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A Low-Cost and Simple Arduino-Based Educational Robotics Kit

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***Abstract*—This paper presents a low cost educational robotics kit based on the UNO Arduino platform. The prototype is intended to be applied in secondary (high) schools by means of educational workshops on robotics. The project is supported by a step-by-step documentation (e.g. booklet) that addresses basic physics, mathematics, logic programming and robotics concepts. It also offers all the steps for evolving in the construction of a robot, and it employs a block-structured environment (such as Minibloq) to allow easier programming.**

***Index Terms*—Robotics, STEM, Education, Engineering, Mathematics, Physics, Arduino, Block Programming, Digital Inclusion, Technological Inclusion.**

I. Introduction

WE are surrounded by technologies and information that are constantly being renewed. The transformations of the information era must be implemented in schools in order to support students facing new challenges. Robotics may have a direct impact on schools (and students) performance in the sense that it brings to classroom life experiences that children may have had with electronics, computers and games outside school. Robotics can trigger creativity, team work and autonomy, thus fostering students with a formation based on ethics and technology.

Educational robotics can be defined as an environment built from computers, electronic components, electro mechanicals and programs, which together have the goal to explore several areas of knowledge. It is used as a teaching tool, and although it is frequently related to mobile robots, it is in fact much broader. Searching for a playful and inclusive education, robotics changes the traditional and conservative teaching approaches, as it allows development of new experiences and the re-application of dynamic technologies. Robotics represents the revolution on the teaching-learning process.

From a broader perspective, robotics must promote the development of competences and basic cognitive abilities of its users. It allows people to experiment with new educational processes, experiences and ways of learning. Robotics is an attractive element that invites teachers and students alike to teach, learn, discover and invent through collective processes. It is with the understanding of innovation and inclusion that we endeavored into the construction and reapplication of technologies to the educational area, taking robotics as the main tool to help transform the educational landscape.

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A. Goals

One driving concern of this work is the affordability and accessibility of educational tools to students and schools that do not possess enough financial support. To this end, we envisage the creation of a low-cost robotics kit, which can be applied in workshops, where students may find themselves capable of obtaining a better understanding of the contents approached in the classroom and develop their knowledge in various subjects. The goal it to allow high schools to adopt transdisciplinary courses covering a wide range of topics including electronics, generation and transformation of energy, geometrical optics, electromechanics, foreign languages, communication, computing, sensors, programming, and logics.

From a pedagogical perspective, this project aims at supporting the teacher in diversifying his or her work using this robotics kit (and a related workshop) as a tool to facilitate the handling of advanced technologies in education, while also acting as catalysts of knowledge in schools that are still in technological disadvantage.

Educational robotics was popularized after the development of the LEGO Mind-storms (www.lego.com). This is a small computer inserted within a LEGO brick and sold as a robotics kit. However, this kit is inaccessible to many local schools due to its high cost (around USD 700.00 in Brazil). To this day, other robotics kits available (see Table III in the Appendix) still pose prohibitive costs for the majority of public schools. In order to achieve the mainstream of the Brazilian schools, this is an alternative robot kit with both source code and project that are free and available. It is composed of low-cost components and it is designed to allow students to build themselves the robot.

B. Requirements

The design of this robotic kit is driven by four basic requirements, as stated below:

- *Low-Cost*: It must be affordable to most schools, which can be translated into one robot per student in the class. This latter requirement dictates a cost that should not exceed one hundred USD. This requirement impacts on restricting somehow the level of functionality and performance implemented by the kit.
- *Appeal*: It must be appealing to the students. A aesthetically clean design which stimulates the enthusiasm in working with the robotics kit is a key concern in this project. This requirement limits to some extent the use of recycled or second-hand materials as primary building components. On the other hand, it favors finished and

relatively low-cost components off-the-shelf (COTS) such as the Arduino platform.

