

# Developing Educational Printable Robots to Motivate University Students Using Open Source Technologies

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**Abstract** Educational robotics is one of the most prosperous fields of study currently. Although expensive educational robotic kits are used in high schools to teach robotics. University students do not have the knowledge base on the matter yet. More often, low-cost printed modular robots are used. 3d printers are the emergent tool to do faster prototypes in a cheaper way. Also, Open Source technologies are the way to share information. In this paper, we have done a low-cost printed modular robotic platform to teach robotics. Furthermore, we have done several experiments on how to teach educational robotics. Lastly, we have proposed a statistical model to get results from the experiments.

**Keywords** 3d printers · Creativity · Educational robotics · Innovation · Motivational education · Open source · Printable robots

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## 1 Introduction

Since the insertion of the computer in schools, the desire to incorporate the teaching of robotics in the classroom always remained latent. Technical colleges, mainly those related to electronics, began its first robotics projects connected to the PC interfaces. But this work was only developed in a small set of institutions, because a lot of knowledge was required by both teachers and students [16]. Furthermore, the built robots were not any kind of autonomy and they were required to remain connected to the PC.

In the late 90s, a set of educational robotics kits began to appear on the market. These kits could solve the two mentioned problems, not requiring deep electronic knowledge and allowing the construction of autonomous robots. The most popular of these kits is the Lego Mindstorms kit that broke the boundaries of educational institutions. Today, thanks to the Internet, it has a huge community of educators, scientists and hobbyists developing software and hardware to extend its functionality.

There are every day more professionals in the robotic and education fields that it is focusing their work on educational robotics and human-robot interaction. Authors like Chiou [7], Bredenfeld [6] or Alimisis [1, 2], they have focused their efforts on teaching robotics to kids and young students. Nevertheless, we feel that there is not a real effort yet for new university students, those who we direct our work in this continuous project.

Up to now, the majority of the current projects in educational robotics like Dyne [8] or Bilota [5] projects, it is realized with commercial kits of robots or software that it is very expensive. As it is well known, we live in hard times where universities are reducing the costs at maximum. By this reason, one of the main motivations was to create a modular robotic platform and accessible to any student who wants to learn about robotics.

Educational Robotics is conceived as the mode of adaptation and development of student activities, which is carried an understanding and improved attitudes based technologies. By implementing educational and handling robot controlled through computer systems, students can solve problems of different kinds. Some of the benefits offered by educational robotics are: integration of different areas of knowledge, development of systematic thinking, creation of learning environments, and reduced costs when possible. On the contrary, one of the most important disadvantages to consider is that students need training, especially in the construction and handling of devices, and learning to program. Another important aspect is the need for adequate infrastructures such as laboratories and the cost of devices.

For these reasons, we believe that the teaching methodology must be changed and take one more step in educational robotics. We want any student can learn, investigate or practice in the field of robotics. Gonzalez and Valero [9] proposed a low-cost small modular robot which has some of the features we desired. In this way, being this last project an Open Source project, we had tried to replicate and improve that work realizing modifications in other last projects [10, 11]. That projects were the first idea to finally develop the educational robotic architecture based on their Open Source philosophy. Another tool we have used to teach STEM disciplines are workshops. These workshops were focused for beginner students. We tough the basic knowledge of programming, hardware and modeling among others.

With those workshops, as several other projects like the Project Mindstorms by Chiou [7], our work was initially carried out as an educational activity and not like a research activity. However, observing the high participation in the workshops we thought that robotics could be used for “recruiting” students [8]. The UC3M Association of Robotics (ASROB) [4] has

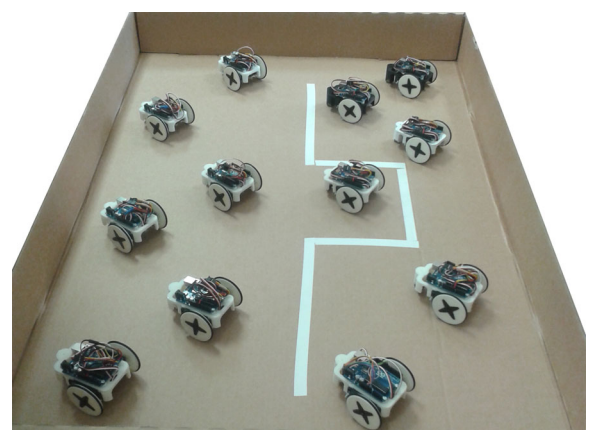
seen an increase in the number of members interested in the robotics field by more than a 50 % of students.

Thus, in this paper, we propose an educative robotic platform based on low-cost Open Source technologies, having built a little fleet of 10 robots (Fig. 1). Also, we present the results of several experiments using educative modular robots. The experiments are focused on the effort and creativity of the students, mainly university students, who have no knowledge in robotics. And we think that it is possible to program simple and useful programs too for a robot doing easy tasks in a reduced time.

