# 128 - A Proposal for the Evaluation of Educational Robotics in Basic Schools

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Abstract: Educational Robotics (ER) is increasingly used to boost student performance in several subjects, being reported successful attempts to introduce ER as a non-conventional way to help students in learning mathematics, sciences or even arts and to implement novel learning approaches, such as constructivism, project-based and problem-based learning. ER has been used to promote multidisciplinarity and collaborative work, to foster students' motivation, imagination, creativity and logical thinking.

However, available studies are mainly descriptive and qualitative. Indeed, fundamental questions, such as "Is ER a suitable tool for basic school students?" or "What are the contents/skills that can be taught/learned using ER?" remain largely unanswered. This paper proposes a methodology to conduct studies that provide an answer to those questions.

Our proposal has two distinct components: (*i*) the planning of a set of ER sessions to conduct with the students; (*ii*) validation instruments to apply, for quantitative and qualitative evaluation of ER as a pedagogical tool. An example is provided for subjects related to the concepts of multiplication/ division in 4<sup>th</sup> grade Mathematics.

Keywords: Educational Robotics, Problem Solving, Mathematics.

## **INTRODUCTION**

In recent years, Educational Robotics (ER) has been increasingly used as a pedagogical tool to boost the performance of students in several subjects and age levels. Many authors report on successful attempts to introduce ER as a non-conventional way to help students in learning subjects such as mathematics, sciences or even arts and to enable technological education (Gura, 2007) and (Bers, 2008). Also, ER is a good way to implement novel learning approaches in the classrooms, as it is the case of constructivism/constructionism, project-based and problem-based learning (Gura, 2007). The unique features of ER have been used to promote multidisciplinarity and collaborative work and to foster student's motivation, imagination, creativity and logical thinking. As a result, this tool can be used to promote a positive technological development of the youngsters (Bers, 2008).

Although the aforementioned results are substantiated by a considerable amount of literature, the fact is that the available studies are mainly descriptive and of qualitative nature. Indeed, fundamental questions, such as "Is ER a suitable tool for basic school students?", "What are the contents/ skills that can be taught/ learned using ER?" or "What ER activities are more suitable for the different subjects and skills of the basic schools?" remain largely unanswered.

This paper proposes a methodology to conduct studies that provide an answer to those questions, combining several types of evaluation instruments of a qualitative and quantitative nature. We will also report on the on-going work to validate this proposal.

Our proposal is made of two distinct components: (*i*) the overall planning of a set of ER sessions to conduct with basic school students; (*ii*) a number of validation instruments to apply, in order to allow the quantitative and qualitative evaluation of ER as a pedagogical tool.

Regarding the first component, the overall planning encompasses three distinct stages:

- (1) a mandatory set of sessions that are used for the students to learning the main concepts of Robotics, using the Lego Mindstorms ER kits;
- (2) a number of modules that apply ER to specific subjects and skills of basic school curricula;
- (3) a number of possible multidisciplinary projects to conduct with the students.

Regarding the second, an example will be provided where ER is used for subjects related to the concepts of multiplication and division in Mathematics for the 4<sup>th</sup> grade. The latter will be exemplified considering the development of robotics-based storytelling projects.

The previous plan will be accompanied by a set of instruments to be applied in different time points within the study, as detailed in Figure 1. These will include qualitative instruments, such as: initial questionnaires about student perceptions, diaries where students report the events of the sessions, descriptions/videos of the sessions, interviews with students about the sessions and students programming files (used to understand problem solving strategies). Also, quantitative instruments will be applied to evaluate the improvement of the students in particular skills/subjects. These will mainly consist in pre-tests and post-tests about relevant subjects.



Figure 1: Overall schematic representation of the proposed methodology

The remaining of this paper is organized as follows: in the next section the main characteristics of ER are reviewed, together with its pedagogical potential; next, the sessions that are proposed in this work are thoroughly described; the following section describes the validation instruments that were developed on this work; finally, conclusions are drawn and future work is outlined.

#### EDUCATIONAL ROBOTICS: CHARACTERISTICS AND POTENTIAL

In this section, the basic characteristics of ER will be reviewed and analyzed, focusing on the features that make it an attractive pedagogical tool. Next, the basic school contents and skills that can be addressed using ER will be reviewed, with an emphasis on Mathematics.