- *Simplicity:* The concept of simplicity translates into three dimensions in this design: 1) Assembly 2) Operation 3) Maintenance and 3) Understanding. We seek an assembly time of the whole kit of no longer than 2 hours once the bare components are acquired. Once the system is assembled, its operation should be manageable to those who are novices in robotics. Furthermore, maintenance of the kit should be kept minimal, requiring no more than a simple replacement of any damaged components. Furthermore, it is again necessary to keep functionality minimal in order to avoid overloading the student with too much information and facilitate the understanding of basic concepts. These features all corroborate to improve the system's usability. They also qualify the robotics kit itself in the category of a starter kit.
- *Open source:* An open source is the best model for dissemination of this initiative. Clearly, the robotic kit must be easily available to all interested parties, including teachers, professors, students as well as laboratories, schools and colleges.

C. Review of earlier work

There are in the literature a number of robotics kits for academic research and/or educational projects. Therefore, in the next paragraphs we discuss a few examples of what is currently available in order to provide a general overview of the landscape on robotics kits without attempting to be exhaustive.

Connaughton and Modlin [1] present a robotics platform built upon a set of existing technologies, including a Vex Robotics kit, a Nintendo Wii remote and a Bluetooth modem. The system allows the introduction of a variety of computer science and engineering concepts at middle school, high school, and college level. The modular system components allow students to replicate, improve, and experiment with individual parts of the system in both research-oriented and lecture-based environments. Their work also include observations from using the system in a high-school robotics club.

Research on collective algorithms is typically carried out either via simulation or using a small number of robots, due to their complexity. In order to tackle such limitation, Rubenstein, Ahler and Nagpal [2] designed a robot (Kilobot) that allows research on collective algorithms on a large number of robots (hundreds or thousands). The robot allows one single user to easily oversee the programming, powering on, and charging all robots, which would be quite challenging or even impossible with current robotic systems. Each robot costs only 14 USD and takes 5 minutes to assemble.

Mondada *et al* [3] introduced the E-Puck robot design. Due to its particular design, the E-puck is not strictly related to robotics, i.e. it can be used in a large spectrum of teaching activities. Through a systematic evaluation by the students, the authors showed that this robot fits its educational purpose and it is appreciated by 90 percent of a large sample of students. This robot specifically targets engineering education at the college level.

McLurkin *et al* describe the experiences of using an advanced, low-cost robot in STEM education [4] [5]. The robot design has many features specific to educators: it is advanced enough for academic research, it has a broad feature set to support a wide range of curricula, and is inexpensive enough to be an effective outreach tool. This robot was used in three different classes and it was the foundation for an innovative problem-based learning curriculum. Specifically, the robot has specialized sensor systems and a communication interface that supports a multi-robot curricula. The system is composed of four major parts: 1) the r-one robot; 2) a Python development environment; 3) a camera tracking system, and 4) a server software that integrates all the components together. The hardware can support classes in computer science, electrical engineering and mechanical engineering. The system enables a novel multi-robot curriculum while fostering collaborative team work on assignments.

Sipitakiat, Blikstein and Cavallo [6] introduce the GoGo Board, a low-cost programmable brick that allows the user to actively participate in its production process. They discuss the use of found and broken materials as sources of construction supplies. Additionally, they analyze two case studies from projects developed in Brazil from 2002 to 2003. Specific attention is given to the design of the GoGo board, which allows for diverse and socially relevant learning projects to take place. Due to its relatively lower cost, the project extends the audience beyond well-funded schools and institutions, allowing for the inclusion of economically challenged students and schools to the context of educational robotics.

Filho, Almeida and Martins [7] developed the design of a six wheeled, multitasking, educational and mobile robot. The main features of their project are the following: 1) it is built with electronic garbage and easy-to-obtain materials; 2) it is based on the PIC16F628A micro-controller, actuators (dc motors for movement and accomplishing tasks) and sensors (responsible for the interaction with the external environment). Furthermore, micro-controller programming is directly carried out on the motherboard, without the need to remove any components.

Our robotics kit presents a lower cost than the kits described previously, with the exception of the work by Filho *et al*, Kilobot and GoGo board. However, the design specification by Filho *et al* infringes at least two of our requirements: it uses electronic garbage which may add more logistic effort in the construction process, as the acquisition these types of materials (in our context) is not always scalable and it does not always lend itself easily to an attractive look in the final design. Secondly, it employs the exclusive use of either an assembly language or a high level language, which violates the requirement of simplicity (i.e. not always accessible to introductory level students).

