day in each of the schools chosen to host the activities.

4. Achievements

The results reached through the activities were substantial and quite significant for the locality of Parnaíba, as well as for the teacher training of undergraduate students and the development of their research skills in the field of education. The educational robotics exhibition was an alternative and innovative way to raise the interest of high-school students by means of the field of science and technology.

Furthermore, the PIBID students had the opportunity to create teaching strategies along with programming logic, learning how to develop both biomechanics systems similar to the ones of living beings, and robots of industrial utility and environmental probing (see table 1). Remarkably, all these are low-cost robots built by PIBID students using electronic scraps. These activities established a stronger link between the knowledge experienced in classrooms by undergraduate and high-school students, and their social environment, making clear the possible differences to the reality for these students. It is worth stressing that the development and modeling of robots, along with the demonstration of physical principles using cheap materials of easy acquisition, and that promoted by PIBID through scientific shows and workshops, among others, provided students proof of the theories discussed in class, contributing to their cognitive development and teaching practice.

Another important aspect to be mentioned was to encourage the use of programming languages, as these are tools increasingly used in several areas of current research, such as nuclear physics, condensed matter, particles and fields. For this reason, the contact and use of these tools also contributed to the motivation of undergraduate students who intend to pursue these areas in the future.

The school teachers that participated in the activities reported that their students began to interact more in their classes, frequently questioning the role of science and its importance in society. Since recyclable materials were used in some prototypes, the activities were a way to call the community's attention to the advantages of

Table 1. List of the prototypes and robotics projects associated with the respective physics subjects studied.

Robot and physics theme
Robotic arm and electrical circuits and dynamics
Tracer robot and modern physics, kinematics and electromagnetic waves
Mouse robot and electrical circuits and kinematics
Biped robot and electrical circuits and dynamics
Cambate robot and electrical circuits, kinematics and dynamics
Insect robot and electrical circuits
Car robot and electrical circuits, undulating and acoustics
Quadricopter and electrical circuits, dynamics and hydrodynamics
Vehicle solar-powered eco and modern physics, electromagnetic waves, electric circuits, kinematics and dynamics

recycling, also reinforcing the importance of sustainability through teaching.

5. Conclusion

The most modern aspects of education advocate a focused education to build a dynamic mentality and constructivism in students. Based on these aspects, this paper explored the possibility of using interdisciplinary themes, in relation to the teaching of physics, be treated with an innovative methodology by building and exposure robotics projects. This new methodology was a big challenge for the students, since they had to learn while facing the poor conditions of (or sometimes a lack of) the science laboratories in their schools. For instance, not all prototypes had a micro-controller, and most were architectured so that there was a dynamic and autonomous physical structure driven by electrical and electronic circuits.

Despite this, many of the difficulties were overcome, and we expect that the implementation of a programming logic for all the projects, and the development of more sophisticated chassis and structures can come into reality in future activities.

Our hope is that the excellent results presented here encourage other groups, supervised by university teachers, to establish similar activities in order for science to be disseminated among young students. By doing this, we are able to introduce the technological reality of current society to those students, making them feel included and stimulated to become future teachers and scientists.

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