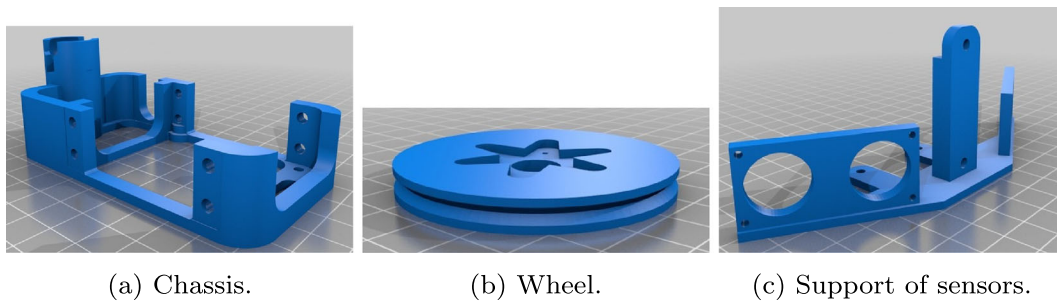
The rest of the paper is organized as follow. In Section 2 the robotic platform is presented. There, we describe the main parts of our robot (the design, the electronics and the software used). Section 3 contains all the experiments and results we have developed and obtained. We try to explain the aims of the experiences and how good the results have been. And lastly, Section 4 shows the conclusions from the results and the experiments. Also we do a brief summary of the future work that we would like to do.

## 2 The Educational Robotic Platform

Education is the process of transmitting a series of concepts or skills. This process works with a lot of methods which use different supporting materials. In our case, we propose a new robotic platform as supporting material which will allow us to develop our activities. The educational robotic platform is a mobile mini-robot based on a modification of the Protobot



**Fig. 1** Main mobile robot colony and parking space



**Fig. 2** Arduino Uno hardware platform with the integration board. **a** Chassis. **b** Wheel. **c** Support of sensors

robot model<sup>1</sup> by A. Valero. The main features of this robot model are low-cost and easiness of producing-replicating it. This is because the platform is totally based on Open Source technologies.

On the one hand, this platform has two versions. Both are based on the same Open Source principles, and the second version is an improvement of the first version. On the other hand, as in any manufacturing process of robotic architectures, the process of development is divided in three different parts. In our case and firstly, we have designed a mechanical model, which was developed with the OpenSCAD program. Secondly, we have selected an open hardware platform. In this case, Arduino UNO micro-controller is the platform used for the first version and Freaduino UNO micro-controller for the second version. And finally, the robot must be programmed. For this, Arduino IDE programming software has been used. Thereby, the philosophy of knowledge sharing and making available to other members of the robotic community is fostered.

## 2.1 Design

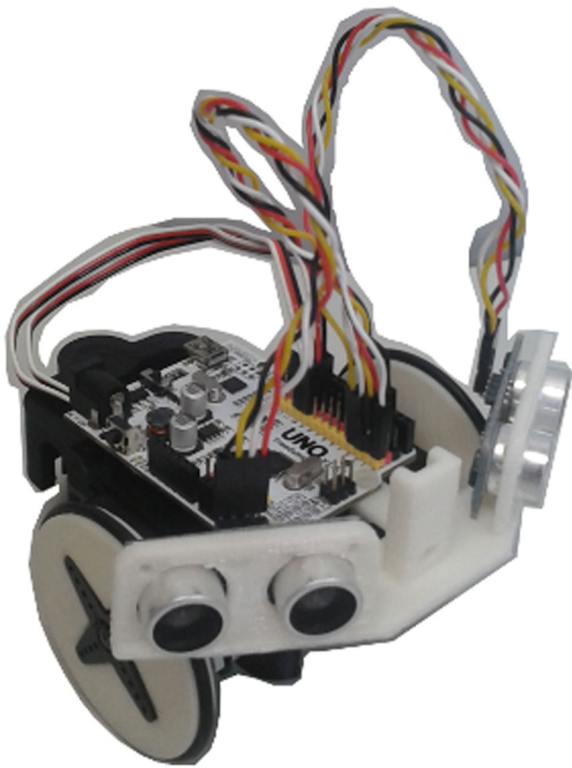
When a new robotic platform is designed, there are four aspects that must be considered in a manufacturing process. The four aspects are not equally important. First and most important, we must choose the intrinsic capabilities of our platform. The assigned qualities will impact on the other aspects of the design and manufacturing process. Second, we must consider the dimensions and the electrical features of the coupled devices (micro-controller, servo motors,

batteries and ultrasound sensors). This is very important because it can happen that the pieces do not fit together properly or there are gaps among them. Third, we must decide what tools we will use to make prototypes or parts. The manufacturing process will impose certain limitations that we must consider in the designs. And finally we must select what tools we will use to perform CAD designs (Computer Aided Design). The software will depend on the above three aspects.

In our case, we have decided that the design should be compact, small, easy to replicate, modular, economical, and of course printable. When we are designing the pieces, these qualities must be present at all times. Thus, we get that the robotic platform is robust.

Physically, our educational robotic platform is divided into three different parts. The chassis, the wheels and the support of sensors. The first two pieces have been created by other designers, so we encourage further Open Source principles. The chassis is the main piece of the mobile robot. This piece was designed by A. Valero and this frame takes care of loading with most devices (motors, batteries, micro-controller and the support of sensors). In addition it incorporates a third support based on an idler wheel. Figure 2a shows the CAD design of the chassis. The wheels are the mainstays of the robot and transform the torques generated by the motors in motion. The wheels are directly coupled to the engine without any gearbox. Figure 2b shows the CAD design of the wheel developed by J. Gonzalez. Finally, the support of sensors is designed by the authors of this publication and it is responsible for providing an attachment for the ultrasonic sensors. The orientation angle has been chosen is 30 degrees respect to the

<sup>1</sup>Download: <http://www.thingiverse.com/thing:18264>



**Fig. 3** Educational robotic platform

sagittal plane. Figure 2c shows the CAD design of the support of sensors.

