A Study of Educational Robotics in Elementary Schools

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Introduction

Background and Motivation

Every teacher aims to find new pedagogical tools that motivate the students and that are ultimately effective in the teaching/learning process of a broad set of contents. Frequently, novel educational tools are developed that bring new sheds of hope to teachers, parents and students. Some of them are able to survive in the fierce competition, but most disappear in a short span of time.

The Information and Communication Technologies (ICT), as a whole, have offered lots of promises to education, and some even talk about a huge revolution. Nowadays, it is certain that its impact on the classrooms is still far from these promises, mainly in what regards elementary education. But, it is undeniable that nowadays there are already a number of tools that can be used by teachers and students. The question is shifting from “Will we use ICT in education?” to “How can we use ICT in education to obtain good results?”

In this context, Educational Robotics (ER), the research field that studies the application of Robotics as a pedagogical tool, has been growing in importance in the last few years as an emergent approach to Education. This development has been made possible by the technological advances in ICT and electronics, as well as by the progressive drop of costs.

The pedagogical potential of this new tool makes it suitable for a number of areas such as Mathematics, Physical Sciences and Technological Education. The results obtained with these tools have reported a lot of enthusiasm from the actors of the teaching/ learning process: students, teachers and parents. But if this enthusiasm is undeniable, lots of questions remain to be answered, in order to obtain a systematic and unbiased evaluation of this tool.

In fact, the use of Robotics in pedagogical tools has not been progressing in a homogeneous way, clearly lacking a systematic strategy to adopt this tool in the national curricula at the different levels. A large number of reasons can be identified to justify this fact, starting with the lack of adequate formation to teachers and ending with the lack of pedagogical material that can be used in the classrooms by teachers and students.

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Many of the unanswered questions about ER are no doubt due to the fact that the field is still in its infancy and will be solved with its natural evolution. In this process, it is important that the sciences of Education fulfil their role and conduct studies that can answer questions such as:

- The students learn with Robotics?
- In what way(s) do the students learn and how does this learning differs from other pedagogical tools?
- Who has more to gain from this tool?
- Which skills can be learned and what contents can be taught using ER?
- What individual characteristics of the students (e.g. gender, technological fluency) are important to constrain their performance in ER activities?

It is, undoubtedly, a huge task to answer all these questions and an even greater task to really integrate ER in the educational systems. But the future of this tool will depend of the successful compliance of this task and the results that are obtained. Those will tell if this is one more hope that vanished in the air …

Aims of the Work

The main question approached by this work is the following:
"Is Robotics an appropriate tool to allow elementary school students to acquire skills important in their instruction level?"
This question can be segmented into sub-questions, namely:

- Do Robotics activities motivate elementary school students to learn?
- Is the usage of Robotics kits that allow the construction and programming of robots adequate to elementary school education?
- What contents of elementary school can be approached using robotics bases activities?
- Are Robotics activities able to promote the acquisition of skills in elementary school education, and if that is true, which?

Educational Robotics

In the last decades, in several places in the world, a number of experiments with the use of Robotics in educational activities have been conducted. These have focused mainly on university education, although a number of these experiments have also been conducted in secondary and elementary levels. The introduction of Robotics in the school curricula can be achieved by simply inserting it has one more subject to teach/ learn, in a traditional view of this process [19]. This is the practice of some university degrees, where Robotics is explained at a technical level, focusing on electronics, automation or programming.
However, in this work, another view will be followed, where Educational Robotics (ER) will be approached as a broad educational tool, used in several levels of

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education, as a way to approach a number of subjects, under a constructivist view of the learning/teaching process.

