ROBOTICS IN PRIMARY SCHOOL: A REALISTIC MATHEMATICS APPROACH

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Abstract. Robots are technological tools of great interest in primary education for many reasons, but mainly for their compatibility with the STEM (Science, Technology, Engineering, and Mathematics). However, it is very important to minimize the impact of the technical issues associated to robotics on the teachers, providing simple and functional tools that allow them to focus their attention in the creation of STEM content. To this end, this chapter presents a methodology, based on Realistic Mathematics, for the integration of Educational Robotics in primary schools. This methodology has been tested during one semester in the Sigüeiro Primary School (Spain) in the subject of Mathematics, with students of different ages ranging from seven up to eleven years old. Two different educational robots, with different features, was used to highlight that the methodology is independent of the robotic platform used. Motivation surveys were administered to the students after the classes. Surveys reported highly successful results, which are discussed in the chapter.

Keywords: Educational Robots, STEM, Realistic Mathematics, Primary Education, Robobo

1. Introduction

Educational Robotics is a broad term typically associated with the use of real robots in pre-university education. In the last ten years, the introduction of robots as didactical tools in primary and secondary schools has been very remarkable. The main reason behind this boom comes from the decrease of hardware cost, and from the development of programming environments adapted to younger students, mainly based on blocks. Robots are used in classes as highly motivating platforms where students can learn programming, electronics and basic mechanics.

But the fast development of Educational Robotics has led to different approaches towards the integration of robots in general education. Different countries, regions, or even single schools, have adopted their own didactical model that introduce robots in different subjects, without a formal analysis of the most convenient way to do it. As a consequence, nowadays one can find many educational robots in the market, all of them in use, with different technological features, target ages, and offering different learning options.

In primary schools, robots have been used mainly as platforms, alternative to classic computers, in which to run computer programs. At this educational level, the students acquire basic programming skills while they can observe the consequences of their programs in a real device that, typically, can move, thus increasing their motivation. Typical robots used in this age range are the Dash&Dot (https://www.makewonder.com/robots/dash/), LEGO WEDO (https://education.lego.com/en-us), Cubetto (https://www.primotoys.com) or Root (https://rootrobotics.com), which are simple and robust, and which can be programmed using a block-based language.

Here, a more formal perspective of Educational Robotics is presented. Robots are a very powerful tool to introduce the STEM methodology in primary schools. To this end, this chapter follows an approach where robots are introduced in the official curriculum of the mathematics subject, in a progressive way from the first grades and in particular topics. This approach makes it simpler to introduce robots in schools right now, without requiring a profound reorganization of curriculums, like the one proposed in (Scaradozzi, 2015). The objective of using robots in classes should be acquiring basic competences of such subjects through the programming of the robot, and not just the programming itself.

As a first approach, the proposed methodology has been designed to be applied in the subject of mathematics, so the aim is that students learn specific mathematics contents with each robotics teaching unit. To reach such objective, they have to apply many different abilities from different disciplines, as will be explained later in detail. But, first of all, in the next section we will discuss why this practical approach to mathematics has been chosen.

2. Realistic Mathematics

There are numerous methodological perspectives on the teaching and learning of mathematics like those presented in (Karampinis, 2018; Karkazis, 2018; Daniela, 2016; Moro, 2018), but we are interested in highlighting Realistic Mathematics Education (RME) (Freudenthal, 1977). The aim is to move away from classical, memory-based, and abstract learning in which the teacher is limited to giving lessons and correcting written tests. Realistic Mathematics proposes seeking, in an initial phase, real contexts for the meaningful construction of mathematical learning, trying to make more concrete the abstract contents of this subject. Realistic Mathematics and cooperative learning are the two pillars on which the theoretical foundations of this chapter are based, and where robotics and mathematics walk hand in hand in primary classrooms.

According to Freudenthal (1971), in RME the teaching of mathematics is determined by an activity described as:

> *An activity of solving problems, of seeing the problems, but it is also an activity of organizing a discipline. This can be an issue of reality that has to be organized according to the mathematical patterns if problems of reality have to be solved. It can also be a mathematical matter, of new or old results, ours or of others, that have to be organized according to new ideas, be better understood, in broader contexts or by an axiomatic approach. (Freudenthal, 1971, 411).*

Following Freudenthal ideas, later several authors (Alsina, 2009; Alsina, 2011; Bressan & Zolkower, 2004; Martinez, Da Valle, Zolkower & Bressan, 2002; Van den Heuvel-Panhuizen, 2000) have described the RME from of the following principles:

1. *Activity*: Mathematics conceived as a human activity. The purpose of mathematics is to mathematize (organize) the world around us.
2. *Reality*: Mathematics is learned by doing mathematics in real or realistic contexts.
3. *Levels*: Students go through different levels of understanding: Situational (in the context of the situation); referential (schematization through models, descriptions, etc.), general (exploration, reflection and generalization), formal (standard procedures and conventional notation).
4. *Guided reinvention*: A learning process that allows the reconstruction of formal mathematical knowledge through mediation.
5. *Interaction*: The teaching of mathematics is considered a social activity. The interaction between the students and between the students and the teachers can cause each one to reflect on what others contribute and thus reach higher levels of understanding.
6. *Interconnection*: Mathematical content blocks (numbering and calculation, algebra, geometry, and so on) cannot be treated as separate entities.

Based on these principles, Alsina (2011) includes the characterization of the most significant features of RME, these are:

- Situations of everyday life or contextualized problems are used as a starting point to learn mathematics.
- These situations are mathematized to form more formal relationships and abstract structures.
- It is based on the interaction in the classroom among the students and between the teacher and the students.
- Students are encouraged to interpret mathematics under the guidance of an adult, rather than trying to transmit a pre-constructed mathematics to them.

Children must, therefore, learn mathematics in real and close contexts that have meaning for them, from which to develop concepts and apply rules. This way the need for mathematization arises: moving a problem from everyday life to the world of mathematics, solving it, and returning it to the real world, which familiarizes the student with the mathematical world.

Finally, it should be noted that, according to Freudenthal (Gravemeijer and Teruel, 2000), the strongest argument that supports and justifies the existence and importance of RME is that not all students will be mathematically mature, but almost all of them will use those mathematics that help them solve problems of daily life. Robotics, as a support for teaching and learning mathematics, has obtained considerable contributions (Pinto, Barrera & Pérez, 2010), making it ideal for learning by playing in an interdisciplinary fashion.

3. Proposed methodology

To clarify how this methodology can be realized in practical terms, this section describes the specific experience carried out during the year 2018 in Spain. The sample of participants is composed of all elementary students of the CEIP school in Sigüeiro, a total of 233 students, with an age range from 6 to 12 years, as shown in Table 1. All the gathered data from the participating students respect the ethical implications of the projects in the educational field, which refer to, generally, the establishment of an atmosphere of trust between the teaching staff and researchers, and to the adequate treatment of the data of sensitive nature. Both of these aspects are taken into account to be conveniently treated from the perspective of the Socially Responsible Research (SRR). For the treatment of the information obtained through direct involvement with the students, authorizations were requested to the parents or legal guardians of the minor, in order to collect the data through audio and video, as well as in written form. In any case, it is maintained that the privacy of the students is respected in the publications derived from this studied, always identifying them under pseudonyms.

Table 1. Details of the participants in the workshops that make up the proposed methodology

Course/Grade	1st	2nd	3rd	4th	5th	6th	TOTAL
Nº students	48	18	24	48	48	47	233

The proposed methodology for introducing educational robots in the existing mathematics curricula of primary schools starts from the two following general premises. First, on each primary school grade, some specific mathematics lessons from the official curriculum are selected to be reinforced, or taught, using the robot as a real-world application platform following the Realistic Mathematics methodology. Such lessons were organized in the form of a practical workshop. Second, these robotic classes were programmed in all the primary education grades, that is, the robot was used as a long-term didactical tool as students grow, so they were acquired technical knowledge about its operation in a progressive way.

According to the methodology, the main aims is to organize which topics of mathematics will be covered in each school year. In this sense, Table 2 summarizes the specific topics selected for each workshop in each of the six elementary grades (from six to 11 years of age). These topics are organized according to the existing curriculum. The table also includes a possible way to teach programming concepts. Each workshop lasts 2 hours, which is the minimum time required to administer a class like this. The number of robots per workshop depends on the number of students and the number of teachers who control the workshop.

Table 2. Specific topics selected for the workshop depending on the grade

Grade	**Workshop 1**	**Workshop 2**	**Workshop 3**	**Workshop 4**
1ST	Natural numbers	Sequential operations	Distances	Open and closed lines
2ND	Natural numbers: comparison	Time units	Straight and curved movement	Planar figures
3RD	Natural numbers: basic operations	Distance units	Angles	Following a path
4TH	Decimal numbers	Measuring distance and time	Angles	Basic algorithms
5TH	Decimal numbers	Measuring distance and time	Angles	Symmetry
6TH	Integer numbers	Measuring distance and time	Angles	Cartesian coordinates

Two different educational robots were used in the workshops: the MBOT (www.makeblock.com/STEM-kits/mbot) and the ROBOBO (http://theroboboproject.com/en/), to show that the methodology can be applied independently of the specific robotic platform the school has. This affects the specific challenge that can be carried out, of course, being the responsibility of the teacher to design the most appropriate ones according to the robot.

The MBOT (Fig. 1) is a small mobile robot based on Arduino, which is cheap and has many possible expansion options. It can be programmed using mblock, a programming environment created by Makeblock which is based on the Scratch block-based language (http://scratch.mit.edu). It is equipped with two motors for the wheels, one ultrasonic sensor and a line sensor. Students have to construct the robot for the first time, which can be used as a part of the initial workshops. With this robot, three workshops have been carried out for the 4th, 5th and 6th grades. Here, we will explain in detail of the one given in the 5th grade, focused on symmetries.