Moreover, the tool used to perform the CAD design has been an Open Source 3d modeling software. For this task, OpenSCAD is the software used. OpenSCAD is a free software application for creating solid 3d CAD objects, which is available for any OS (Operating System). In addition, we have developed a user manual.<sup>2</sup> In this guide, we have explained the basic knowledge of this software. We have described the basic tools and added examples and exercises. In this way we have managed to have a self-taught manual. So anyone can learn to create simple pieces in little time.

Figure 3 shows the final design of the mobile robot designed with all the mounted devices. The global dimensions of our platform are approximately 12cm x 12.5cm x 7cm (length, width and height).

Finally, the designed 3d models of the mobile mini-robot are printed with a 3d printer. So in this case, we

have used a 3d printer as a tool to build the prototypes or pieces. Nowadays, 3d printers are becoming the most common tool to build prototypes. 3d printers are a recent technology with an exponential growth. The RepRap Project (replicating rapid prototyper) is an initiative that aims to create a self-replicating machine that can be used for rapid prototyping and manufacturing. A rapid prototyping machine is a 3d printer that is able to made three-dimensional objects based on a computational model. Due to the capacity to be self-replication and an Open Source machine, Josef Prusa revolutionized the mechanical design of this device when he dramatically simplified the construction of the RepRap Mendel. The result of his efforts, the Prusa model has become a standard in RepRap building. Therefore, this Prusa model is an Open Source design. To build our fleet of mini-robot, we have used a spanish 3D printer model named Prusa Air 2. This model is distinguished from the rest by his body of transparent acrylic, which makes it more elegant, robust and easy to calibrate. Table 1 shows the main characteristics of our 3d printer.

## 2.2 Hardware

### 2.2.1 Micro-controllers

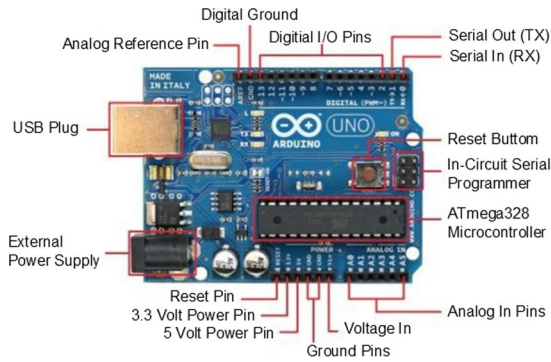
As mentioned previously also the hardware architecture of our mobile robot is Open Source. In addition we have said that we have developed two versions. In any case, for both versions, we decided that a low cost and easy integration should be the main features of the micro-controller.

On the one hand, the first version of the educational robot is based on the Arduino UNO. The Arduino UNO is an Open Source hardware platform. It consists of an Atmel 8-bit AVR micro-controller with

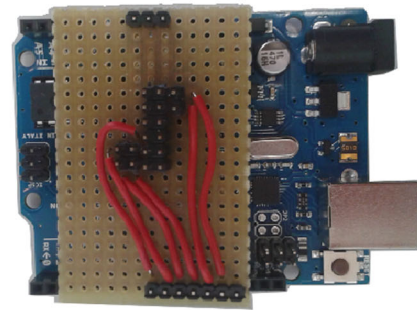
**Table 1** Main features of the 3D printer Prusa Air 2 model

Features	
Total size	410mm × 405mm × 400mm
Print volume	3910cm <sup>3</sup> (20×17×11,5)
Hotend type	J-Head MKV 3mm
Extruder	Jonaskuehling 3mm
Electronics	Sanguinololu 1.3b
Structure	Acrylic laser cut
Base hot	MK2

<sup>2</sup>OpenSCAD User Guide: <http://educatech.sytes.net/wiki/OpenSCAD>



(a) Arduino UNO.



(b) Developed integration board.

**Fig. 4** Arduino UNO hardware platform with the integration board. **a** Arduino UNO. **b** Developed integration board

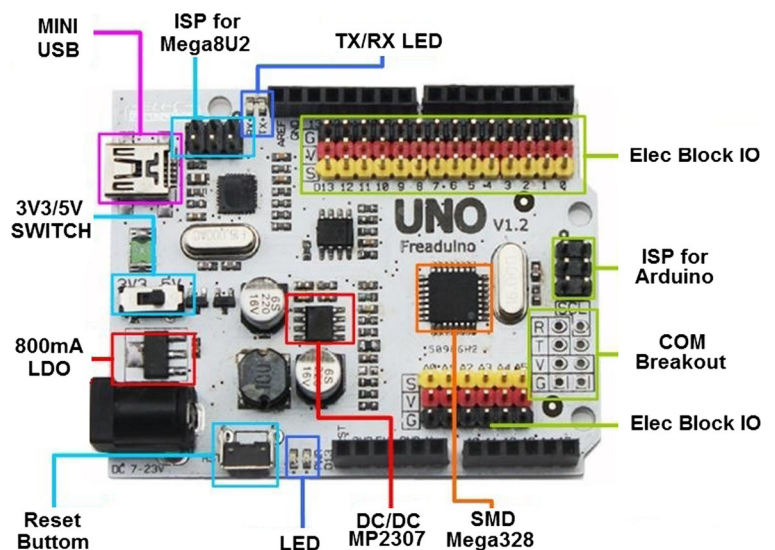
complementary components to facilitate programming and incorporation into other circuits. An important aspect of the Arduino is the standard way that connectors are exposed, allowing the CPU board to be connected to a variety of interchangeable add-on modules known as shields. Besides, The Arduino board exposes most of the micro-controller’s I/O pins for use by other circuits. It provides 14 digital I/O pins, 6 of which can produce pulse-width modulated signals, and 6 analog inputs. For this first version, we have developed a small board of integration through a prototype board. Figure 4b shows the Arduino UNO micro-controller with the integration board coupled.