#### **Features of Educational Robotics**

A number of potentialities are normally attributed to ER in the teaching/ learning process. Some are briefly discussed here.

*Motivation and enthusiasm*: This is probably the most common feature mentioned by ER researchers. Indeed, the enthusiasm of all the participants (teachers, parents, students) in ER activities constantly mentioned in the descriptions of ER activities. In fact, ER seems to be able to motivate and involve students in learning by stimulating their natural curiosity. Given these reports, it is not surprising to find that ER is usually a good solution to motivate students in "difficult" subjects such as Mathematics and Sciences, where good results have been reported (Nagchaudhuri et al, 2005)]. Portsmore et al (2001) even report students that were always ready to work during breaks and other spare time. It is also reported by some researchers that

students that are normally inattentive in daily activities, show a special motivation in robotics activities (Rogers and Portsmore, 2004).

*Multi-disciplinarity*: Robotics is clearly a multidisciplinary field involving a set of disciplines like Physics, Mathematics, Computing or Electronics. The activities in ER integrate a number of subjects and skills, from areas such as Mathematics and Sciences, but also Arts and Languages. Thus ER possesses all the necessary conditions to allow multidisciplinary activities promoting a transversal learning of the different subjects (Ribeiro, 2006). Currently, the traditional learning systems do not seem to be prepared to provide challenges where the solutions require knowledge and skills from different fields, rather imposing scattered knowledge in distinct subjects (Morin, 1999). ER may provide a contribution to overcome this problem.

*Project-based learning*: Most ER activities, such as competitions or robotics clubs, revolve around the notion of a project that typically involves several stages (e.g. design, construction, programming, testing) that require distinct skills and knowledge. The notion of being involved in a project with a tangible outcome implies a different kind of commitment from the students in the required tasks and reinforces the connections with the real world and the meaningfulness of the learning process. Also, the students are called to make decisions that have an impact on the outcome of the project, thus making them in more active subjects in the learning process.

*Collaborative work:* Most of the activities involved in robotics are executed in teams working in tight collaboration. The decisions made while developing the projects are, therefore, reached through a process of group discussion. The efficiency in communicating good ideas and persuading the colleagues to adopt them, as well as the capability of accepting good suggestions are major ingredients for the success of the projects. Thus, ER activities are excellent means of promoting collaborative work and communication skills (Castilho, 2002).

*Problem solving*. When involved in ER activities the students (and of course also the teachers) are faced with numerous problems that originate from the obstacles that have to be overcome to reach the goals implied by the aim of the project under development. The fact that these problems arise from the real world makes them very different from the "artificial" problems solved in the classrooms. Indeed, these real world problems can be difficult or impossible to solve, require the application of other techniques to be solved (e.g. trial and error procedures) and sometimes the solutions are a best effort and not a "perfect" solution.

*Imagination and creativity*: The idea of "novelty" is normally connected with imagination, and those are related to the processes of problem solving. The processes of building and programming robots require a process of creativity, inviting the students to innovate in the process of problem solving. With ER, students develop their creativity by designing and creating their prototypes, attending to the final aim of the exercise. By going from a set of blocks and building and programming their robots, children are challenging their creativity.

*Logical and abstract reasoning*: The process of building a robot implies the capacity of planning and designing it in order to be able to work well under a given environment and accomplish a number of tasks. This implies a process of modeling the robot and the environment in an abstract way, in order to predict its behavior. Furthermore, the observation of errors implies the ability to reason about alternative scenarios and address concepts such as robustness. On the other hand, the programming of robots is conducted using a symbolic visual language, where the student needs to be able to map a set of symbols into the robot's physical behavior and predict the behavior of a given program or sequence of instructions. By projecting himself into the robot, the student is thinking about the process of thinking (metacognition) (Lau et al, 1999).

*Autonomy*: The whole process of developing a robotics project, where students try to solve a given challenge, through planning, building, programming and testing robots provides numerous problems that require an autonomous attitude from the student and the capability to use previous knowledge to search for the solutions, also resorting to heuristic approaches. Teachers have the role of making available learning environments where the student can feel safe in applying her/his ideas and searching for the appropriate knowledge. ER provides a suitable platform to achieve this endeavor (Castilho, 2002).