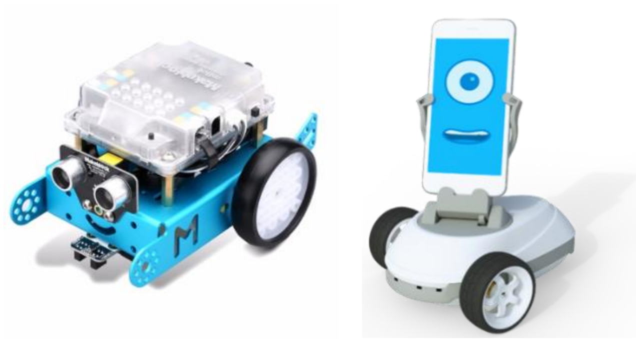

Fig. 1. The two educational robots used in the workshops. The mBot (left) and the Robobo (right)

The ROBOBO (Fig. 1) is an educational robot based on the combination of a smartphone and a simple mobile base (Bellas et al., 2017). The smartphone is attached to the base as shown in Fig. 1 and linked by Bluetooth, so students can program both elements from the computer as if they were a single robot. ROBOBO has a much higher technological capability than the MBOT due to the smartphone's features, and the students can use advanced sensors like cameras, microphones, gyroscope, accelerometer and so on. In addition, the speaker, screen and base motors provide a large amount of interaction possibilities, so it is a very powerful robotic platform for teaching human-robot interaction topics. This is the reason why it was applied in the workshops for younger students, those in the 1^{st}, 2^{nd} and 3^{rd} grade (between 6 and 9 years old). ROBOBO can be programmed, as well, using the Scratch block-based language through the ScratchX environment (https://scratchx.org). Here, we will explain in detail a case study within the 2^{nd} grade, focused on geometry, specifically, basic planar figures.

The workshop organization, which is an example the methodology application, will be described in detail in the following sub-sections:

3.1. Didactical basis

From a didactical perspective, the workshops have been designed considering a STEM project-based methodology.

Project-based: there is a challenge to be solved with the robot that students must solve at the end of the workshop, and which is focused on the specific selected mathematics topic. This global challenge must be divided by the teacher into small robotic activities that lead to its completion in a progressive way. This division is important in our methodology because it is crucial that students understand how to face a complex problem in a hierarchical fashion. The mathematics concepts required to solve the challenge should be introduced in previous classes, and students can use in the workshop the sources of information that were provided.

To solve the challenge, it is required not only to solve the mathematical aspects, but many other related to robotics: students must build an experimental environment or arena where the robot operates, they must manipulate different accessories or tools like screws, insulating tape and so on, and, of course, they must program the robot using the computer. All of these activities are inherent to the project-based methodology, and it is very important that the teacher provides students with a general view of the tasks they must face, in order to carry them out in an ordered manner.

The solution to the activities, and global challenge, must be autonomously obtained by the students, with the guidance of the teacher mainly in the correct selection of steps to solve the problem, and not in the particular way it is solved.

STEM: although the final objective of the workshop is stated within the subject of mathematics, to solve it with the robot implies integrating knowledge from other disciplines, like programming, physics (kinematics), mechanics (design, manipulation) and, of course, robotics. A very relevant topic at this educational stage is that of learning the basics of programming, which can fit in the mathematics curriculum as well, as it trains logical reasoning. In this sense, the following considerations must be made:

- Programming knowledge will be introduced in a progressive way during the different workshops. This is a very important aspect of this methodology, as it does not require previous programming skills. They are acquired as the global challenge is addressed. Remember that this robotics methodology is opposite to the traditional use of robots just to learn programming, so these skills are acquired as they are required to solve the mathematics challenge, but they are not the main didactic goal.
- Each activity requires programming the robot, which must be introduced by the teacher following an adequate order, with the objective of teaching a complete set of programming skills in a long-term setup, that is, during the whole primary education. As a consequence, the proposed challenges must be adapted to the programming complexity.
- The programming language at this age should be based on blocks, as it is simpler for students and the learning stage is short.
- The programming concepts can be explained in different order, but here we propose adhering to the following one. We also indicate an optimal learning age:
    - Programming basics: sequential operation, logical thinking and basic blocks usage (from 7 years old)
    - Sensors and actions (from 7 years old)
    - Conditionals (from 9 years old)
    - Loops (from 9 years old)
    - Variables (from 10 years old)
    - Expressions (from 10 years old)
    - Functions (from 10 years old)

Regarding robotics itself, there are many concepts that are specific to this discipline and that will be introduced during the different learning stages. Specifically:

- *Sensors*: understanding basic concepts of sensing like the magnitude to be measured, the data processing, the calibration or the noise.
- *Actuators*: understanding how the robot can act in the real world, mainly in terms of motors and how they work.
- *Reality gap*: it is a key aspect when learning robotics, because students have to understand that the real world where robots operate is complex and the translation between the program logic and its real consequence is not direct.

In addition to these general aspects, students must perform many physical manipulation tasks, both with the robot but also with the experimental environment where the robot performs the task, so teaching them basic manipulation skills like screwing or gluing is very important. In fact, some challenges may imply a more elaborate environment for the robot, that students should construct in previous classes. For instance, a small city created with streets the robot must travel.

3.2. Evaluation

The evaluation of the workshops is based on the analysis of the student's notebooks and on rubrics. An example of the used rubrics is that of Table 3, that allows the teacher to evaluate the student's competence and motivation in different aspects of the workshop, as well as their knowledge in specific questions about the mathematics concepts treated during the workshop. Each student has its own notebook (Fig 2) where they must take notes about the steps followed to achieve the objective of the workshop, mainly those related to the challenge and activities proposed by the teacher, but all he/she considers important. This notebook can be used to assess what data each student collects and how they do it when they are doing the workshops. Likewise, it serves to complete, in the rubric, the aspect about the attention placed in the classroom.

Table 3. Proposal of possible rubrics that can be used for each student

Level (score) / Aspects to be evaluated	Expert (4)	Competent (3)	Partially competent (2)	Not yet competent (1)
Time management	Satisfactory use of time during the entire workshop.	Uses time well but can be delayed in some aspects.	Has issues with time management and can cause delays to the team.	Has serious issues with time management.
Design and construction of the solution: ability to understand the objective	Understands the objective of the workshop, and the path to reach it, and to obtaining the solution of the activities.	Understands the objective of the workshop, but the path to reach the solution is unclear.	Has doubts when understanding what is the objective of the workshop.	Has great difficulties to understand the objective of the workshop.
Mathematics knowledge	Recognizes and relates the mathematical concepts involved in the workshop.	Recognizes the concepts appropriately, although has trouble establishing relations between them.	Has difficulties to recognize some concepts involved in the workshop.	Does not recognize the majority of the mathematical concepts involved in the workshop.
Attention in the classroom.	Always pays attention to the teacher's explanations and to everything discussed in the classroom.	Pays attention to the teacher's explanations and to everything discussed in class most of the time.	Pays attention but is frequently distracted.	Does not pay attention to the material discussed in the classroom, focusing on things that have no relation to the teacher's explanation.
Attitude: active participation	Always participates in an active and voluntary manner.	Usually participates in an active manner in the classroom.	Often participates, only when asked to.	Does not participate in class, not even when asked to.

Problem solving: practical ability	Contributes with information and abilities when solving problems, showing initiative and fomenting other's work.	Usually contributes with information and abilities when solving problems showing initiative.	Contributes with information and abilities when solving problems, only if asked to.	Hardly ever contributes with information or abilities when solving problems.

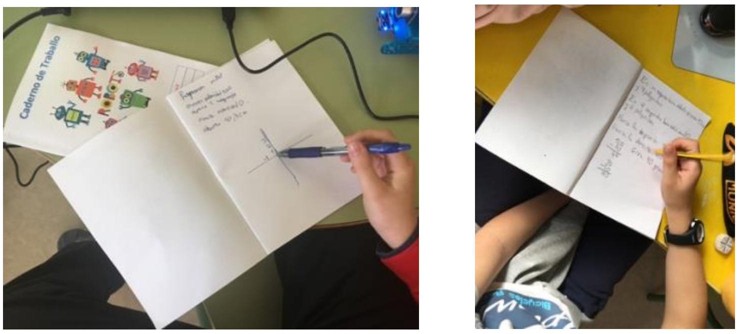

Fig. 2. Examples of students' personal notebook that they must use in the workshop

In addition, with the aim of evaluating the student's motivation when working with robots, a questionnaire with 12 items in a five-level rating scale (nothing, little, something, enough, a lot) was created. The specific items are included in Appendix 1. This motivation questionnaire was applied at the end of each session so that each student could fill it individually in the classroom. With respect to its analysis, the first thing that we are going to indicate is the degree of satisfaction of the students with the robotics session in which they participated. This is observed in the second item (did you find the class fun?) and in the twelfth one (would you like to continue learning with robots?). In general, the results of the class were positive for all levels, which are discussed in section 5.

3.3. Classroom organization and equipment

The classroom organization and features where the workshops are carried out are very important in this methodology. A properly organized teaching space as well as different tool and practical elements are required for each group. In this sense, Table 4 contains a specific list of elements that should be present in the classroom:

Table 4. Elements that should be present in the room and basic equipment

Room	**Equipment for each group**
Round tables where students can work in teams of 4 or 5	1 educational robot, mBot or Robobo
Flat open space, in the floor or in an additional table, where robots can move freely	1 computer (ideally a laptop)
Workshop space	Connection cables and power supply (power strip)
WIFI connection available	Screw, measuring tape, insulating tape and scissors.
1 projector to show slides of the workshop contents	
1 computer or laptop, for the teacher	

The students of each class were divided into groups of four members per group. Each group contemplates the following roles:

- *Programmer*: responsible for programming the robot using the computer
- *Robotician*: responsible for manipulating the robot (turning it on and off, moving it from the table to the moving area and so on) and taking care of it (controlling that is has enough battery charge for the workshop, that it is not damaged during the class, etc).
- *Technician*: responsible for all the external elements and devices required to carry out the workshop, for instance, measuring tape, obstacles, etc. If any element must be constructed to carry out the lesson, it should be made before the workshop period in order to optimize the existing time.
- *Organizer*: responsible for managing the group activity, controlling the time used on each activity and interacting with the teacher in case of questions or comments.