On the other hand, the second version is based on the Freaduino UNO (Fig. 5). Also it is an Open

Source hardware platform. Freaduino UNO is an improved and updated board based on Arduino UNO (ATmega328P), 100 % compatible with all interfaces, shields and software designed for Arduino.

The reasons why we decided to change the micro-controller are three. The first is its new design. This allows attaching more easily any peripheral device. Thus, we do not need to build any integration board and therefore, we have reduced costs a lot. Another reason is the price of the Freaduino. This is cheaper than Arduino. A Freaduino costs 17.73 € and the other micro-controller costs 20 € + VAT. The last reason is associated with the restart Arduino UNO micro-controller. When there are multiple peripheral devices connected to the board, the electronics is unable to supply power enough. Because of that, the current

**Fig. 5** Freaduino UNO hardware platform





**Table 3** Main features of the peripheral devices

Feature	HC-SR04 ultrasonic sensor	SM-S4303R servomotor
Power	5 V	5V
Current	15 mA	100 mA
Size current	45 × 20 × 15 mm	41.3 × 20.7 × 40.2 mm
Weight	8.5 g	41 g

### 2.3 Software

To program Arduino/Freduino UNO micro-controllers, both use the software IDE with the same name Arduino programming IDE (we use version 1.0 or higher), which is Open Source and multiplatform.

Arduino programming is based on an extension of the C programming language. Furthermore, it is possible to use external libraries for receiving information from the most common sensors or controlling the actuators. Many of them are free on the Internet.

The program structure for Arduino is very simple and any inexperienced student can develop a simple program quickly. A common program in Arduino has at least three parts. First part is the library inclusion, in this case we only work with the **Servo** library. Second part is the *setup*, when serial is configured and pins are assigned. Third part is the main *loop*, when the main program is being executed forever. This last part is the most crucial and difficult part to understand for the students because is different than other programming languages. Having a continuous loop executing makes students open their minds to program with another methodology.

To program the activities we proposed, students need the common library Servo, that it is included by default in Arduino, and the library for the ultrasonic sensors. To get last one, it is necessary to access to the Internet and download a zip file with the code.<sup>3</sup> That code has to be located in the “libraries” folder inside the *skechbook* workspace of Arduino.

### 2.4 Cost

Table 4 shows the total unit cost of a single robot. In this, the prices of each component are disaggregated. As we can see, the electronics and actuators are more

<sup>3</sup>Download: [http://www.electfreaks.com/store/download/product/Sensor/HC-SR04/HCSR04Ultrasonic\\_demo.zip](http://www.electfreaks.com/store/download/product/Sensor/HC-SR04/HCSR04Ultrasonic_demo.zip)

expensive devices. In contrast, the pieces printed with the 3d printer are the cheapest. This is due to the modularity of our platform. So this allows the student to modify the mobile robot to its shortcut, without changing the expensive devices. Also we can say that we have developed an educational robotic platform that has a lower price to 50 € and has endless possibilities.

## 3 Evaluation and Results

The evaluation and results which we have obtained from the experiences in the activities done are completely explained next. Briefly, we have done three experiments with success on participation and results. For each experiment, we show many statistics about gender, age, etc. which we think it is important and useful information to gather for future experiences.

Before to show each one of the experiments, there is to keep in mind that two of the experiments are focusing in one way, to educational robotics focusing on teaching the use of new technologies as 3d printers, Open Source technologies, and agile programming of mini-robots. And, on the other hand, last experiment is focusing on teaching Open Source techniques to realize modular designs for the mini-robots.

### 3.1 First experiment

This experiment was the first of all. To this experiment we built a fleet of 10 complete mini-robots. It had a duration of one session of one hour and a half. The experiment was done with a group of 20 students. The initial idea was to have two students per robot because programming and test were not too much difficult.

**Table 4** Breakdown of the costs of the mobile robot

Quantity	Description	Unitary Price	Subtotal
1	Freduino UNO	17,730 €	17,73 €
2	Servomotors SM-S4303R	13,190 €	26,38 €
2	Ultrasonic sensor HC-SR04	2,590 €	5,18 €
1	Printed Chasis	0,100 €	0,10 €
2	Printed Wheels	0,020 €	0,04 €
1	Printed Sensor plugin	0,020 €	0,02 €
2	O-ring	0,035 €	0,07 €
1	Marble	0,020 €	0,02 €
Total			49,54 €



**Fig. 7** People from TechF3st workshop

As it is showed in Fig. 7, the activity took place within the TechF3st<sup>4</sup> workshop at the University Carlos III of Madrid, Spain. And, the main goal consisted in programming parking movements in a semi-close space.

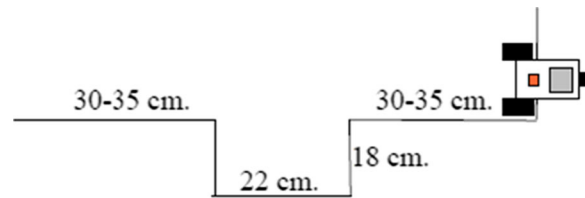
Figure 8 shows the parking scenario with concrete measures and the initial position of the robot. Students could do the task as they want. They are able to park the robot passing the parking space and going to back or going directly straight forward and turning.