Lego Mindstorms Platform

In 1998, a cooperation effort from MIT Media Lab and Lego Company gave rise to the creation of first Lego Mindstorms robotics kit that was based on the RCX controller. The main components will be briefly described next, once this was the platform used in this study:

- the RCX - It is the control unit (the brain) of the robot, possessing a microcontroller and internal RAM memory. It can execute programs that are loaded in its internal memory, being also able to interact with the environment through a set of sensors and actuators (Figure 1). The I/O interfaces allow the RCX to be connected to three input sensors and to three actuators (typically motors). It also has a LCD screen that transmits information to the user (e.g. the battery status or the selected program) and a speaker to emit sounds.

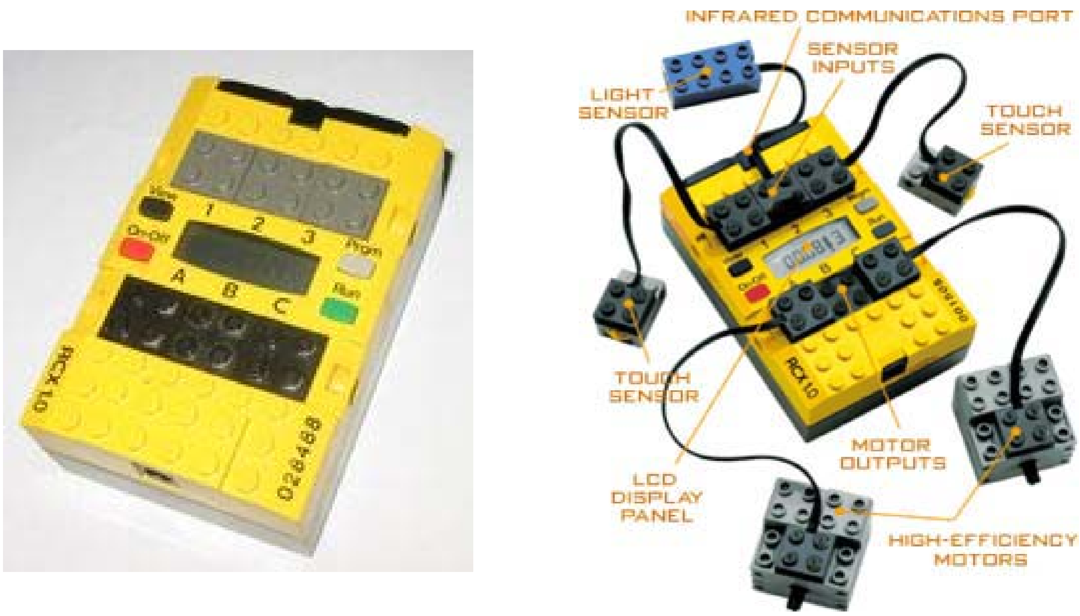

Figure 1. Lego Mindstorms RCX and its interfaces

- sensors – the sensors allow the collection of information from the environment and its transmission to the RCX. The basic kits have touch sensors that can detect obstacles in the neighbourhood of the robot (essentially a switch that is on when it is pressed) and light sensors that can measure the intensity of light.

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- motors – these are the actuators that are included in the basic kits. These are rotating motors that can be activated with several levels of tension, therefore varying the velocity of their movement.
- construction pieces – all kits have hundred of Lego building pieces that allow the construction of wide range o distinct robots. These include lots of technical pieces including several types of wheels, wheel rims, axes, pulleys, levers, etc.
- programming tools – there are several interfaces to program these kits. In this work, the option was to use Robolab, developed by National Instruments and Tufts University. This application is based on iconic programming and has different complexity levels, allowing the natural evolution of its users. With the development of this application the aim was to create an environment accessible to children and adults, but that would not impair the full potential of the equipments [14].