Each student can help others in a different role in case of necessity, with the aim of all of them being active during the whole class. The teacher must assign to each students in a group one of the previously mentioned roles before the workshop and explain to them the main responsibilities associated with it. The roles must be interchanged during the four workshops that will be carried out during the school year, so that each student in the group assumes each role at least once.

4. Workshop description

In the following two subsections, two specific workshops for each robot will be explained in detail, in particular those marked in red in Table 2 corresponding to the 5th and 2nd grades.

4.1. 5th grade workshop

First of all, students were organized before the workshop into groups of 4 members with their specific roles previously assigned. Each group had its own table and chairs, with one laptop and one robot, as it can be observed in Fig. 3. The class starts with the teacher presenting the robotics challenge they must face, in this case summarized in the diagram displayed in Fig. 4. They must implement a program in Scratch so that the robot can *avoid a rectangular obstacle ahead*. The specific obstacle was the mBot box, which could be located in any position in front of the robot, so it has to detect it using the sensors and then perform the movements displayed in Fig. 4.

Fig. 3. Classroom and groups organization

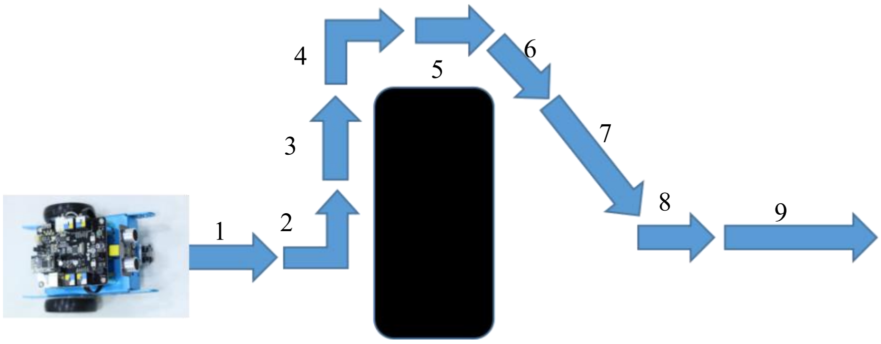

Fig. 4. Path that the robot must follow in the 5th grade workshop

Once the challenge is clearly understood, the student responsible of each role starts preparing his/her own part: turning on the computer and launching the programming environment (mBlock software in this case, which uses standard Scratch blocks and additional blocks specific for the mBot robot), turning on the robot, preparing the space on the floor, and preparing the additional elements, like the measuring tape. To solve the challenge, each group must have the following additional elements: measuring tape, protractor, mBot box, adhesive tape and scissors.
To guide students towards the completion of the challenge, the teacher proposes the steps to be followed in the form of activities, and gives time to students in order to carry them out. In this workshop, 7 small activities were proposed:

1. *Moving the robot to a certain distance*: to move the mBot a certain distance, students have to make a small program because this robot does not have any predefined block to do that. Following the proposed methodology, first the teacher shows students a program with a preliminary solution to this problem, displayed in Fig. 5 left. Before they copy the program in their computer and execute it on the robot, the teacher must explain the behavior of the blocks *if it is the first time students use them*. It is important to remember that, although the objective of the workshop is not on the robotics part, students must understand its basic operation. For instance, in this case the first block "- at speed -" makes the robot move in different directions and with different speeds using the wheel motors. There are two fields in this block the teacher should explain showing their effect in the robot movement, and the physical reason of such effect. The left field allows to select the robot direction between 4 options: "run forward", "run backward", "turn right" or "turn left". The teacher should explain that behind these pre-defined directions, the motor speeds are different for each wheel, obtaining this way a different direction. The right field allows to choose the robot speed, and it ranges from -100 up to 100. The teacher should explain that this is an arbitrary unit, it does not correspond to any standard speed unit like cm/s or m/s. Moreover, the difference between using positive or negative values must be remarked too, highlighting how the wheel turning direction creates forward and backward movements. Summarizing, explaining the details of each block and its relation with the robot response is very important in this methodology to allow students to understand the robotics background and get used to it.

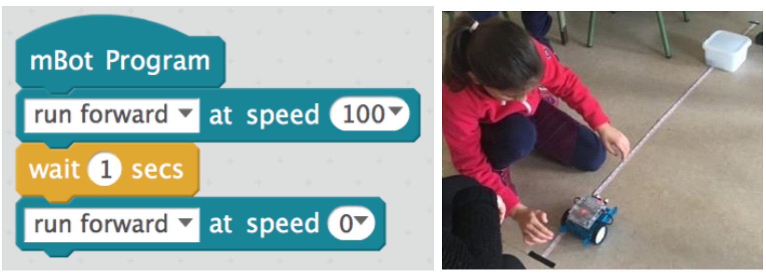

Fig. 5. Preliminary solution (left) and distance measurement procedure (right)

The third block in the program displayed in Fig. 5 is a “wait - secs” block, which is a basic block in any programming language, and has the effect of pausing the program the number of seconds established in the field. This time can be an integer or decimal value, and it is important that students understand this difference. The fourth block is, again, a movement block, in this case “run forward at speed 0”, which makes the robot stop. So, once all the blocks are clear, the teacher must carry out an overall explanation of the program logic before students try it: the robot starts moving forward at speed 100 and one second later, it stops.

To execute this particular program, students must first know how to download the program to the robot using the USB cable or by Bluetooth. This is part of the *Robotician* role in the group who, in addition, must put the robot on the floor and leave free space in front of it. Moreover, they must fix a measuring tape to the floor and make the robot move next to it, as displayed in Fig 5 right. After executing the program, the robot moves straight during 1 second at a speed of 100, and the students must write down the distance covered by the robot in their notebooks. In this specific case, the distance covered by the mBot was about 5 cm. It is important that the teacher emphasizes that the measurement must be reliable, so the robot must start in the zero value of the tape, and they must be precise with the measurement of the final position. Moreover, the program execution should be carried out more than once in order to avoid punctual fluctuations. All of these tips are very important to introduce students to the relevance of being technically formal.

Next, students had to measure the box sides with the measuring tape and annotate them again. Considering the distance covered by the robot when executing the program shown in Fig. 5, and without changing the speed, students had to adjust the time the robot moves in the “wait – secs” block in order to make it advance these two distances (in the case the box is not a rectangle but a square, they will have only one distance). Students at this level know the mathematical concept of rule of three, so instead of trying different time values, they have to calculate the right one, put it on the wait block and test if the calculation was right. Specifically, for a box of 22x22 cm side:

$$5 \text{ cm} \rightarrow 1 \text{ second}$$
$$22 \text{ cm} \rightarrow x$$

So, the time they should try is 4.4 seconds. If the distance covered is not exactly the expected one, students can slightly adapt it. Notice that in this initial activity they worked with time and distance measurements, integer numbers and decimal numbers in an integrated fashion, as proposed.

2. *Turning the robot 90 degrees*: once the students know how to make the robot move frontally the predefined distances, the second step towards the completion of the challenge is to make it turn 90º. If you see the path displayed in Fig. 4, the mBot must perform two 90º turns, one to the left and another to the right, in order to avoid the obstacle. Again, the mBlock software does not have any block that allows the robot to turn a specified value, so students must create a program to do it. In this case, the teacher presents the program displayed in Fig. 6, explaining that the only difference with respect to the previous one is in the first block, where now the specified movement is “turn right”, so the logic would be: the robot starts turning right at speed 100, and one second later, it stops.

Students copy this new program in the mBlock software, or modify the previous one, and then they download it and execute it on the robot. To do it, the one with the *technician* role must fix the protractor on the floor using the adhesive tape, as shown in Fig. 6 right, and the *robotician* puts the robot on top of the protractor. Students must measure the degrees rotated by the robot in this specific case, and annotate this value in the notebook. From this value, and using again a rule of three, students must now calculate the time required in the "wait – secs" block to make the robot turn 90º right. This value was around 1.2 seconds with the selected speed. Finally, they must change the program to make the robot turn 90º left, which implies changing the first block and selecting "turn left at speed 100", using the same value of 1.2 seconds for the wait block.

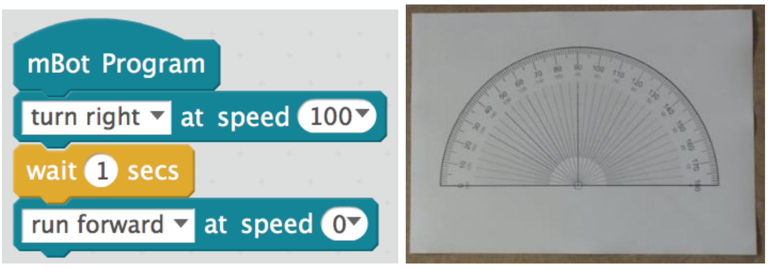

Fig. 6. Preliminary solution (left) and protractor fixed to the floor (right)

3. *Turning acute and obtuse angles*: now students have three small programs that allow them to move straight a predefined distance and turn 90º right and left. The next step to solve the challenge displayed in Fig. 4, is to perform a small turn to the right and then to the left to return the robot to the original path. To do it, students must understand the concept of acute angle. In addition, we introduce here the concept of obtuse angle although it is not necessary in order to solve this particular challenge (the diagram displayed in Fig. 7 is shown through the projector). So, in this activity, students must modify the previous program to make the mBot turn an acute angle and then an obtuse angle (the specific values must be selected by them) by changing the time in the "wait – secs" block.
They test their solution using the protractor and annotate the time in their notebook. There are many possibilities on each case but, for instance, in the case of the acute angle the time used in the block must be lower than 1.2 seconds.