Next, we show the statistics we got for this experiment. Figure 9 shows the ratio between men and women in the experiment.

About gender, we checked that there are more men than women. For that reason, we tried to promote to women next experiments.

In Fig. 10, we show the ratio about the ages. We divided the students in three groups, ages between 10 and 17 - pre-university students, ages between 18 and 25 - university students, and ages between 25 and 50 - master and non-university students.

This group was mainly adults between 18 and 25 years old, which is our mainly audience. Also, we had



**Fig. 8** Parking scenario

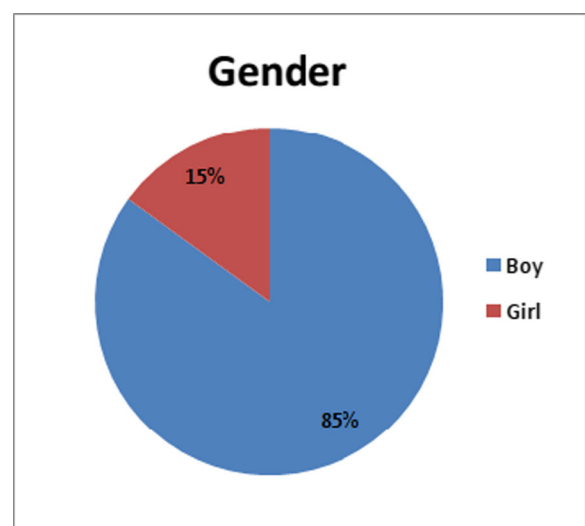
a 10 % of people in the third group who were pre-university teachers.

Lastly, Fig. 11 shows the results from the experiment. Results are divided in three groups, students who complete the task; students who almost complete the task, this group did the program but its robot cannot complete the task completely; and students who do not complete the task.

All the students in this experiment succeeded in programming the task with the robots. These results show how the task to implement was not too hard to teach in a session because everyone complete the task. Also, this results were a motivation for us to keep trying to teach robotics to university students.

### 3.2 Second Experiment

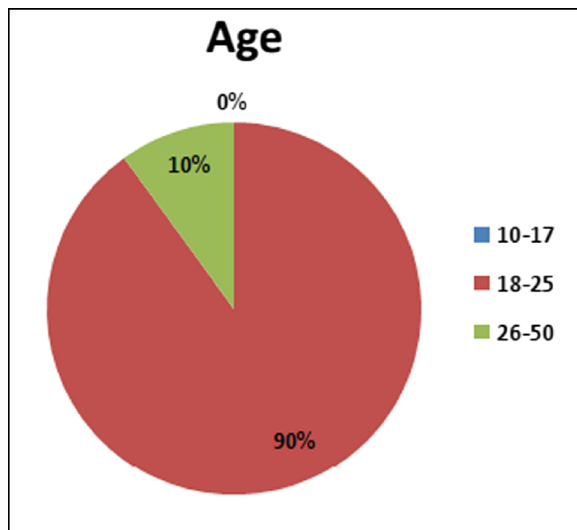
Second experiment tried to be a replica of the first one, checking if good results are repeated or it was an isolated result. We used the same fleet of robots as before experiment. It had a duration of only one session of



**Fig. 9** Diagram of gender ratio in experiment 1

<sup>4</sup>Official website: <https://techfest.uc3m.es/2013/>





**Fig. 10** Diagram of age ratio in experiment 1

one hour and a half per workshop. We did three workshops this time. In this experiment there were groups of around 30 students (2 or 3 students per robot).

The activity took place within the Robocity13<sup>5</sup> workshop at the University Carlos III of Madrid, Spain. Figure 12 shows the huge participation in these workshops. The goal of this experiment was the same of the first experiment.

Next, the statistics we get for the second experiment are showed. Figure 13 shows the number of men and women and the total amount of students by workshop.

From these partial results we can conclude that the number of men still follows being higher than women. Having approximate ratios of 60 % of men and 40 % of women in the first workshop, and 70 % of men and 30 % of women in the second and the third workshop. Then also, can be observed from the graph that assistance was too much higher than the first experiment, having groups of till 30 students instead of 20. Finally, we can conclude that even though still lower, the number of girls was plenty increased in comparison with last experiment.

The graph of Fig. 14 shows the information about ages. Being the groups divide at same from before experiment.

The slot with biggest number of participation was the second (university students) again. However, the

<sup>5</sup>Official website: <http://roboticslab.uc3m.es/robocity13/>

workshops had a high participation of pre-university students due to workshops were open doors to all kind of public this time.

In this experiment, we have added a new graph, Fig. 15, that show the ratio of students in groups, that is, if the task was realized in pairs or in groups of three students.

This graph is useful as previous step to analyze the results. Results, Fig. 16, show the number of groups (pairs or trios) who have completed or not the final task.

In this case, almost every group achieves to finish the task of programming the parking movement. As same as the first experiment results were positives, but this time having in mind that the number of participants had been incremented a lot.

### 3.3 Third Experiment

Trying to change the goal and also the destination of the workshops we decided the third experiment would be different from the previous. The main goal of this experiment was to design a new and original prototype of a modular mobile mini-robot. The new design had to be based on our original model, taking present the sensors and actuators used originally. Another goal we pursue was to teach how to use a 3d printer (Prusa Air 2) to print the models designed and to check if the prototypes work appropriately. This experiment was done with a group of 10 students and had a duration of 6 sessions of about 2 hours.