Another lower-cost robot is Kilobot. However, as mentioned earlier, Kilobot was designed primarily for research on collaborative algorithms. Therefore, it surpasses the level of simplicity that is aimed in our context. The GoGo initiative has also an attractive cost-benefit ratio, but the value listed (see Table III in the Appendix) includes a bare micro-controller board with sensors and interfacing capabilities: once a full-fledged robot kit is assembled using this board (e.g. including actuators, engines and drivers) its cost may escalate and fall well beyond the scope of our requirements.

The rest of this paper is organized as follows: Section II presents the platform used to design the low-cost educational robotics kit (hardware and programming environment); In Section III we introduce the design of the robotics kit, covering its architecture, the software, the power supply system and the cost analysis; In Section IV we discuss the results and finally, in Section V, we address our conclusions.

II. Background: Development Platform

In this section we introduce the hardware and software platform employed in the design and implementation of the robotics kit.

A. Hardware: Arduino UNO

The Arduino prototyping platform [1] was used in the development of this robotics kit. Arduino was designed in Italy in 2005 and since it is open-source it facilitates hardware acquisition and implementation. Arduino is a multi-platform tool for Windows, Linux and Macintosh, based on IDE programming, and has a development environment based on C. However, its design accommodates some alterations that facilitate the understanding and the development of all end users (i.e. students, hobbyists and experienced developers). Currently, the Arduino Project is composed of 19 board models - one for each type of project. Specifically, this robot kit employs the UNO board.

Some features have been decisive in the choice of the Arduino UNO model, such as processor and power consumption. The UNO consists of an 8-bit ATMEL micro-controller, the ATmega328P, with an internal, permanent memory (EEPROM) for both code (including applications created by the students/developer) and data storage, and an internal volatile memory (RAM) for storage of temporary information. Another important feature of the Arduino UNO is its low-power consumption, since it can be powered by a simple 9V (volts) battery. The operation and performance of the UNO model has shown a versatility that is critical for the development of this educational robotics kit, as it offers autonomy for a reasonable period of time.

B. Programming environment

Minibloq is a graphic programming environment used in this work. It facilitates the introduction of students into the world of programming. The students use colorful blocks to program physical computing devices very easily. Minibloq [2] is described according to three environments:

- *Hardware environment:* In this environment, students attending a workshop on introductory robotics may select which Arduino model they will program and work. Clearly, it is important to select the correct board model, since each model has a different I/O system. It is also important to correctly select the USB input, i.e. the one that is connected to the Arduino board, so that the software uploads the code developed.
- *Blocks environment:* In this environment the student is in touch with actual programming in a simple way: the student uses colorful blocks to generate programming code, resulting in a colorful syntax that facilitates the learning of the programming logic.
- *C environment:* In this environment all the programming and syntax developed by the student is dynamically converted to the C programming language. Therefore, the students become familiar with the structure and syntax of the language. While in this environment, the student is not allowed to alter the original program, i.e. this screen is exclusively for visualization and follow-up.

[1] www.arduino.cc

[2] Minibloq - http://blog.minibloq.org/

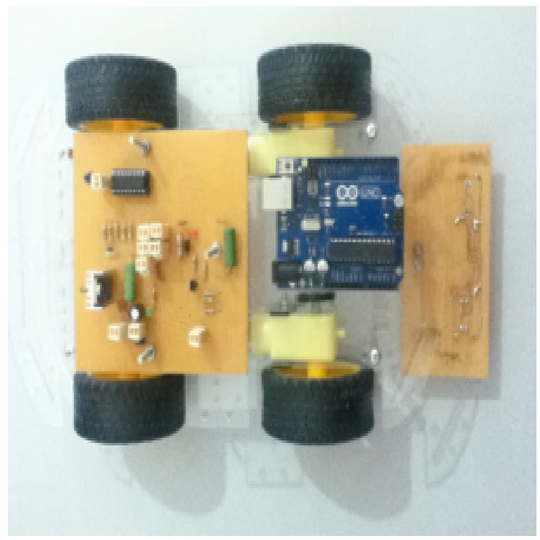

Fig. 1: The Low-Cost Robotics Kit

III. Robotic kit Design

Fig. 1 illustrates the robotics kit proposed in this project. The design is conceived around its architecture, the hardware, software, and the power system, as described in the following subsections. We also discuss the costs incurred in the design as it is a priority requirement.