State of the Art of Educational Robotics

In this section, the purpose is to make a non exhaustive overview of the some projects and initiatives that were developed in the field of ER. In this field, the competitions have gained a special role, being the most participated activities in ER once they exert a special fascination over students, teachers and parents. In this context, the following can be referred:

- First Lego League (FLL): It is a competition created in 1992 by a partnership between FIRST and Lego that involves students with ages in the range from 9 to 16 years. In the 2006 edition, more than 60000 children were involved from 32 countries. In each edition, the competition has a different theme (in 2006 it was Nanotechnology and in 2007 it will be Energy Resources) and a number of challenges are proposed involving construction and programming of Lego robots. The teams have a period to train and then meet in regional, national and world-wide competitions.
- RoboCup Junior: This competition is incorporated in the RoboCup project, where the purpose is to organize several competitions of robotic soccer, with several types of robots. Since 1999, a partnership was made with Lego, enabling competitions of robots programmed by children, in a project named RoboCup Jr [8]. In this competition, teams of two robots compete playing soccer among each other. Other competitions have been created within RoboCup Jr, namely the rescue and dance events, therefore making the universe of events more diverse and also being more attractive to the participation of girls.

But, competitions are not the only activities in ER. In fact, numerous schools and other institutions all over the world numerous activities have been developed. These have been mainly developed as extra-curricular activities and the inclusion of ER in national curricula is still not quite developed. Some interesting works can be summarized in the following:

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- Bers and Urrea [2] describe a workshop promoted in Argentina in 1998 where 4^{th} and 5^{th} grade students, accompanied by their parents, spent two weeks involved in robotics projects. Each team selected a project, collected the necessary materials, built and programmed the robots and prepared a presentation for the other teams. Both parents and children worked in the project in full time (8 hours a day and 5 days per week) for the two weeks.
- In Tufts University, a number of ER projects have been conducted. Bers et al [1] describe a work made by pre-service teachers, working with K-2 children. The work implied the implementation of some constructionist environments and its evaluation. The projects developed with the students included the exploration of the concept of metamorphosis (with 3 year students), the concept of balance by building cranes (with 4 year students), the notion of life cycle (with 5 year students) and the construction of a robot able to protect some planted seeds (with 1^{st} grade students).
- In the same institution, Hacker [5] implemented an extra-curricular workshop with children from the 3^{rd} to the 6^{th} grades. In a first stage, the students learnt the basics of robotics, and in a later stage they developed their own projects, building and programming the robots. These projects were presented to the parents and other members of the community.

Pedagogical Foundations of Educational Robotics

The pedagogical foundations of ER are based on the work of Seymour Papert [13] and the ideas proposed by the constructionism. This is based on the constructivist theories and can be considered an approach to the learning/ teaching process based on constructivism.

The constructionism is based on the idea that human beings learn better when they are involved in planning and building artefacts that are significant to them and they share this with the community. The process of building the object is accompanied by the internal construction of the knowledge about the process.

The innovation, regarding constructivism is cantered on the added value given to the physical objects as a support to mental representations. The computational environments and Robotics make powerful tools to implement these ideas [16].

The origins of the constructionism can be found in the group leaded by Papert in the MIT during the 60s that became well known with the work on the LOGO language. This group built a shared vision of education that was based on the following main ideas [1]:

- Learning by designing – students learn by designing meaningful projects. Resnick [15] suggested that the interactions of children with technology should be more like finger painting than watching TV. In fact, computers and technology in general, can complement existing practise and extend these experiences to “learn by designing” [6].
This approach involves the students in learning through the application of concepts, skills and strategies to solving relevant real world problems that

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have a meaning and relevance to student. In this process, students are involved in problem solving, in decision making and in a process of collaboration [18]. The activities of ER fit perfectly in the previous description, since in this type of activities students learn by designing and building robots, solving problems created by a project and its underlying aims, where a number of obstacles created by the real world have to be overcome.