The activity took place as a seminar in the first semester of the course 2013-2014 within the Master in Robotics and Automation program at the University Carlos III of Madrid,<sup>6</sup> Spain.

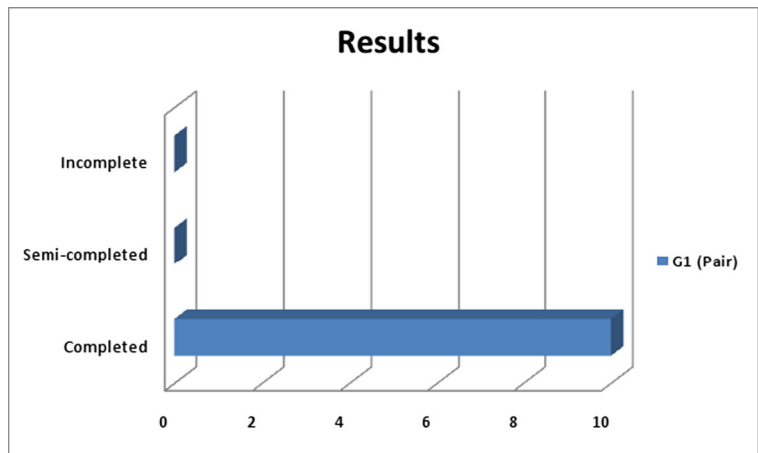
To pass the seminar, every student had to publish their work under a free license (Creative Commons Attribution-NonCommercial-ShareAlike)<sup>7</sup> on the web page Thingiverse [14]. In this way, students learned how to publish the work accessible for all the community and with a correct license.

Although the results were evaluated in a different way, we tried to give the same relevance to age and gender as in the other experiments. The graphs in Figs. 17 and 18 show the ratios between men and

<sup>6</sup>Official website: [http://portal.uc3m.es/portal/page/portal/postgrado\\_mast.doct/masters/robotica\\_automatizacion](http://portal.uc3m.es/portal/page/portal/postgrado_mast.doct/masters/robotica_automatizacion)

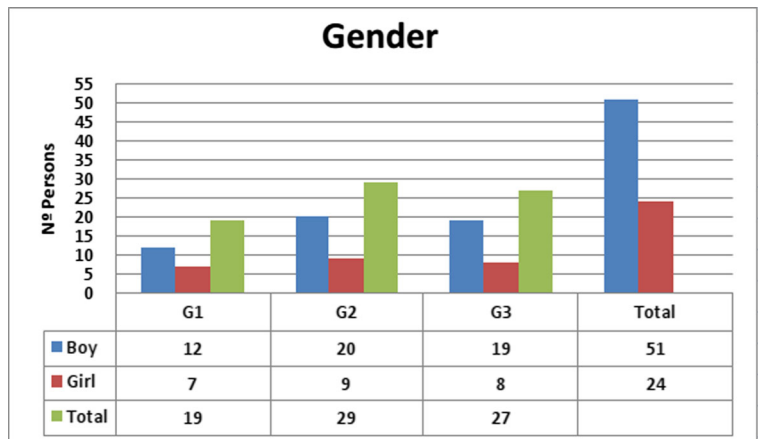
<sup>7</sup>More details in: <http://creativecommons.org/licenses/by-nc-sa/3.0/>