## **Educational Robotics and the basic school**

Robotics has been used, over its path in Education, as a useful tool for the learning of distinct contents, as well as for the acquisition of numerous skills. Within this large set, the areas of Physics, Mathematics and Informatics are normally emphasized, being the ones more directly connected with Robotics. Robotics provides an excellent mean to make lots of different mathematical concepts, at all levels, into very tangible and useful concepts. Robotics makes possible to design activities that implement project based learning approaches.

Furthermore, Robotics also allows working concepts related to areas like Arts Education. In fact, when planning and building robots a number of skills related to these subjects come into play. On the other hand, some of the Robotics activities (e.g. competitions) have been developed in order to include Music and Dance as major areas, being approached activities that involve different types of choreographies.

Robotics can be used in the teaching/ learning of some of the contents and skills related to the major areas of basic or elementary school (i.e. within the first 4-5 years with students between 6 and 10 years old). Indeed, many of the major contents from areas like Mathematics, Sciences, Languages and Arts can be included into well designed and planned Robotics activities. An analysis to the curricula in the Portuguese system (CNEB, 2001) allowed to identify, for the main curricular areas, a set of application domains, learning experiences and contributions to reach the proposed basic skills, detailed next.

*Mathematics*. The emphasis on Mathematics in this level should be focused in solving problems, thinking about them and communicating with others to exchange ideas. Robotics offers a field full of opportunities, allowing to work on the main skills of the different domains, such as Arithmetic, Geometry, Algebra and general problem solving.

*Sciences*. Robotics can contribute for reaching the main aims in the teaching of natural and physical sciences, such as: acquiring a general understanding of the ideas and structures that explain scientific concepts; understanding and applying the procedures of the scientific research; questioning the impact of Science and Technology in our societies. Robotics is able to provide a set of learning experiments that include planning projects with certain aims, detailing the major steps, since the definition of a problem to the understanding and divulgation of the results and doing cooperative work.

*Technological Education*. Technological Education should be built upon the development and acquisition of skills in a sequence of learning steps along the elementary school levels. These should be able to integrate concepts and skills shared with other areas and promote the application of these concepts into new situations.

Focusing on Mathematics, ER offers a broad set of opportunities allow to plan, build and program robots using and improving skills previously acquired by the students in several subfields of Mathematics, but also leading to the discovery of new skills not yet acquired. ER projects illustrate clearly the relationship between Mathematics and its practical applications, providing numerous examples. Robotics involves essential mathematical skills such as measuring, counting, calculating mentally and estimating. These are included in the basic fields of arithmetic, estimation, algebra and geometry. Furthermore, these are not presented in isolation, but fully integrated in a way no text book can provide (Gura, 2007).

Within the Mathematics curriculum of elementary schools, ER can offer its contribution in the following subjects:

- *Numbers and calculations*: execute mental calculations, estimate approximate values and decide upon its reasonability; interpret numeric problems and connect to real world; identify arithmetical operations to execute in a given problem and explain the methods used;
- *Geometry:* plan and execute geometrical constructions, analyzing their properties, using software and raw materials; visualize and reason spatially in problem solving; understand to concept of perimeter, area, volume; measure and estimate spatial measurements; argue using visualization and spatial thinking;
- *Algebra and functions:* analyze numerical relationships representing them symbolically and explaining them in current language; build and interpret tables and graphics; understand and use the concepts of correspondence and transformation.

## SESSIONS FOR EDUCATIONAL ROBOTICS IN BASIC SCHOOLS

This section will provide the description of the sessions that were planned as a result of this work. The overall set includes three distinct groups:

- sessions that are used for learning the main concepts of ER;
- sessions applying ER to specific subjects of basic school curricula, in this case applied to subjects related to the concepts of multiplication and division in Mathematics for the 4<sup>th</sup> grade;
- a number of possible multidisciplinary projects to conduct with the students exemplified considering the development of robotics-based storytelling projects. The three components are further described in the next sub-sections.

Also, all the materials mentioned in these sections are provided in a web site named RoboWiki (<u>http://darwin.di.uminho.pt/robotica</u>) written in Portuguese. This site also includes other materials to help students and teachers to get involved in Robotics, aiming to be a portal, where ER resources can be shared within the community.