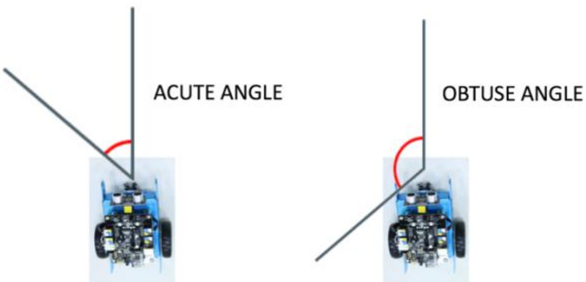

Fig. 7. Example of acute and obtuse angle turned by the robot

4. *Stopping the robot in front of the obstacle*: the previous activities create small programs that move or turn the robot a predefined value. This type of program is not very useful in robotics, because the actions should rely on the sensing, that is, depending on what the robot perceives, it moves or turns in a different fashion. To show that to students, they put the robot on the floor with the box in front of it at a distance of 15 cm and they execute, again, the program displayed in Fig 5 using a time of 4.4 seconds which correspond to covering 22 cm. The result is that the robot crashes with the box. Next, they put the box at a distance of 40 cm from the robot, and try the same program. The result now is that the robot stops far away from the box. What the teacher must point out is that this program

depends on a predefined distance to the box, which is not useful in many real cases, where the robot doesn't know, beforehand, where the obstacle will be placed.
The solution is using a sensor that provides the distance to the box, in this case, the ultrasonic one that is placed on the frontal part of the mBot. The teacher shows the program displayed in Fig. 8 left, which makes the robot start moving straight at speed 100, then it waits until the distance returned by the ultrasonic sensor is lower that a threshold (the robot keeps moving), and then it stops. Students copy and try this program placing the robot in front of the box at an arbitrary distance. In fact, they should try the program with different distances to realize that now the robot is really autonomous, that is, it stops without knowing the distance to the box beforehand. The threshold value (10 cm in the example shown by the teacher), must be adjusted by each group considering that the robot must have enough free space to turn without crashing with the box (see Fig. 8 right). Once chosen, students must annotate it in their notebook.

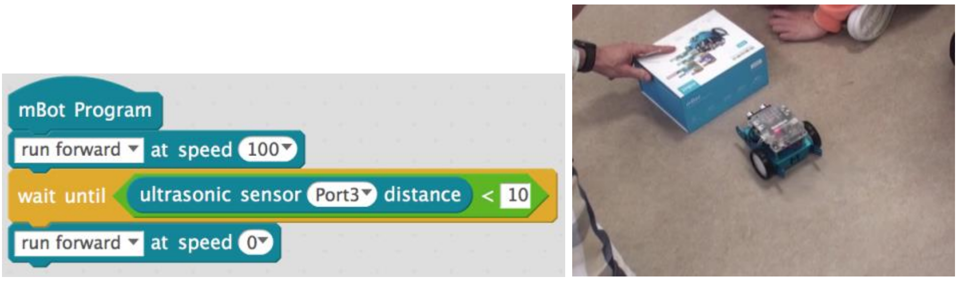

Fig. 8. Preliminary solution (left) and obstacle used in the workshop (right)

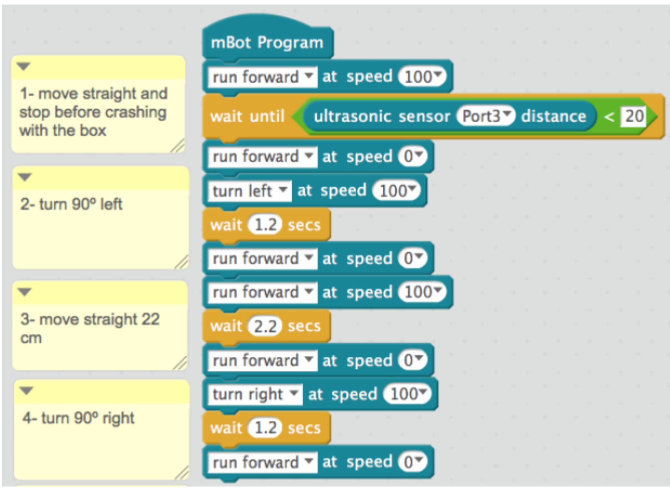

Fig. 9. Partial solution to the 5th grade workshop

5. *Stopping the robot and avoiding the obstacle*: at this point, students have all the components of the global program, so they have to join them to create the solution to the challenge. Thus, starting from the program shown in Fig. 8 with the threshold distance adjusted by each group, the first step is to concatenate it to the program that performs a 90º left turn developed in activity 2 (step 2 in Fig 5). Second, students must add the program developed in activity 1 which moves the robot straight for a distance equal to the box width, in order to overpass it, as represented by the step 3 in the diagram of Fig. 4. The third step is to use again the program developed in activity 2, but now to perform a 90º right turn (step 4 in Fig 4). The solution to this activity is displayed in Fig 9, and it must be found by

the students, which may require a period of thinking and reflection before trying it on the robot. When executed, the robot finishes at the left side of the box, which must be tested by all groups before moving to the next activity. Although it is not mandatory to stop the robot after each single movement with the block “run forward at speed 0”, it is interesting to do that at this level, in order to show that the global movement is composed by discrete steps which are easier to compose and control.

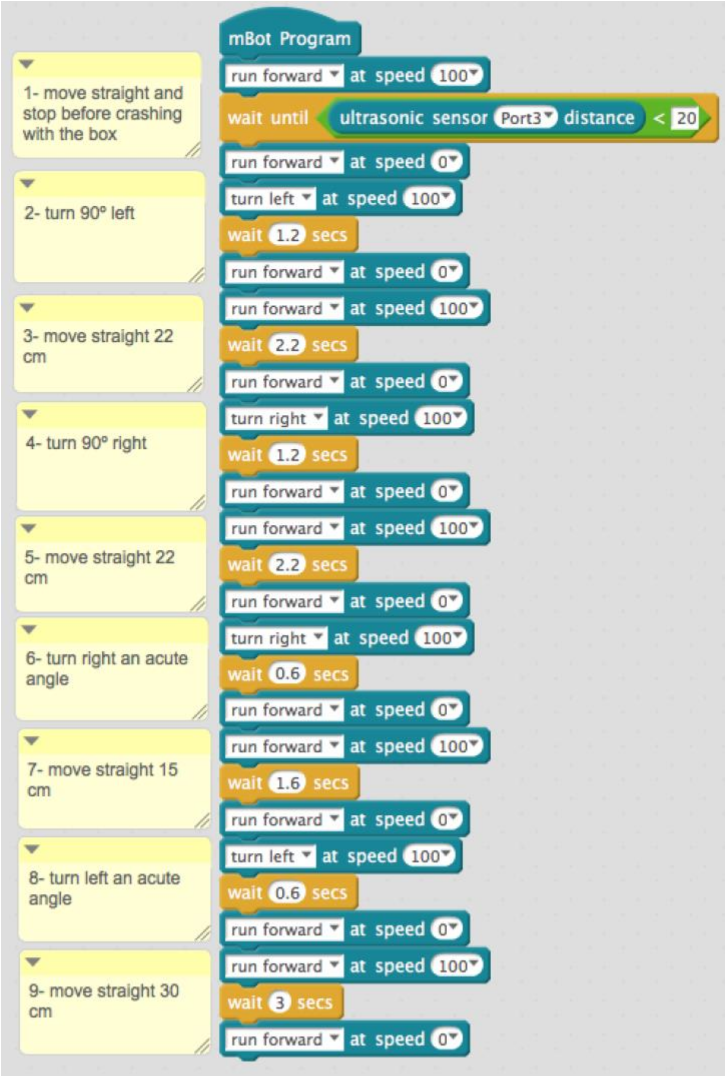

Fig. 10. Final solution to the 5th grade workshop

6. *Returning the robot to the original path*: the steps required to complete the program are those shown in Fig. 4 as 5, 6, 7, 8 and 9: moving the robot straight until it overpasses the box left side, turning right an acute angle, moving straight until it reaches the original path, turning left the same acute angle and, finally, moving straight a predefined distance just to show that it has avoided the obstacle and can keep on moving. These four steps can be carried out using the programs developed in previous activities, but this is part of the student’s job, that is, it is important that they understand the objective and how it is related to the previous steps, so they can divide the whole problem into small ones by themselves in the future.
A possible solution to this activity is shown in Fig. 10, but each group can perform their own variation. The execution of this program solves the global challenge, so it is important that the teacher emphasizes that it is important to reach a valid solution in practice. They must recognize whether their solution is successful, that is, if the robot returns to the

original path or not, although high precision is not required. The final movement of the robot could be recorded on video by the students.

7. *Symmetric movement*: the main objective in this workshop was to solve the challenge displayed in Fig. 4, but with the aim of understanding the concept of symmetry. So, at this point, the teacher can pose the following question to students: why do you avoid the obstacle on the left part of the box? Why not on the right? The typical answer is that, of course, it is possible to do that and it would be a symmetric movement, as shown in Fig. 12 in red color. So now, the students have to create a copy of the final program, and change it so that the robot avoids the obstacle on the right (we do not show this solution because it is equal to that of Fig. 11 but changing steps 2, 4, 6 and 8).