**Fig. 11** Diagram with results of experiment 1

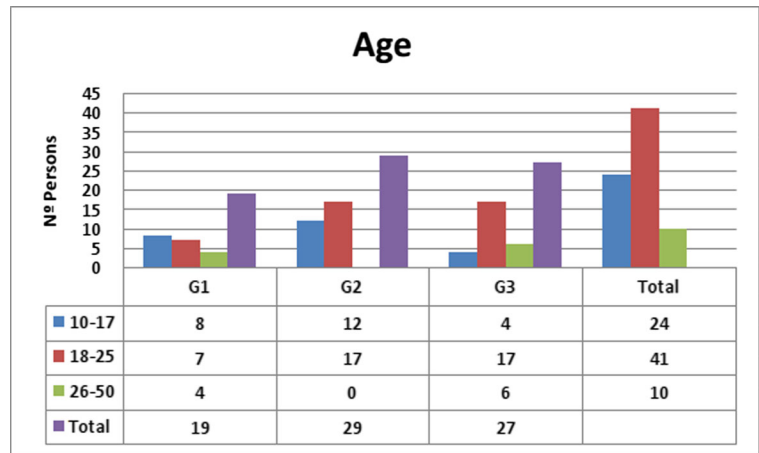


**Fig. 12** People from Robocity13 workshop

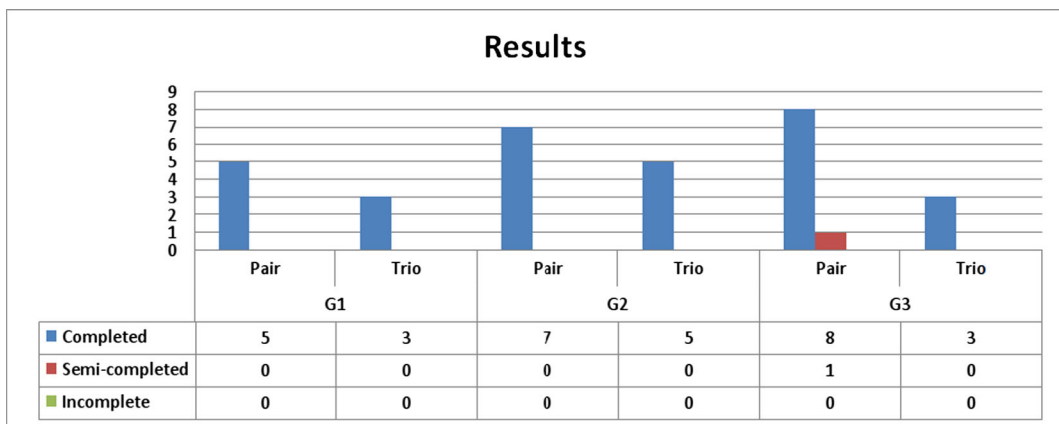
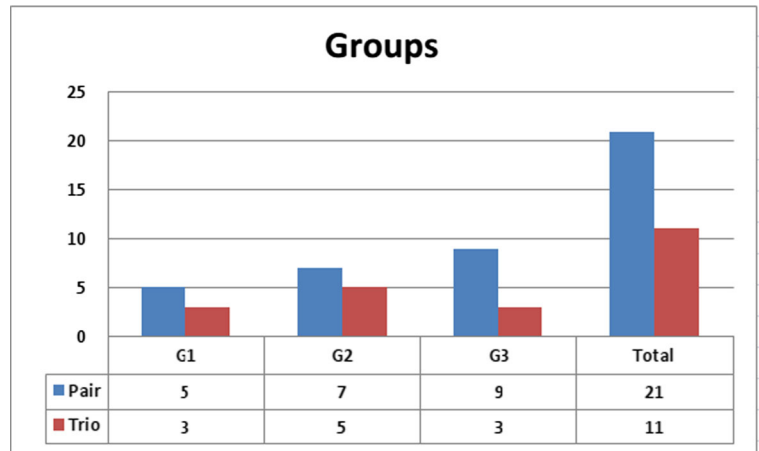
**Fig. 13** Diagram and table of gender statistics in experiment 2



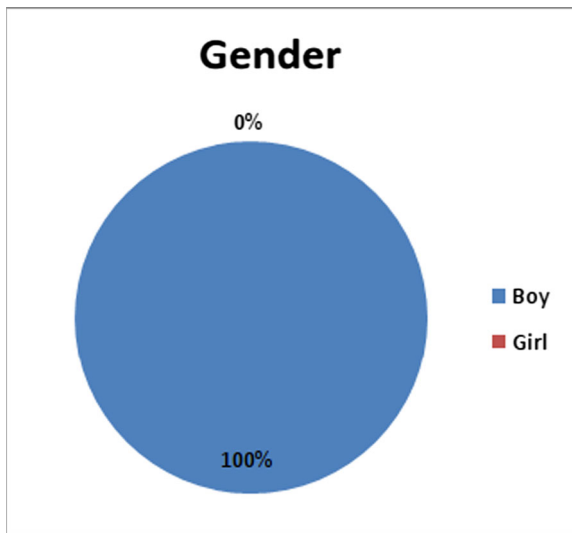
**Fig. 14** Diagram and table of age statistics in experiment 2



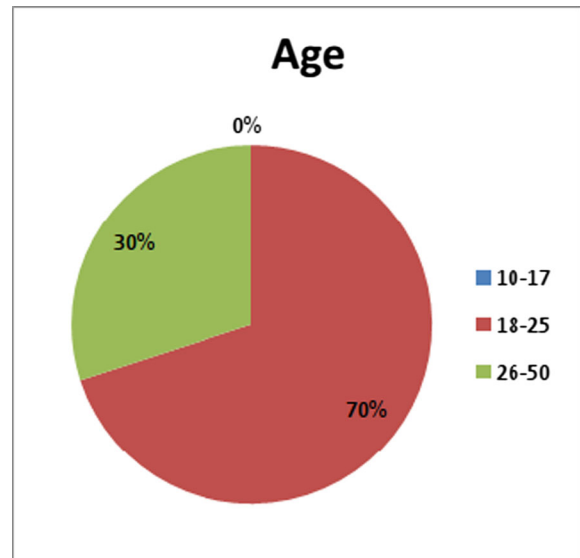
**Fig. 15** Diagram and table of groups statistics in experiment 2



**Fig. 16** Diagram and table of results statistics in experiment 2



**Fig. 17** Diagram of gender percentages in experiment 3



**Fig. 18** Diagram of age percentages in experiment 3

women, and the slots of ages evaluated respectively. As can be observed, in this experiment we had the disadvantage of having no women in the group.

Nevertheless, we follow with the main goal of these experiments. To intent all efforts for teaching university students with no previous knowledge in the matter. By this reason, students in the second slot of ages still follow predominating.

Lastly, the final results (Fig. 19) of this experiment have been evaluated in a different manner of the rest because the complexity of the designs. In this case, the evaluation considers the efficiency, the creativity, and the functionality of the designs. And, on the other hand, if the student have done documentation and have published correctly the design on the Internet.

Conclusions obtained from this experiment were the following. Every student document and publish their design satisfactory. Students learned, in this way, the philosophy of the Open Access/Source. At least, 3 of the 10 designs reach to be totally functional, the rest of them had some difficulties easily rectified to become it. The creativity of the designs was very innovative in general, standing out 4 designs from the rest. And last but not least, the feature more harmed was the efficiency of designs, having in mind the sensors and actuators they start having. The reason of that happened was because the most of the modular accessories were attached to the main structures with no having in mind the connectors and wires.

Some of the final designs done by the students are showed in Fig. 20. Observing very good results in general for all of them.