## Learning the basics of ER

The authors have developed a course to address the basic concepts and skills involved in building and programming robots, using the Lego Mindstorms robotics kits. This course includes a set of planned sessions, with available scripts and other materials (presentations, videos, exercises, etc) that allow every teacher that has access to a few ER kits to implement the course in its own class. The full set of materials is available in the RoboWiki site.

The proposed sessions are organized in the following stages:

- Robotics basic concepts: what is a robot; history of Robotics; related videos; discussion on what makes a robot.
- Building robots using Lego Mindstorms kits: main hardware components; available Lego blocks; building exercises.
- Programming in the robot: using the interfaces of the robots to create simple programs; exercises (see example in Figure 2).



Figure 2: Example of an exercise to program on the robot (students have to identify the behavior of the programs shown)

• Programming using the NXT software: using the visual programming software to create programs and transferring those to the robots; several sessions with exercises are made available, together with their resolution (see example in Figure 3).

#### Exercise 6

- **a.** Program the robot to move forward (power of the motors -50) for 5 seconds
- **b.** Program the robot to move backwards (power of the motors -100) also for 5 seconds



Figure 3: Example of an exercise in the programming with the software section together with the solution

• Programming the robots to use sensors: more advanced programming blocks are explained that allow the use of the several types of sensors available (sound, ultrasound, touch, light). An example of an exercise is shown in Figure 4.

## Exercise 15

- **a.** Program the robot to move backwards.
- **b.** Program the robot to react when the sound sensor is activated.
- **c.** Program the robot to turn right.
- d. Program the robot to stop when the touch sensor is pressed.
- e. Program the robot to move forward 4 rotations.
- **f.** Insert a *loop* surrounding the steps a to e



Figure 4: Example of an exercise in the programming with sensors section together with the solution

## ER for Mathematical subjects

As an example of a curricular subject where Robotics can be used to enhance the teaching/ learning process, the authors chose *problem solving involving the arithmetical operations of multiplication and division*, focusing on students from the 4<sup>th</sup> grade. The proposed sessions are also provided in the RoboWiki site, corresponding to a set of activities and exercises with available solutions, with a predicted duration of 10 hours, that teachers can use in their classes. It is assumed that the students underwent the course described in the previous section, prior to the sessions presented here, i.e. they are aware of the basic concepts in building and programming the robots.

The main pedagogical objectives of these sessions is the following:

- To understand the meaning of the operations of multiplication and division and how they relate with each other;
- To calculate fluently and to provide reasonable estimates of the results of these operations;
- To discover, using ER, proportionality relationships among several measures: distance, rotations, time;
- To define procedures to convert the different measures among themselves, using multiplications/ divisions;
- To predict the behavior of robots using interpolation and extrapolation;
- To test hypotheses from experiments, using robots.

The proposed activities explore a set of proportionality relationships that the students need to understand in solving several types of problems in the programming of the robots. The strategy used consists in promoting the experimentation with the robots to motivate the inference of the relationships. Once the students understand the proportionality relationships they are able to use those in solving the exercises and predicting the behavior of the robots in certain situations. An illustrative example is given next in Figure 5. This type of exercises is also complemented with some games that are devised to work the same concepts but make the learning more playful.

#### Exercise 15:

Let us try to program a robot to draw a circle, rotating over itself.

a) Program your robot to rotate over itself using as a measure the number of rotations. Try the values of 1, 2, 3 rotations. What do you observe?



b) Measure the distance between the two wheels of the robot.

c) Using the measure from b calculate the length of the circumference that the robot will draw rotating over itself.

d) Measure the diameter of the wheels in your robot. Remember how you can use this value to know how to program the robot to travel a given distance.

e) How do you think you can program the robot to rotate over itself for exactly one turn.

f) What if you want the robot to complete three turns?

Figure 5: Example of an exercise in the sessions working Mathematics concepts

## **Multidisciplinary projects**

The third group of ER activities in the proposed framework includes multidisciplinary projects. These are typically open activities that can be planned in the context of a given community. Some examples of these activities are shown below, being mentioned some projects from the authors' previous experiences:

- Dramatization of popular tales, using robots as the characters. Examples include stories such as the Carochinha (Ribeiro, 2006), The Little Red Riding Hood and The Three Little Pigs.
- Fashion parades, dance shows or other similar activities.
- Participation in Robotics festivals (e.g. RoboParty), often involving different types of competitions (e.g. dance, football, rescue);
- Other activities

From the authors previous experiences, these activities are quite effective in engaging both students and teachers to the field of robotics, promoting high levels of enthusiasm and motivation from all involved.