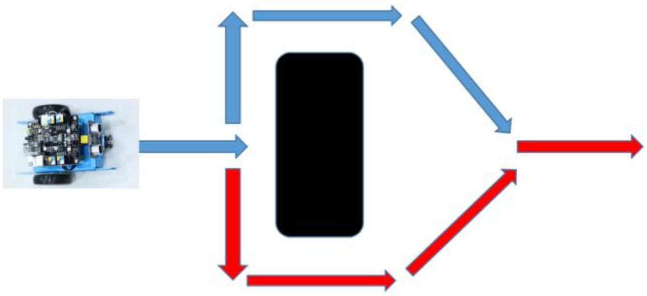

Fig. 11. Schematic view of the symmetric movement

Summarizing, the proposed methodology has been clearly shown with this workshop example. The main didactical objective was understanding the concept of symmetry from a practical point of view, and it has been clearly achieved. To reach it, many other mathematical concepts have been used: integer and decimal numbers, time and distance measurements, rule of three and angles. From an algorithmic perspective, students have created a simple solution based on the sequential combination of small programs, which is very important in programming. Regarding specific programming topics, students have learned o reinforced basic blocks as “wait” or “wait until”. Finally, from a robotics point of view, basic concepts of motor movement and ultrasonic sensing have been used. As it can be seen, the STEAM methodology is clearly exploited in this type of workshop.

4.2 2nd grade workshop

According to the proposed methodology, students were previously organized into groups of 4 members with the specific roles previously assigned. Again, each group used a round table with chairs, one laptop and one robot. The class starts with the teacher presenting the robotics challenge, in this case summarized in the diagram displayed in Fig. 12: they must implement a program in Scratch so the robot can *move describing two simple planar figures, a square and a diamond*. Both figures will be drawn on the floor using masking tape, so the robot must follow this path. Take into account that these students are younger than those of the previous workshop, so the challenge is simpler. Following the STEAM approach, to reach this final didactic objective, many other topics will be necessary: natural numbers, distance and time measurements, simple sequential algorithms or angles.

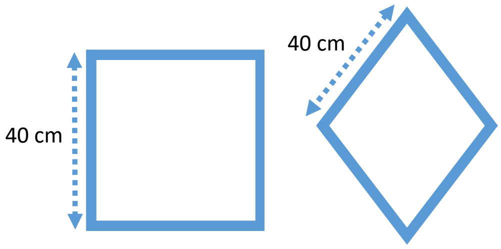

Fig. 12. Representation of the type of figure the robot must describe in its movement

As in the previous workshop, once the challenge is clearly understood, the student responsible for each role starts preparing his/her own part: turning on the computer and launching the programming environment (ScratchX in this case, which uses standard Scratch blocks plus specific Robobo blocks), turning on the robot, preparing the space on the floor, and preparing the additional elements, in this case, measuring tape, masking tape, a protractor and scissors. Considering the student's age, the teacher must organize the workshop into very simple and clear activities so the way towards the completion of the challenge can be easily followed. In this workshop, 5 small activities were proposed:

1. *Moving forward and backwards*: in this case, due to the students' age, their programming skills were very limited. As a consequence, the workshop does not use the original Scratch blocks, but custom blocks the teacher must create first. In this first activity, the goal was to move the robot forward and backwards by using the blocks shown in Fig. 13. These blocks are custom blocks defined by the teacher in ScratchX (following the same procedure than in Scratch) as can be seen in the bottom part of this figure. For instance, the "move forward – seconds" blocks, makes the robot advance in straight line the time specified in the field. Internally, this custom block contains many interactive elements that Robobo allows to use. Thus, the robot first says "forward" using the smartphone's speaker, then it changes the robot emotion (facial expression) to "laughing", and finally, it turns on the frontal leds in magenta color. All of these actions are performed before the robot starts moving with the command "move wheels at speed R – L for – seconds", which is responsible for moving the robot wheels. When the movement is finished, the robot says "stop", changes its emotion to the normal state, and all the leds back to green. The "move backwards – seconds" block is similar to this one and it can be observed in the right part of Fig. 13. The specific interactive actions that have been included in this workshop are not relevant, and many others could be used. The most important aspect here is that students perceive the change in the robot state when it moves or when it stops.

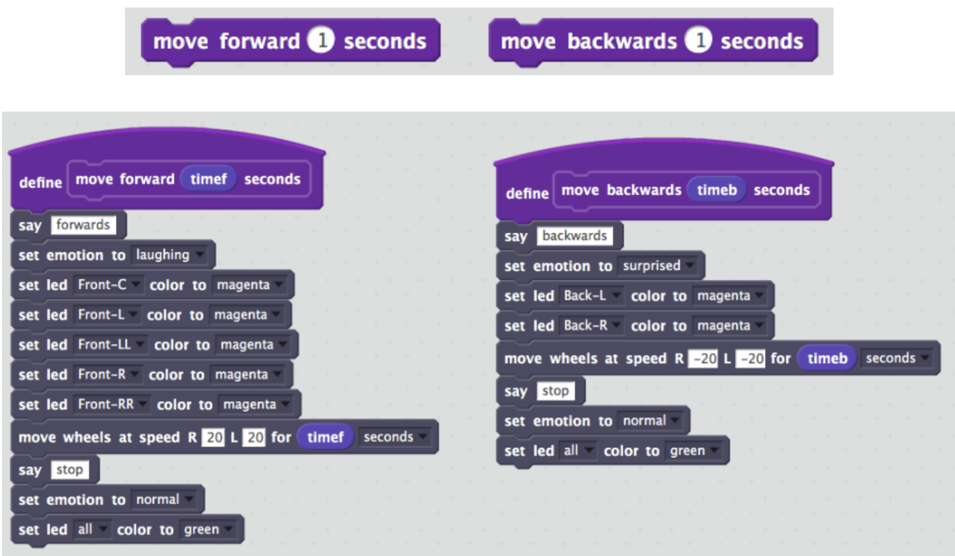

Fig. 13. Custom blocks for activity 1 created by the teacher (top) and their internal code (bottom)

Regarding the activity itself, students must execute the “move forward 1 seconds” block and measure the distance covered by the robot. As in the previous workshop, to do this, they fix a measuring tape on the floor and place the robot at the beginning, as displayed in Fig. 14, so they can measure the real displacement of the robot. This value was annotated by students in their notebook (see Fig. 14), and then the objective was to adapt the time field in this block to reach a 40 cm displacement. At this grade level, students may not know the concept of cm, but it is not relevant because the key aspect here is that of measurement unit. That is, the teacher must emphasize that, to compare different distances, it is required to have a reference one, and the measuring tape has some of them (m, cm and mm). So, although they do not understand the difference between these units, they can use the cm marks in order to compare the robot movements. In this case, as students didn’t know the rule of three yet, this adjustment was carried out by using a simple proportionality rule. In 1 second, Robobo covered 10 cm approximately, so students easily find out that they must use 4 seconds in order to advance 40 cm. In this grade level, only natural numbers can be used, so a more precise adjustment through decimal numbers is not possible.

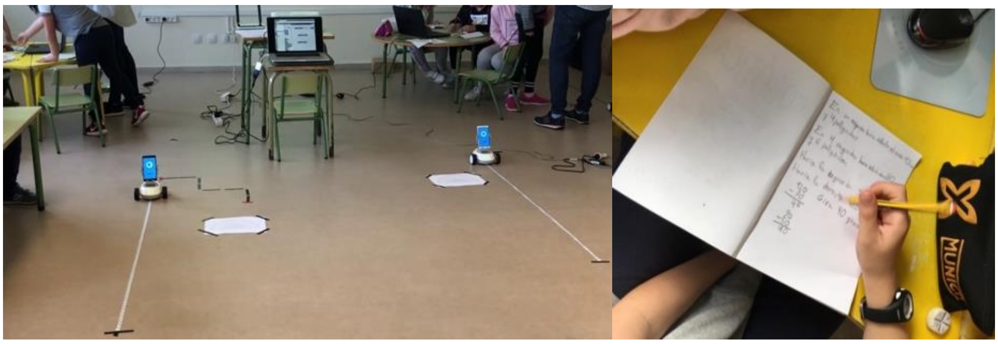

Fig. 14. Setup created by students to solve the challenge (left). Students writings results in their notebook (right).

2. *Turning left and right*: once the students know how to move the robot 40 cm in a straight line, now they learn how to turn the robot left and right an arbitrary angle. To do it, again, the teacher must prepare simplified blocks that allow the robot to rotate in place an angle that is specified as a parameter. The blocks used in this activity were those displayed in Fig. 15. On the top, the custom blocks are shown, with their corresponding internal blocks on the bottom. It can be seen that now the robot says that it is turning left or right, and leds corresponding to this side are turned on. In the “move wheels” block, the time has been adjusted using a simple rule of three, so the robot moves a time proportional to the specified turning degrees at a speed of 20 on each wheel.
In this activity, students must try 90º right and left, and annotate what happens, that is, how the robot finishes with respect to its initial orientation. To do it, as in the previous workshop, each group must fix a protractor on the floor and put the robot on top of it, as shown in Fig. 16. In the specific workshop carried out at Sigüeiro school, it was the first time the students saw a protractor, and the concept of rotation degrees was also new to them, but this was not a problem, and all of them could follow the activity without trouble. As in the previous case, the specific concept of degree is not as important as the concept of measurement unit, and how the turns can be compared using it. Once the 90º rotation was understood, the teacher explained the concept of acute and obtuse angle, and students had to select a value to obtain such rotations in the robot, one larger than 90º and other

smaller than 90º. These specific values were annotated by the students at the end of this activity.