- Using concrete objects – In the elementary education there is a tradition of using manipulated materials (e.g. Cuisenaire bars). ER makes an interesting opportunity to follow this trend, allowing the students to design and create interactive objects. These work with concepts from Engineering, such as wheels, motors, sensors, pulleys or levers. They are also encouraged to integrate artistic materials to make their projects more aesthetically more pleasant.
- Powerful ideas – this term is used to denote a set of intellectual tools that when used with competence are really "powerful" in the sense that they allow novel ways of thinking not only about a problem, but also about the overall reasoning process. There is a consensus about the support to give children in the process developing new ideas by active experimentation and interaction with the surrounding environment. Is this process, powerful ideas come up and should be encouraged by the teachers [1].
- Self reflection – Self reflection has a prominent role in constructionism, allowing the author of the learning process to reflect about it in a critical way. In this context, documentation has a major importance as a basis to the analysis of this process and its adjustment. In ER, the documentation of the projects is a common practice and it is also a tradition to show the results of the projects to the community. Indeed, competitions are the more extreme example of this.

Potentialities of ER in the Reaching/Learning Process

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

- Motivation and enthusiasm by the students: this is a common feature mentioned by most researchers that have conducted studies in the field. Indeed, the enthusiasm of all the participants (teachers, parents, students) is a constant in the studies in ER. Portsmore et al [14] even report students that were always ready to work during breaks and other spare time. It is also reported by some researchers [18] that students that are normally inattentive in daily activities show a special motivation in robotics. 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 [11].

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- 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.
- 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.
- 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 modelling the robot and the environment in an abstract way, in order to predict its behaviour. 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 behaviour and predict the behaviour of a given program or sequence of instructions.

Methodology of the Study

In this section, a description of the study that was conducted is performed, by characterizing the nature of the study, the subjects that were involved, the surrounding community, the stages of the study and the instruments for data collection.

Nature of the Study

The study conducted in this work was of a qualitative nature, under an interpretative and subjective perspective of educational research. According to Bogdan and Bilken [3] 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 behaviours but is mostly worried with the meaning that the subjects give to their actions and experiences, as well as with others.

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Merriam [9] 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 behaviour, attitudes and opinions, enhancing richer and more significant conclusions. On the other side, they have a natural limitation in the lack of generalization.
Ludke and André [7] identified several distinct forms of qualitative research. One the main approaches is the case study, the option followed in this work. This approach is characterized by the following main features:

- The aim is to discover novel elements and issues that are important to research that were not considered initially;
- Emphasis is given to the context where the study takes place, and to its importance on the final outcome;
- They characterize reality in a more complete and deep way;
- They use a more diverse set of information sources;
- They seek to represent the distinct perspectives in any situation;
- The language used is more accessible when compared with other methods of educational research.

The option to use this type of study in this work was, on one hand, the natural result of the objectives of the study and of the constructivist view that underpins this investigation. On the other hand, the resources available also limited the options available. Therefore, the main objective was to understand the phenomena related to ER, focusing on the processes that allow the students to acquire new skills.

Description of the Study

The study described in this text involved the development of a complete Robotics project, using Lego Mindstorms kits and involving a set of elementary school students (3^{rd} and 4^{th} grades). The project was implemented within a club of extra-curricular activities, organized by the parents association, during 5 weeks in the months of June and July 2006.
The robotics kits were partly gathered from a project leaded by the University of Minho that involved the Agrupamento André Soares, a group of schools that includes the elementary school where the study was conducted. Some of the kits were kindly lent by some members of the ER community from Minho, which is a quite dynamic group of teachers, parents and students. The study had a total duration of 30 hours, divided by 15 sessions of around 2 hours.
The main idea of this project was to dramatize a Portuguese popular tale: “Carochinha”. In this story, the famous lead character “Carochinha” is cleaning her house and finds a coin. She decides it is time to get married and announces her decision to the world, seeking a suitable candidate. A number of potential grooms appear, namely the cat, the dog and the ox but none of them is chosen by the demanding bride. Finally, the mouse comes and conquers the lady’s heart. But, he is quite gluttonous and ends up drowning on the pot where the wedding lunch was being cooked.