## VALIDATION INSTRUMENTS

In this section, the instruments used for validation in each of the stages of the proposed methodology will be described. The explanation will be divided into qualitative instruments and quantitative instruments.

## **Oualitative instruments**

According to Bogdan and Biklen (1994) the qualitative research has as its main features the natural background, where the researcher becomes the main agent involved in data collection. Therefore, the data collected are descriptive, typically words and pictures. Qualitative research focuses on the processes and less on the results or final products. Data analysis is performed in an inductive way. This type of research is not limited to analyzing behaviors but is mostly worried with the meaning that the subjects give to their actions and experiences, as well as with others. Merriam (1998) emphasizes that in qualitative research the subjects are not treated as numbers, but are analyzed in their natural environments. Using descriptive data allows us to better capture some behaviors, attitudes and opinions, enhancing richer and more significant conclusions. On the other side, they have a natural limitation in the lack of generalization.

The main qualitative instruments are listed next.

Direct observation and video recordings: The direct observation of the sessions is still one of the most valuable instruments in any study. This can be complemented by the use of video recordings that allow a more thorough analysis of some details that can escape the perception of the observer. Both the direct observations and video visioning can be written down in reports of each session that capture all the relevant actions, behaviors, reactions, attitudes and dialogues of the subjects. Some of the advantages of this type of study are the fact that the researcher can select, register and analyze only the most relevant occurrences and develops an informal and intimate relationship with the participants (Bailey, cited by Cohen and Manion, 1994). The direct observation is complemented by the use of specific sheets where some relevant information is collected (e.g. tasks completed by students).

Questionnaires (initial): An initial questionnaire about student perceptions relating to Robotics is recommended. The objective is to determine the previous ideas and attitudes of the students towards the field of Robotics. Also, including some other questions about the student's performance in different subjects and all relevant opinions and preferences prior to the study.

Diaries: The use of diaries where students report the events of the sessions is a common tool in Robotics studies. It allows an additional tool for the researcher, while it promotes the self-reflection of the students, an important feature in constructionist pedagogical tools.

Interviews (final): In the end of the study, oral interviews with the students allow the recollection of the main opinions about the study. The set of questions should be predefined but the researcher can change or add new questions to get deeper insights on some issues. The oral form allows the student to provide longer replies and the researcher to ask some follow up contextual questions.

*Programming files:* the programming files produced by the students while solving the problems can be kept, maintaining all versions of the programs for every student. In this way, the problem solving strategy of each student can be better understood and the evolution of the students can be studied in more detail.

#### **Quantitative instruments**

Also, quantitative instruments will be applied to evaluate the improvement of the students in particular skills/subjects and also to measure the skills of the students in some specific robotics tasks. The main quantitative instruments are listed next.

*Robotics tests*: These are used to measure the skills of the students in some specific Robotics tasks. A test is recommended after the stage of learning the basics of Robotics. The performance of the students in this test can be used to check if the students were able to learn the basic concepts in building and programming the robots. Some examples of these tests will be provided in the RoboWiki site.

*Tests about curricular subjects*: For every specific subject to be considered in the second stage of the proposed methodology, a pre-test and a post-test about the subject should be applied to the group undertaking the course. These tests should be carefully designed to assure that they are as similar in structure as possible. This should allow the comparison of the scores obtained in both tests as a way to measure the improvement in the performance of the students promoted by the ER. The effective comparison of these scores can be improved if two conditions are met: the number of students taking the course should be as high as possible to improve the statistical significance of the comparison; a control group that does not take the course should answer the pre and post-test in a similar way allowing the comparison of the results removing possible sources of bias.

#### CONCLUSION

In this work, a methodology for the evaluation of the merits of ER in basic schools was proposed. The authors believe this is am important contribution to an effective use of ER as a pedagogical tool confirming all the merits that many authors have identified.

This is still ongoing work and as such many important results, mainly in quantitative terms, are still missing. The future work will, therefore, be mainly devoted to the implementation of this methodology in the field, a task that is already under way.

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