A. Architecture

Fig. 2 illustrates the major blocks of the architecture.

Besides the Arduino platform (block 1), the robotics kit has two other electronic boards for the interface and communication with the external environment. The larger board (board 2) is responsible for the following functions: 1) Power supply regulation (5 V), which is the ideal voltage to supply the Arduino and all the others electronic components; 2) Input voltage regulation of the power supply to 3.6 V, which is the voltage level used to recharge the batteries; 3) Receive output control signals from the Arduino board and boost their levels. These are the control signals used to activate and power the engines; 4) Provide the power supply to the sensors board.

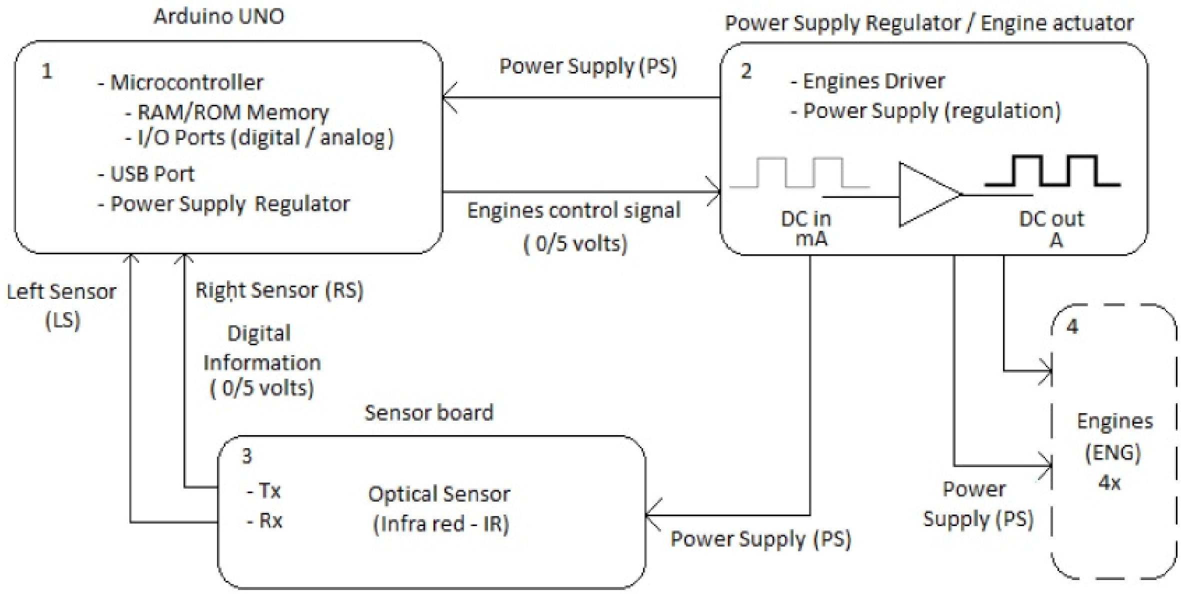

Fig. 2: Block Diagram of the Hardware Design

The smaller board (board 3) performs optical reading of the floor, and sends the signal to the Arduino board. The Arduino in turn interprets this signal and make its own decision allowing the robot to perform its function, i.e. follow a certain trajectory set by mat material fixed on the floor.

B. Software

Fig. 3 illustrates the basic software for path control. This is a line-following robot. Therefore, the software implements a simple loop that steers the robot back to its intended path once it is detected that it is about to leave the intended (line) track.