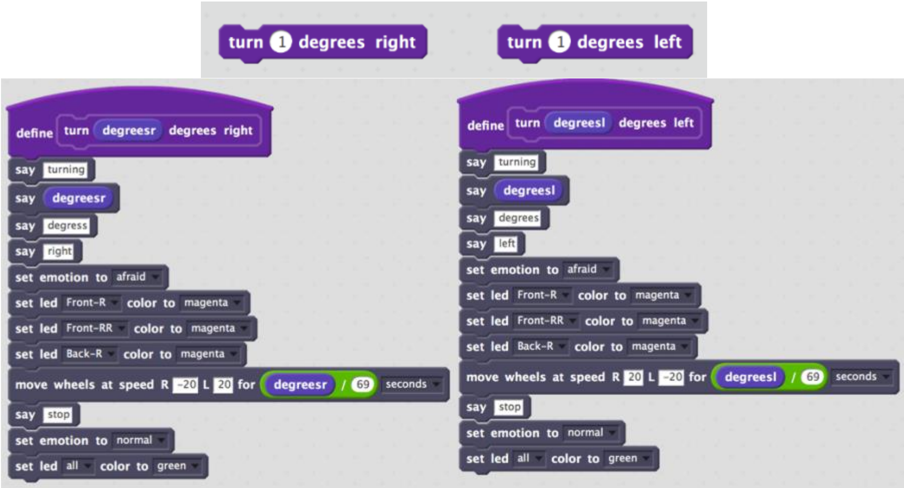

Fig. 15. Custom blocks for activity 2 created by the teacher (top) and their internal code (bottom)

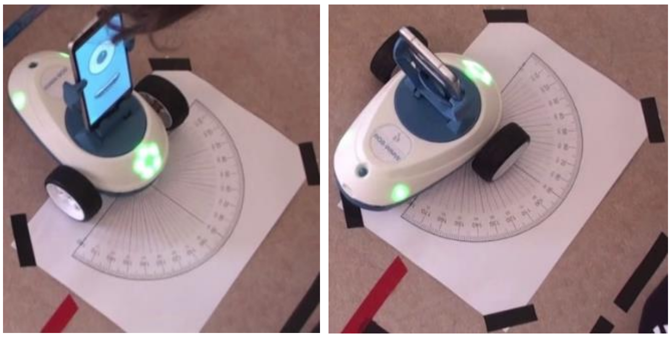

Fig. 16. Measurement of turned angles using the protractor

3. *Following a square*: at this point, students now how to move the robot 40 cm in a straight line and how to perform different types of rotations. In this activity, they have to compose these two custom blocks in order to make Robobo follow a square drawn on the floor with masking tape. Each group must create its own square of 40 cm per side, implement the program in Scratch and modify it until they reach the solution, shown in Fig. 17. It is a simple solution that implies repeating the same pattern of moving and turning four times. Once it is achieved, students must annotate this solution and the teacher can record the real execution on video. Fig. 17 shows the same solution but using a very simple loop with 4 repetitions. This program can be explained to the students so they have a simple and clear introduction to the concept of loop in programming.

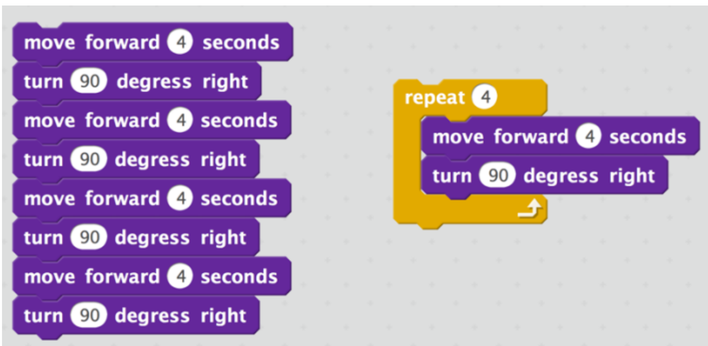

Fig. 17. Solution that makes the robot describe a square using (right) and not using (left) a loop

4. *Following a diamond*: with the square activity already finished, students must solve the last activity, which is making Robobo follow a diamond drawn on the floor with masking tape again. In this case, the angle that must be turned on each vertex must be adjusted by measuring it with the protractor or by simple trial and error. What is relevant is that students understand that the diamond requires two turns larger that 90º (obtuse angles) and two smaller that 90º (acute angles). Fig. 18 shows the solution obtained by one of the groups, where the different turns created by the students can be observed.

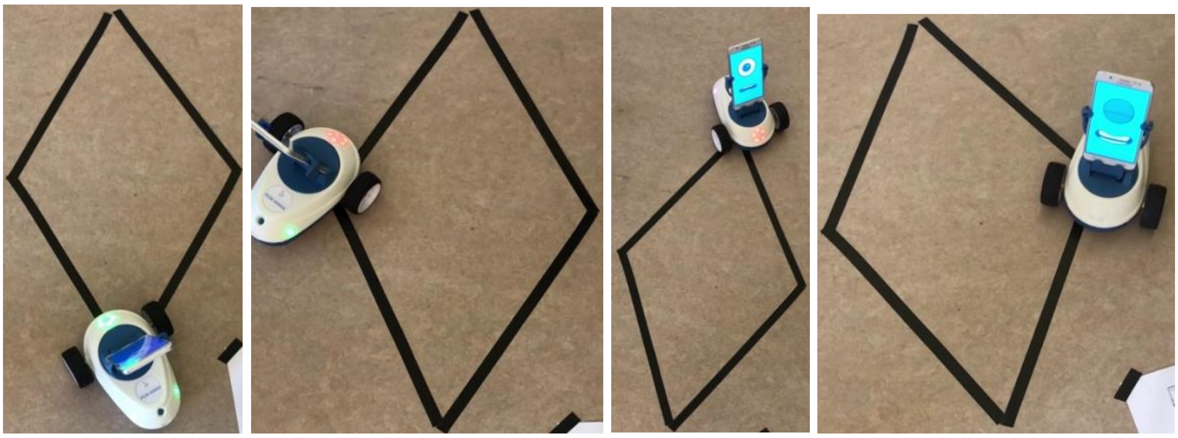

Fig. 18. Example of a final diamond movement obtained by students

5. *Optional (new figures):* as an optional activity, in case the workshop still has time, or some groups finish the diamond before the class ends, they can draw a more complex planar figure on the floor and implement the Scratch program to follow it. For instance, students can try to follow a pentagon, hexagon, etc.

This second workshop example is interesting to show how this robotics methodology can be introduced in early stages easily by adapting the topics to the level. In this sense, the mathematical concepts are imposed by the official curriculum and the natural development at this age, so the main work of the teacher lies in adapting the programming language and in seeking a simple challenge which does not require advanced programming skills. The main didactical objective in this case was around the concept of planar figure, which can be reduced to work with linear displacements and turns, so the main concepts that students reinforce from a practical perspective are those of distances and angles. The programming topics were very simple, focused on the use of simple motor commands and sequential operations. Finally, regarding robotics, at this level, the most important aspect is that students become familiar with this new tool, understand how to interact with it, and see some of its limitations.

5. Motivation questionnaire analysis

The objective of this point is to verify whether robots can be considered or not a motivating tool for the classrooms and the development of mathematical contents in primary education. Motivation largely determines the performance of students. It can be said that improving motivation is one of the two main purposes of schooling as it can influence how and when they learn (Shunk, 2001). There is a reciprocal relationship between motivation, learning and execution, so motivation influences learning and execution and what students do and learn affects their motivation (Pintrich, & De Groot, 1990). The sample of participants in this case was composed of all elementary students of the CEIP school in Sigüeiro, a total of 233 students, with an age range from 6 to 12 years. The instrument used was the questionnaire presented in Appendix 1.

The analysis is presented through the components of motivation proposed by Pitrich and de Groot (1990); (1) the value component, (2) the expectation component and (3) the affective-emotional component. The value component would be related to the question "Why do I do this task?" It would include those motives, purposes and reasons why the student would carry out this activity. This is very much linked to motivation since, depending on the weight of that reason for oneself, the motivation will be greater or lesser. The expectation component is related to the question "Am I capable of performing this task?", it would fit in with individual perceptions and beliefs about one's ability to perform the task. If a student believes that he can do the task and that he hopes to do it well, he is likely to obtain good performance, involving himself cognitively and persisting for a long time in the task (Pitrich and Shunk, 2006). The affective-emotional component is related to the question "How do I feel when performing this task?" refers to the feelings and emotions that arise when the activity is performed.

5.1 The value component

The value component is included in items 1, 8, 10 and 11 The following dimensions are differentiated within the value component: the intrinsic value, the utility value and the cost value.The intrinsic value related to the satisfaction that is obtained during the activity. Many of the experiences on robotics in the classroom coincide in that this methodology achieves a high degree of involvement in children, pointing out the satisfaction that children obtain when carrying out the challenges as one of the main reasons. From our observations, in general the boys and girls were very committed to the task and many were implicated in the importance of correctly carrying out the challenges. This could be observed every time they checked their experiments and robots, as they placed themselves around or inside the circuit, attentive to the robot, often nervous. Within this item, Krapp, Hidi and Renninger (1992) distinguish situational interest, influenced by factors such as novelty or intensity, and topical interest. Without any doubt, the context created can be considered as an important motivational factor. The novelty, the playful nature, the freedom and responsibility that was perceived generated great interest in the children and thus great motivation. This was clearly expressed it in the questionnaires, for instance, analyzing the responses of item 10 shown in Fig. 19. It displays a bar graph where the colored scale indicates the grades (from 1st to 6th) and the y-axis corresponds to the average value for each grade considering the previously explained scores (1-nothing, 2-little, 3-something, 4-enough, 5-a lot). So, in this case, Fig. 20 clearly shows that students feel they put interest when working with robots, a little more as the age increases.