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The project involved the dramatization of a simplified version of this story, where each student was responsible for a character that was represented by a robot. The tasks of the project involved learning the basic of the Lego Mindstorms kits, how to build and program the robots for the project tasks, and also to design and build the scenario where the play took place.
The objective was to create a project that would be attractive to the students enhancing their motivation in a season where the competition was huge coming from outdoor activities such as the swimming pool. One important aim was to create a “show” that could be presented to the overall community.
The activities were organized in the following stages:

- Preparation: devoted to learning the basic concepts of Robotics and Lego Mindstorms. This was organized into three steps: first contact of the students with Robotics (1 hour); learning to build Lego robots (4 hours) and learning how to program Lego robots with Robolab (5 hours). These sessions included solving a number of exercises organized by increasing complexity in a script [17].
- Dramatization of the play “Carochinha”, organized into four main steps: first experiments in programming the characters (4 hours); rebuilding the robots for enhanced robustness (2 hours); programming the definitive versions of the characters (4 hours); integration of the wardrobe and final rehearsal (3 hours). The first programming experiences were conducted on the robots built in the first stage and in a preliminary set. Then, robots were rebuilt to avoid some problems (such as wheels that came out) and a new scenario was built, taking into account the results from these first experiences. Finally, the programming was fine tuned to this new set and all components were thoroughly tested in a final rehearsal.
- Presentation of the project to the community: firstly, presenting to the ATL where the project was developed and then a participation in the Science Fair and Robotics festival of the Hands-on Science 2006 Conference. These events were of extreme importance to the students that were extremely motivated and were quite satisfied with the positive reception of their work. The publication of two news in local newspapers gave them an extra motivation and reward to the participants.

Characterization of the Individuals and Community

The study was conducted in a Robotics club that was integrated in a summer program organized by the parents association of an elementary school, situated in the centre of Braga, the capital of Minho in the north of Portugal.
The overall program had about 40 students and 3 elementary school teachers. Only 5 of the students were directly involved in the project, but most of the others were involved by helping in the construction of the set, the wardrobe and the characterization of the characters (the cat, the mouse, the ox, etc). There was also an interesting cooperation from the parents of all the students. The community of this school can be socio-economically characterized as middle/ upper class with an

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urban prevalence.
The students in the Robotics club were from the 3rd (3 students) and 4th grades (2 students). Those were average students in Mathematics, Portuguese Language and Science subjects. They had a good background in Informatics, since they were involved in the Informatics club from the school. There were 4 boys and only 1 girl involved in the project.

Instruments for Data Collection

In the research, a number of instruments were used to collect data that are typical of qualitative research. These were all designed by the authors.
The main instrument was the direct observation. In the study the first author was also the participant researcher who did the observations. Bogdan and Biklen [3] suggest that this form of observation allows an increased approximation of the researcher to the participants and consequently a better evaluation of the meaning that the students give to their experiments and also of the context of the investigation.
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 [4]).
In this study, the researcher was also the teacher and coordinator of all the activities. It is a complex role, but it also allowed an atmosphere of more complicity.
Furthermore, the sessions were all filmed on video for posterior observation. This allowed the researcher to carefully study all the sessions, capturing some details that its involvement in the activities impaired during the sessions and therefore improving the reliability of the study [4].
Both the direct observations and video visioning were written down in reports of each session that captured all the relevant actions, behaviours, reactions, attitudes and dialogues of the subjects.
Other important instruments were the questionnaires and interviews conducted both in the beginning and end of the project. The first questionnaire, answered by all the students previously to the study, had as an objective to determine the previous ideas and attitudes of the students towards the field of Robotics. So the students were asked to define robot and Robotics, to tell how a robot could be built and programmed and which tasks it could perform.
The final questionnaire had the aim to evaluate how these ideas evolved during the project. In this case, the questionnaire was performed orally. So the students were able to give longer replies and to explain clearly their opinions about the study. The set of questions was predefined but the researcher could follow up on some of the replies and get deeper insights on some issues.
Finally, documents that were produced by the students were also used in the study, mainly the programs developed in Robolab. These were all kept, maintaining all versions of the programs for every student. In this way, the problem solving strategy of each student could be better understood and the evolution of the students could be studied in detail.