The software periodically polls a micro controller input port that senses line detection and then it actuates on the engines. Line detection is performed in hardware through optical sensors. A LED coupled to a photodiode was used as the infrared sensor. It was installed beneath the robot to allow track detection, so that the light emitted by the LED and reflected back on a surface is sensed by the photodiode. Each side of the robot contains one optical sensor, i.e. the left and the right sensors (LS, RS). The path line lies between both tires and once the robot's left side sensor (LS) hits or crosses the path line (meaning that it is about to leave the desired path), the optical sensor outputs an active HIGH (5V), which causes the left engine to stop. This behavior corrects the path of the robot back to the established path line. Similarly, if the right side sensor (RS) goes over the path line, the right engine is switched OFF to maintain the robot within its intended track. Once the robot returns to the normal path, the engine that is OFF is switched ON again (as the corresponding optical sensor outputs a LOW for reading the regular floor).

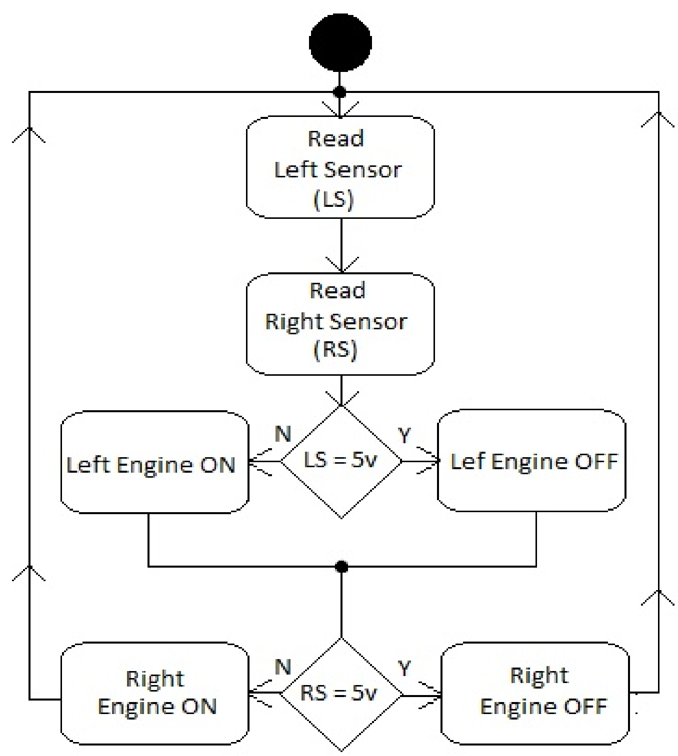

Fig. 3: UML Activity Diagram of the Software Design

C. Power system

Clearly, we must select an adequate power supply for the correct and long-lasting operation of the robotics kit. In this specific case, we have used two Lithium-Ion batteries in series with a discharge capacity of 4.2 Ah (ampére-hour) and with an operation of 3.6 volts each. The current consumption measurements indicated that the robotics kit drains a current of approximately 1.2 A in its full-fledged operation, leading to an autonomy of around three hours and thirty minutes (as expected, this value is obtained by the ratio of the power capacity by the power consumption of the system, i.e. $\frac{4,2Ah}{1,2A}$ = 3.5 hours).

Notice that all electronic material is subject to external environment effects, thus increasing the consumption and decreasing the life span of the batteries. We should also recall that Lithium-Ion batteries have a negligible memory effect, that is, they do not vitiate. In practice this means that we can recharge the batteries at any time and at different periods of time. It is interesting to highlight that they store twice as much energy as a nickel metal hydride (NiMH) battery and three times as much as a nickel cadmium (NiCd) one.

D. Costs

Table I highlights the fact that a large budget is not needed to introduce this robotics kit and workshop in schools, as low-cost and easy-to-find components have been employed (Notes: the main components used in the robotics kit and their cost are expressed in US dollars; the values displayed are the market average cost obtained from different local suppliers; the list of suppliers can be made available upon request).

The "other components" are voltage regulators and small analog electronic elements such as resistors, diodes, LED's, engine current drivers, connectors, cables, and materials for the in-house design of the printed circuit boards.