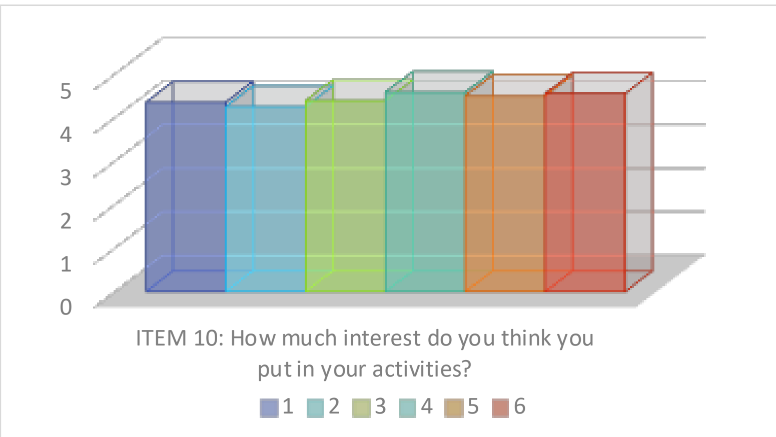

Fig. 19. Results item 10

Regarding topical interest, it is related to the preferences of people for topics such as educational robotics, tasks or contexts. The first question of the questionnaire did not directly ask if robotics was among their interests or tastes, although we can get an idea about that relationship assuming that those who had robotics among their interests would consider themselves more knowledgeable about the subject. As for the results in this case, they were those displayed in Fig. 20. The average response to this item is 2.6, which translated into the established variables, it would be between "something" and "a little", meaning that most of students don't have a clear previous experience.

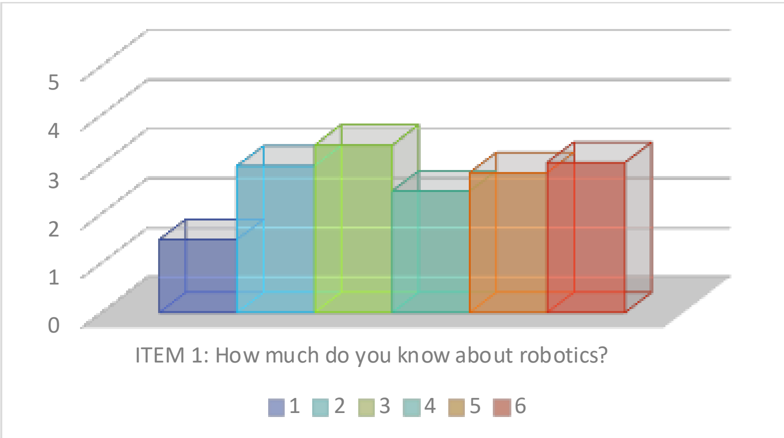

Fig. 20. Results item 1

Regarding the utility value, in item number 11, the results displayed in Fig. 21 were obtained. The average value of the answers is close to 5, specifically 89.27% of the all the children marked "a lot" in their questionnaire.

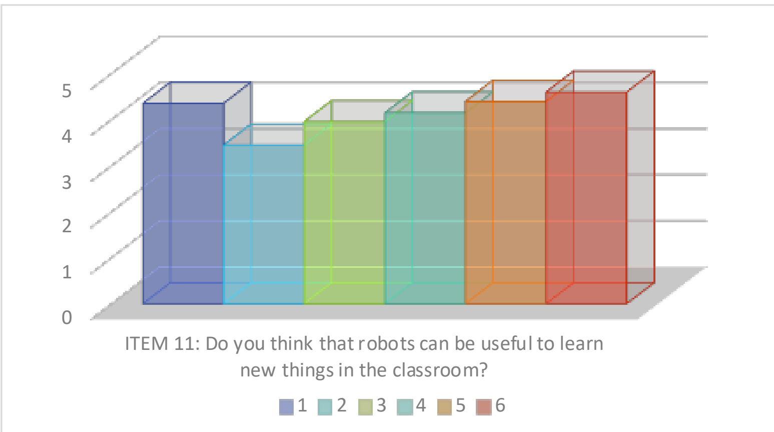

Fig. 21. Results item 11

Finally, we consider the cost value, linked to the negative aspects that imply commitment to the task. These trade-offs include anticipated negative emotional states (e.g., anxiety and fear of both failure and success), as well as the amount of effort needed to succeed in different tasks or activities. (Wigfield, A. & Eccles, J.S., 2000). In robotics, the realization of challenges is often hindered by the lack of precision of the robots or difficulty. During the sessions, it is surprising to see that in spite of the number of mistakes made, the children are still motivated.

5.1 The expectation component

This component analyzes the perception of their own competence. Associated items are 3, 4, and 6 in the questionnaire. Many studies, like (Harter, 1981), state that "students with a positive perception show greater interest in learning, like challenges and, in general, obtain better results in their academic performance". In order to analyze this component, we first consider the perception of the students regarding the difficulty of the challenges. Such difficulty has a great impact in the academic motivation and it can lead to a higher or lower motivation in the student. In this case, items 3 and 4 refer to the difficulty of handling the robots, and item 6 refers to the specific programming language. In both items the results were similar, the great majority of the students answered to these two questions between "little" and "nothing" (see Fig. 22).

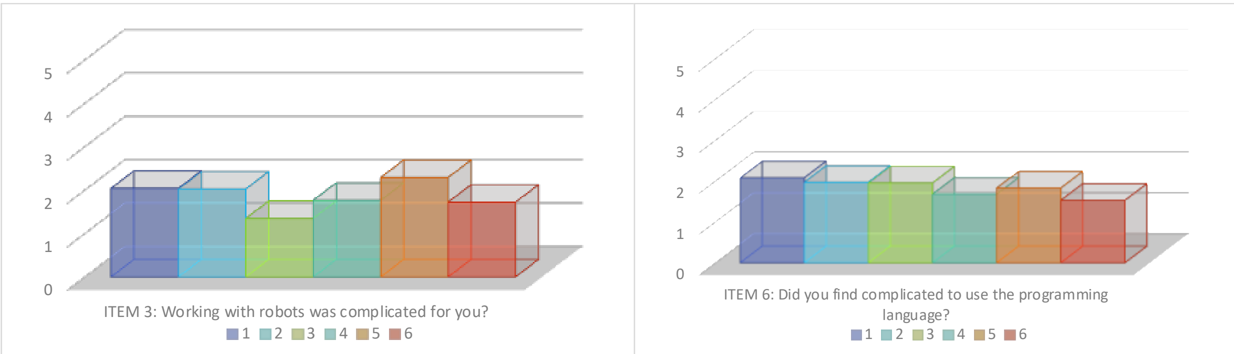

Fig. 22. Result items 3 (left) and 6 (right)

5.1 The affective-emotional component

The items related to this component are 5 (Fig. 23) and 9 (Fig. 24). By analyzing the results, it can be seen how the vast majority of children felt comfortable, that is, had a positive emotional response, although they felt "something" or "a little" confused at some point in the class.

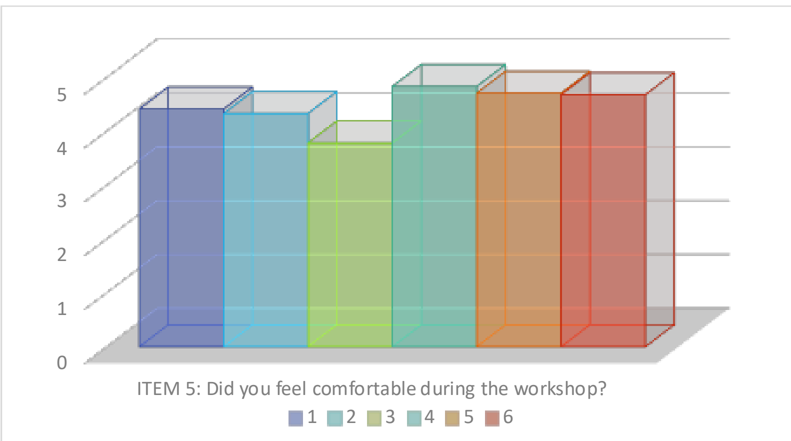

Fig. 23. Results item 5

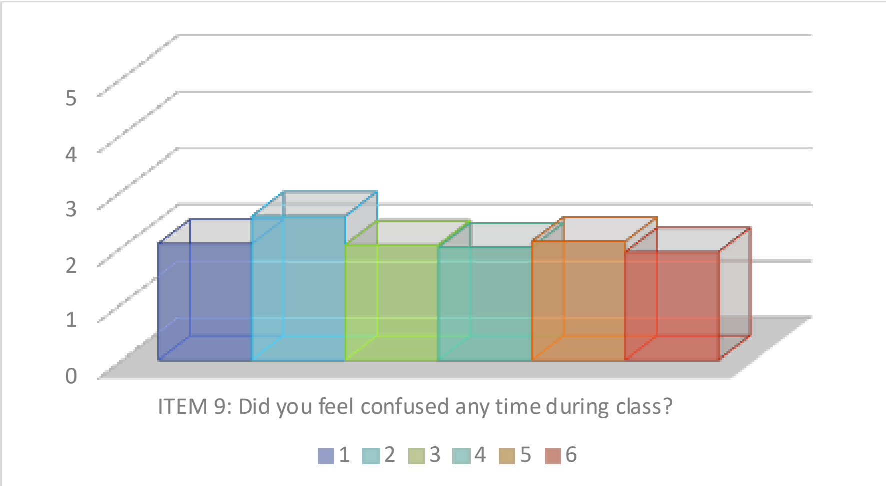

Fig. 24. Results item 9

Going into these responses of the students more in depth, a link can be established between this item 9 and number 7 ("Do you think that programming robots is boring?"), shown in Fig. 25. 85% of children think that programming robots is not. The relation of this with the previous item 9, is that 63,33% of those that concluded in their answer that to program the robots was between a little and much of a pain, also felt confused within that interval, that is, they were between "a little" and "very confused". So, it can be considered that the programming process is one of the factors that lead children to feel confused, and therefore, influence their motivation.