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Analysis and Discussion of the Results

Categories of Analysis

A number of analysis categories were taken into account in the evaluation of the study, with a close relationship to the data collection instruments.
The direct and video observation allowed the researchers to analyze features such as:

- students' attitudes and behaviour: persistence, discipline, enthusiasm, commitment;
- quality of the students' work: organization, fulfilment of the tasks;
- skills: programming and building the robots, Mathematical skills;
- understanding the way students think and solve problems.

On the other hand, the interviews and questionnaires were most useful in:

- analyzing the students perceptions and attitudes towards the project, the tasks and Robotics in general;
- understanding the way students think and solve problems;
- evaluating the students level of enthusiasm and motivation.

Finally, the documents produced by the students allowed:

- understanding the way each students reasoned about the problems and found a solution;
- study the evolution of each student regarding programming skills.

Evolution of the Students' Behaviour

Since this was a qualitative study, a main concern was to describe in detail the attitudes and behaviours of the subjects involved [3]. The complete details of this project can be found in Ribeiro [17] and a brief description is given next.
In the beginning of the project, there was a lot of curiosity and enthusiasm. Everyone wanted to look and touch the robots and the students were anxious to start learning how to build and program them.
The sessions devoted to building the robot were quite enthusiastic and the need to build robust robots was becoming more and more clear.
The transition to programming was quite smooth. The first exercises in the script went very rapidly. As the problems became more complex, some students started to feel difficulties. Trial and error strategies became more common, since the logical reasoning was getting more difficult.
The start of the development of the dramatization increased the levels of motivation. The first signs of difficulty were easily overcome. But the most difficult tasks were still ahead.
The first experiments made clear that the first constructions were not perfect and the programming in the first scenario was difficult. The reconstruction of the robots

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to make them more robust was a success. A new stage was built with routes for each robot that were more adapted to the characteristics of the robots.
The final rehearsal helped to correct some last minute problems. The integration of the wardrobes made the robots more difficult to maintain the balance. Some adjustments both to the wardrobe and to the programming were made.
And everything was ready. The first to see the show were the colleagues in the summer program. And most of them were amazed with something quite different from what they were used. Then, the team conquered the community of robotics and the attendants of Hands-on Science 2006 Conference.

Analysis of Students' Interviews

The conceptions of the students about Robotics in the beginning of the project were rapidly changed by the work developed. They realized the difficulty of the building and programming tasks, even to accomplish simple aims. Some of the student referred the use of Mathematical concepts in these tasks. In the end, all students were quite happy with the results and eager to continue their work on ER in the future.

Skills

During the project a number of skills, identified by the Portuguese national curriculum for the 3rd and 4th grades were approached.
In Mathematics, arithmetical operations are heavily worked in several programming tasks, by calculating times, velocities, distances, etc. The ability to estimate results of operations is quite important, since in Robotics there are always errors and every calculation is approximate.
Geometry was another important area specially in building the robots, were geometrical constructions must be planned and executed, in order that a given aim is achieved. Skills related to visual perception are quite important. The ability to work with spatial routes and program the robots to follow them was essential.
Problem solving was another important area. ER projects create lots of real world problems, where solutions need to be developed and refined frequently using trial and error procedures.
In the subject of Natural Sciences, this project allowed a better understanding of the scientific methods in action. Furthermore, lots of important Physics concepts were pinpointed, namely velocity, acceleration, strength, transmission of motion, and also the concept of luminosity.
The contributions in Technology Education are quite obvious. An improvement of skills related to ICT was certainly achieved, but most importantly the experiment dealt with basic concepts of Engineering education, such as building spatial artefacts, programming, modelling and simulation, as well as dealing with noise, errors and unpredictable and stochastic situations.
The particular nature of this project gave a special attention to artistic expressions. In fact, dramatic expression is quite present in the aim of the project, music is also used taking advantage on the possibility of playing and composing music in Lego

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Mindstorms and plastic arts were heavily used in the sets, puppets and wardrobes. Finally, the Portuguese language skills were also used in the text of the play.