Notice that quite hefty government taxation is embedded in the final cost (at least an overhead of 60% over imported goods and an additional 18 % of state taxes) that turn the kit relatively expensive from an international perspective, despite the effort of reducing costs. Additionally, this cost analysis considered only retail prices, and clearly it can be improved from bulk/wholesale prices once the kit is mass produced.

TABLE I: Robotics Kit Cost

Description	# Units	Cost (USD)
Smart car chassis + motor + wheels	1	15.80
Lithium-Ion Battery (3.7 V - 4.2 Ah)	2	10.98
Arduino Uno	1	8.30
Dual-in-Line IC Socket	1	1.00
Heat sink	1	0.15
Optical Sensor	4	1.80
Battery holder case	1	5.00
Motor Controller Chip L293D IC	1	0.60
Other components	1	50.00
Total	—	93.63

IV. Evaluation and Results

The general requirements initially set forth for the design of the robotics kit were fully met, although the analysis of some of the requirements may be rather subjective. These were validated mainly through workshops using the robotics kit with the target audience, i.e. the high-school students from local schools, which were applied on a regular basis since its introduction in early 2013. The goal of these courses was to disseminate the understanding and practice of basic electronics, introductory robotics and embedded programming. The workshop follows a step-by-step learning approach that students and teachers alike may use to assemble, configure and program the robot in the classroom. This approach is documented in a booklet that has been carefully conceived to allow the interaction of practices of the robotics workshop with the many concepts involved in the construction of the robot. It explains the operating principles of the components used, such as sensors, engines, and resistors. The course also tackles aspects of robot operation, robot control and architecture. It combines both theory and practice following the structure illustrated in Table II.

TABLE II: Stepwise Learning Approach

Steps (Learning Modules)	Contents
What are we going to learn	Workshop introduction
What is Robotics	Introduction to Robotics Robotic Generation Sample Applications
What is Arduino	Introduction to Arduino What is Arduino for Features Installing and setting up
Learning to Program with Minibloq	Introduction to programming Block programming The minibloq environment
Electronic Components	Resistor, Capacitor Diode, LED Introduction to Integrated circuits (IC)
What are Sensors	Introduction to sensor- and sensor systems Sensor systems and types Sample Applications
Robot Architecture (basic)	Introduction to major functional blocks Communication and interfacing between blocks (overview) Introduction to block/functional diagrams
Robot Operation	Introduction to robot operation The path control software Introduction to Activity Diagrams

Most of the course focuses on programming, adopting either the C programming language or Minibloq, depending on the level of knowledge of the students. The programming exercises of this course are performed using the kit as a motivation tool.

Over the first two years using the kit, students were asked to give feedback about the use of the kit to illustrate the concepts of the workshop. The following questions were asked as part of a survey: 1) Was the course load enough for your understanding of basic robotics?, 2) Has the robotic kit and the course helped you with your development and progress at school?, 3) Has the workshop and kit facilitated programming and learning programming concepts?, 4) Has the kit got you interested in robotics? and 5) Has the robotic kit helped you understand and learn basic electronics?.

Fig. 4 summarizes the results of this analysis.