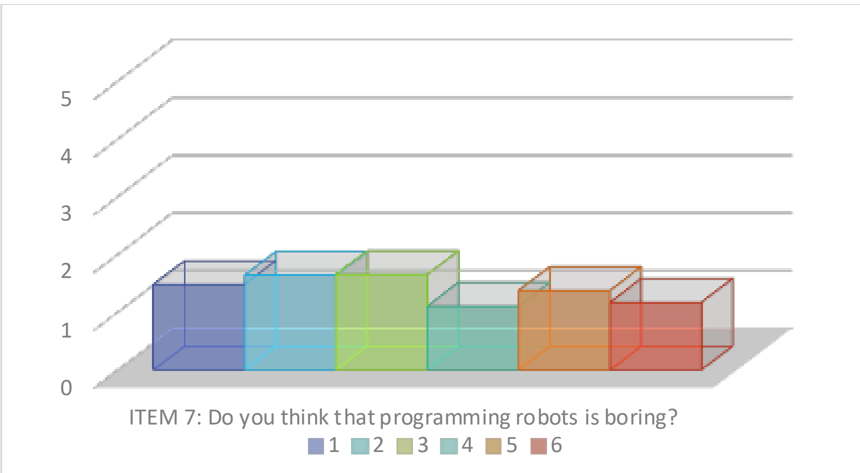

Fig. 25. Results item 7

In general, the results show a high motivation of students, although there are individuals who are not attentive to the task, who let themselves be carried away by the ludic atmosphere of the classroom. The degree of satisfaction of the students with the robotics session in which they participated was high. This is observed in the results of items 2 and 12, displayed at Fig. 26. In general, the result of the class was positive for all levels. The same goes for the twelfth item. In the last question of the questionnaire the answers also had a high degree of uniformity, so the data was concentrated between "enough" and "a lot".

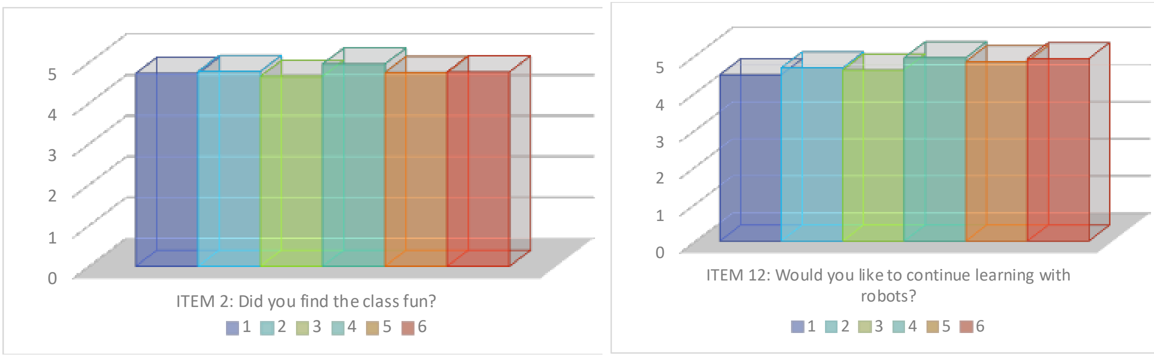

Fig. 26. Results of items 2 and 12

Within the questionnaires, the students in the 1st grade were suggested to add a small phrase to summarize their feeling about it. The great majority of the answers were related to the questions we have just analyzed. Some of them are shown in Fig. 27, and they clearly reflect the motivation of so young students in favor of the robot.

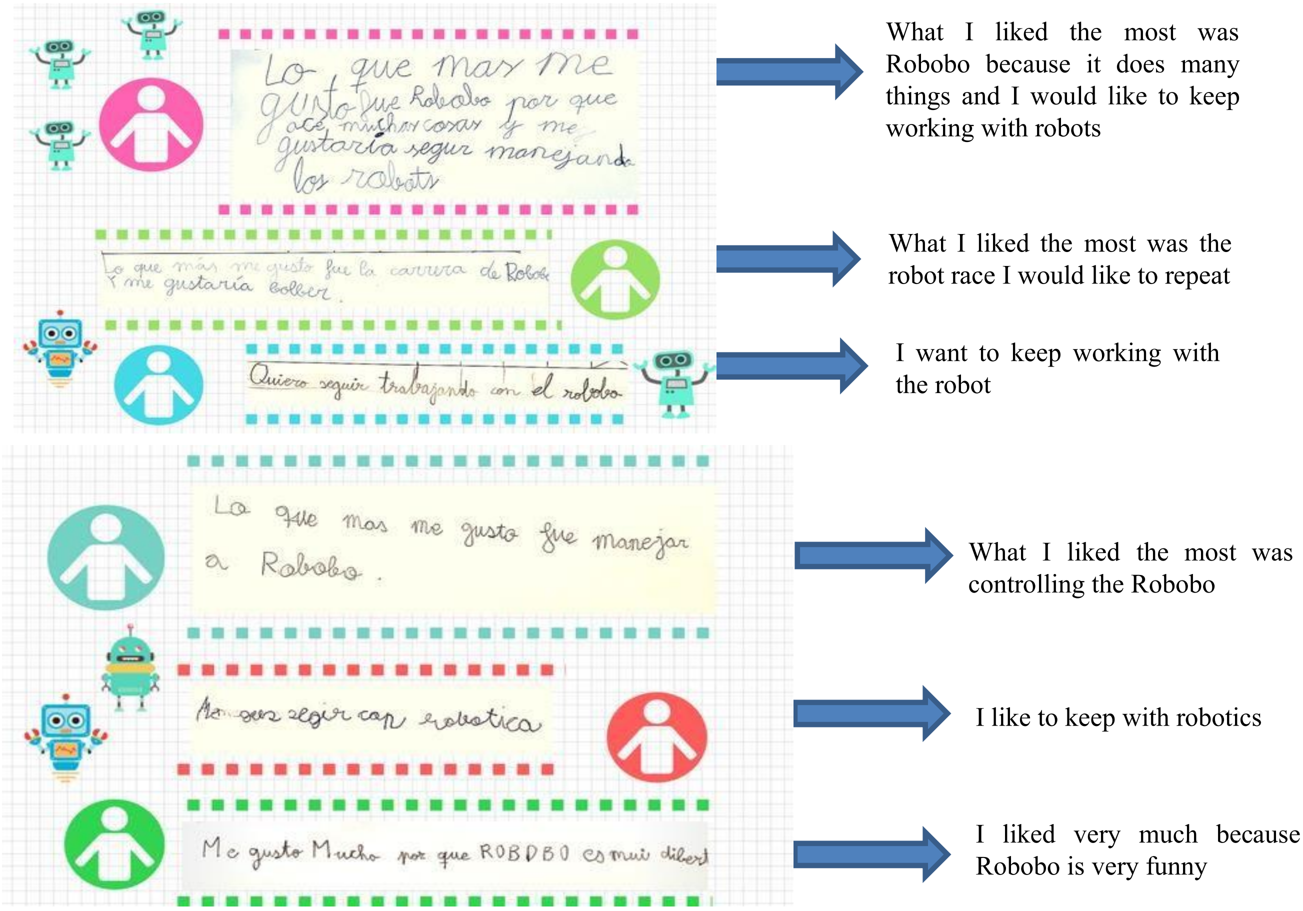

Fig. 27. Some impressions about the workshop provided by 1st grade students

6. Conclusions

This chapter has presented a practical methodology for introducing robotics in primary education in a formal way through the subject of mathematics, and using a Realistic Mathematics approach, as explained in section 2. In section 3, the methodology has been detailed in terms of didactical premises, evaluation and class organization. Two specific workshops carried out with 2nd and 5th grade students were presented in section 4, showing specific challenges that have been solved by students with high success.

One of the main conclusions of this study is that educational robotics has two main motivation sources. The first one is the robot itself, which makes students to be highly interested and curious, as shown in the results of section 5. But we must be careful with this result, because that motivation can be derived for using a new element in classes, and not by the element itself. The second source comes from the learning environment used to carry out the workshops. It must be a comfortable and open space, where students can interact between them and build their knowledge in an autonomous way.

After the implementation of this pilot experience in the Sigüeiro center during the last academic year 2017-2018, the future perspective is very positive with regard to robotics. The center managers, supported by the teaching staff, will create a STEM classroom in the main building of the school and will provide it with non-expendable material (tables, stools, computers, screen, projector, and others) as well as internet and wi-fi connection. On the other hand, for the next academic year, they aim to teach robotics workshops throughout the course with fortnightly sessions in 3 educational levels: 6th grade infant education, 4th and 6th grade primary education. The reason for establishing the workshop in three levels is to guarantee in the long term the opportunity for all the students of the center to learn about, with and through robots.

Moreover, the teaching staff of the center, considering the students' enthusiasm, supports the continuity and immersion of robotics in the school, as they believe in the potential of the robot as an educational tool (Badía et al., 2015). To do this, they propose to continue with robotics in the training plan of the school, thus training teachers to be able to respond to student demand. In addition, the School manager decided to request the regional government, XUNTA de Galicia, the increase of the endowment of educational robots in the school, which at the moment has 6 mBot and 2 Robobo.

Finally, it should be pointed out that, although the workshops were programmed in coordination with the mathematics tutors, it is not stated whether the experience had repercussions on the abstraction and comprehension of the mathematical contents. For this reason, with a future perspective, evaluation is highlighted as a priority element in order to justify the final introduction of this tool in the center to improve the mathematical knowledge of students.

7. References

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8. Appendix 1

Here it is included the specific questionnaire presented to the students at the end of the workshops:

Questionnaire on the motivation of students working with robots

		Nothing	Little	Something	Enough	A lot
1	How much do you know about robotics?					
2	Did you find the class fun?					
3	Working with robots was complicated for you?					
4	Do you consider yourself skilled with robots?					
5	Did you feel comfortable during the session?					
6	Did you find it difficult to use the programming language?					
7	Do you agree that programming robots is boring?					
8	Do you agree that programming robots is boring?					
9	Did you feel confused at some times during class?					
10	How much interest do you think you put into the activities?					
11	Do you think that robots can be useful for us to learn things in the classroom?					
12	Would you like to continue learning with robots?					