#### 4 Conclusions and Future Work

In this paper we have shown how we have completed our main goals for all experiments. We have encouraged the use of Open Source technologies. Also, we have taught robotics promoting the creativity for beginner university students with no previous knowledge in robotics.

We have also collaborated in the extension and construction of an educational robotic platform which is low-cost and open to replicate it. Furthermore, it is developed to be totally modular. And it can offer the possibility to show to the students the essential capacities about sensors and actuators, basic movements with a robot, and easy programming of a micro-controller. We have reached very good results having little time for each experiment and that show us educational robotics it is not the future, it is the present.

In other way, we have achieved offering for university students the opportunity to learn about basic knowledge on robotics, 3d modeling techniques and the Open Source philosophy. Also, having a great

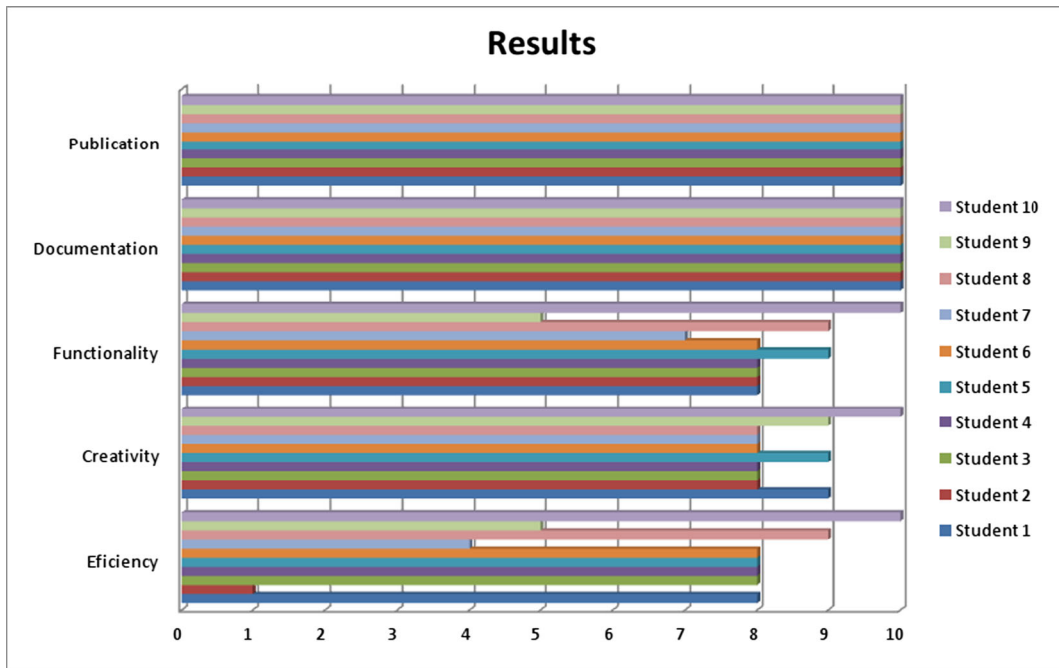


Fig. 19 Diagram with results of experiment 3

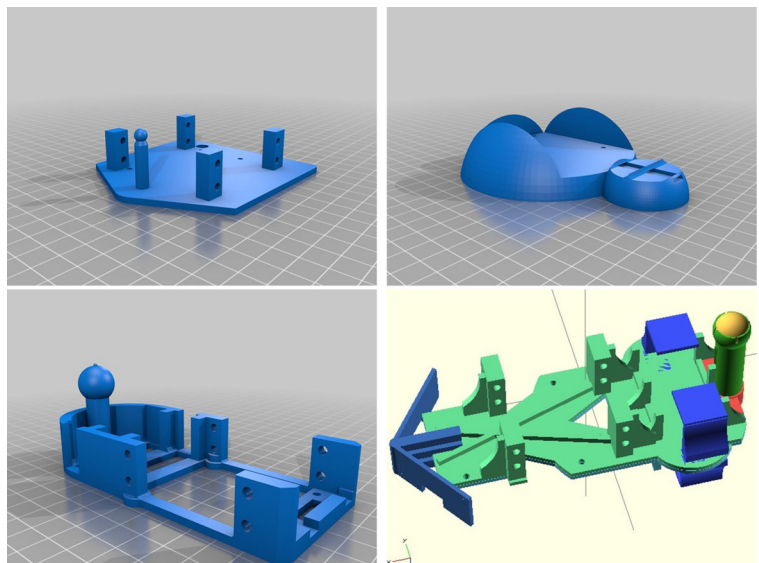
adaptation and results with the master students - students more specialized in the matter.

Lastly, not being our main goal at first, we have presented a pedagogy model to teach robotics, and unified statistics to control and demonstrate that the teaching is valid. This model is neither fixed nor

closed, but it will do that we learn about the necessities of the students in next experiments.

For a near future, we have in mind to follow our experiments in two different ways. The first one will be focused on improving our educational robotic platform, adding new sensors or actuators or even

Fig. 20 Main structure from four different designs



new modular accessories. And, the second one will be focused on teaching new students in other basic technology-related matters like software versioning (SVN, Git), 3d printers (build, materials), Open hardware, etc.

On the other hand, we do not want to leave any student, inexperienced or with some experience, without the opportunity of learning robotics. For that reason, we are proposing new workshops with a higher level of difficulty, taking advantage of all capabilities of our educational robotic platform. Using the sensors of the robots we have the possibility to teach signal processing, control techniques, mapping and localization, etc.

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