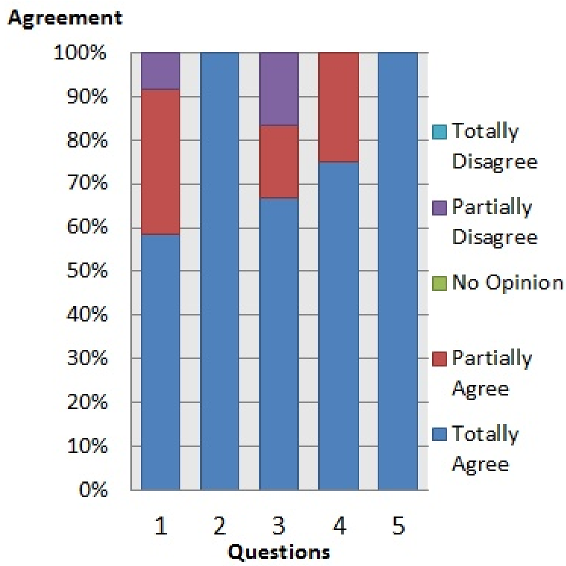

Fig. 4: Results

It shows that 100 percent of the students agree that the robotics kit has helped the understanding of electronics and programming (question 5). The lowest score was on the item "ease of programming and learning programming concepts (question 3)", where slightly over 80 percent of the students agree (completely or partially) on the simplicity or easiness in programming and learning programming through the robotic kit. However, with the fine-tuning of the workshop, these scores are expected to improved over the years [3]. In general, the results show that the robotics kit performed well as a learning tool according to the majority of students consulted.

V. Conclusion

This project allows technology to be used to support and motivate learning. The results obtained in the development of this robotics kit along with the realization of several workshops led to the conclusion that the proposal is economically feasible, taking in consideration its low cost. This low cost is (partially) due to the independence of suppliers of parts and components. This contrasts with robotics kits such as Lego, Fischer and other manufacturers, which have their own standard and proprietary components. Another interesting aspect of this project is the step-by-step approach to learning the kit, which is a vital part of this work.

We are currently extending the design and working on three separate ideas: 1) A new version that replaces the Arduino with conventional combinational logic. This simplified version prevents students from learning programming concepts directly from the robot, through Arduino, but may represent a further reduction in costs of around 10-20%; 2) Enhancing the functionality of the robotics kit in a modular fashion while keeping it simple. Each new functional module is also added to the kit as a new pedagogical/learning unit, thus increasing the learning choices; 3) Another parallel development, more from a cosmetic perspective, is concerned with providing the robotics kit with an attractive body design for high-school students (e.g. such as the one from a Formula 1 racing car).

In conclusion, the use of this robotics kit revealed that it is possible to design and develop projects in educational robotics at a relatively low cost, which are easy to build and implement and therefore are accessible to the reality of the Brazilian schools.

[3]This score also tends to improve with classes where the level of knowledge among students is more homogeneous

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APPENDIX

TABLE III: Robotic Kits Cost (approximate) Comparison

N	Robot	Cost	Author/Company	Web Link / Reference
01	Kilobot	14 USD	Rubenstein *et al*	www.k-team.com [2]
02	GoGo Board	30 USD	Sipitakiat *et al*	[6]
03	Multi-task Robot	55 USD	Filho *et al*	[7]
04	This work's robotics kit	100 USD	Junior *et al*	www.ft.unicamp.br
05	Roomba Create	100 €	iRobot	www.irobot.com
06	Parallax	149 USD	Parallax Inc.	www.parallax.com
07	Bot'n Roll	175	SAR Lda	www.botnroll.com
08	Low Cost Multi-Robot	220 USD	McLurkin	[4] [5]
09	Lego Mindstorms (NXT)	260	LEGO	www.lego.com
10	Circular GT	210 €	IdMind	www.idmind.pt
11	Tomy I-Sobot	299 USD	Tomy	www.isobotrobot.com
12	Hemisson	225 €	K-Team	www.k-team.com
13	ER1 (basic config.)	230 €	Evolution Robotics	www.evolution.com
14	Palm Pilot (basic)	250 €	Carnegie Mellon (CMU)	www.cs.cmu.edu
15	Modular,Extendible Kit	$>$ 400 USD	Connaughton, Modlin	[1]
16	Cye	540 €	Educational Robot	www.personalrobots.com
17	E-Puck	550 €	Mondada *et al*	www.e-puck.org [3]
18	Bioloid Comprehensive	899 USD	Bioloid	www.robotis.com
19	KHR-1	1000 €	Kondo	www.kondo-robot.com
20	Garcia (basic)	1360 €	Acroname	www.acroname.com
21	Kephera II (basic)	1500 €	K-Team	www.k-team.com
22	AmigoBot	1550 €	ActivMedia	www.mobilerobots.com
23	Kephera III	2000 €	K-Team	www.k-team.com
24	Robotino	4500 €	Festo	www.festo-didactic.com