Conclusions and Further Work

Main Contributions of the Work

The work described in this text is one the first (at least to the author's knowledge) that investigates with some detail the applicability of Robotics activities in the context of elementary education. This makes one of its main contributions to the ER field, thus attempting a reply to the main question approached by the study (cf. section 1.2).

In this regard, this work gives an affirmative reply to the question: "Are ER activities suitable to elementary education?"

In fact, the students were quite able of building and programming Lego Mindstorms robots and, furthermore, they were even able to plan and implement a project where the final aim was to create a show where a popular story was dramatized.

All these tasks were achieved with merit and acclamation from all that had the opportunity to see the final result.

One important issue to accentuate is the broad set of skills, in all areas identified by the national curricula. In fact, skills related to Mathematics, Sciences, Technology, Language, Arts, Drama and Music were identified.

Conclusions

When, in a September evening, the team that had just presented the "RobôCarochinha" project in the Hands-on Science Robotics Festival was leaving the premises there was an enormous emotion and joy in all of us, students, teachers and also parents that joined us for the presentation.

The reception of our work from a community with know-how in ER was excellent. The students showed a continuous enthusiasm and a striking group spirit. And they kept saying they wanted to participate in more robotics activities.

It is obvious that none of these emotions are facts that can be used in a rigorous study of ER. Yet, these feelings are a confirmation of some results presented in literature by other ER studies that describe similar attitudes, perceptions and behaviours.

And not all conclusions are so subjective. It is a fact that it was possible to convince 5 elementary school students to voluntarily spend 5 weeks of their summer holidays working on a Robotics project. The persistence they have shown and the results obtained are a clear answer to the first of the sub-questions referred on section 1.2.

In fact, in activities that approach ICT in Education the students show a high degree of motivation in the beginning of the activities. However, as the study develops the levels of motivation typically subside. That was not the case with this work, where although the duration of the study was more than 1 month, the persistence was the dominant note.

The final results of the project, even in technical terms, surprised many of the "experts" in ER, especially given the fact that the authors were quite young (even

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younger than the 10 years recommended by the boxes of the Lego Mindstorms kits).
The success of this experience has opened the way to new experiences of this kind. This makes a different way to work with Robotics that attracts both genders equally and does not have some of the disadvantages of the ER competitions. It is also richer and more attractive than dance competitions, since it demands a more diverse set of skills from the students.
One of the main claims of this work is that it was really multidisciplinary, helping to develop skills in all major areas of the elementary school curricula.
Finally, in terms of pedagogical analysis, this work confirmed in our view, some of the epithets normally attributed to the constructionist practices. In fact, students learnt to build and construct robots, reaching a pre-defined goal and clearly improving their skills along the project.
All this was achieved through a learning process based on solving real problems in a meaningful context. It was clear that these activities meant a lot to the students and they wanted to show their work to the community and were willing to discuss every detail of the project and the best form of solving their problems.

Further Work

Given the innovative nature of the kind of ER activities presented in this work, a lot remains to be done to further validate this approach. So, in the near future the authors hope to be able to implement other projects that enable to further validate this approach in other scenarios.
A lot of work also remains to be done regarding the implementation of ER in elementary schools, namely in what regards the development of materials that teachers in this level can use in their classrooms.
The authors believe that if well designed materials are developed and suitable formation is provided a large number of teachers would welcome the implementation of ER activities in their classrooms.
These materials can focus on well defined skills and contents of the curricula, or they can be developed with a more multidisciplinary nature complementing other curricular activities. A long way is still ahead in this regard and the authors expect to be actively involved in these tasks.

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