It Takes a Village... to do Science Education

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Abstract. This paper describes the efforts undertaken by a small community of concerned teachers to boost science education in the school district of Verona (Italy) by promoting constructivism with the help of various configurations of robotic devices. These efforts have been going on for the last eight years, slowly gaining momentum and impact. However, the most striking difficulties have been with the education environment, rather than the student themselves. We report on the development of curricula for Middle and High Schools using the LEGO kits (the Kineplay and Eddy projects), on our efforts to involve in these activities teachers at various grades, and in particular on the sensibilization of the education administration, of the families, and of different city organizations, thus showing that science education must truly be a community effort.

1 Introduction

In many Civilized Societies, media exposure and loud talk have become a sign of professional competence, and the need of hard work and in depth understanding have become useless and irrelevant for large sectors of the public opinion. This is very evident in Italy, where it is extremely difficult to reverse this established opinion and propose an education model aiming at restoring scientific competence, creativity, and curiosity in the students. In fact, the difficulties are not only in the need of developing new educational formats, since it is not possible to propose educational models of the past century in the world of Internet and cellular phones, but also in shaking up a disappointed educational staff, in getting the attention of the public administrators busy with politicking, and of the entrepreneurial world for whom schools and academia have become almost irrelevant. Science education in Italy should be a truly global effort requiring to address also the following problems:

1. Elementary Schools: Propose new teaching formats that could excite students about science projects.
2. Middle Schools: Overcome the current situation of directing gifted children towards humanistic studies.
3. High Schools: Develop multi-disciplinary projects that could foster team spirit together with scientific excellence.
4. Universities: Exit from the ivory tower mentality and address the specific societal needs of technical innovation.
5. Adult Education: Providing solid means to update the background of technical professionals.

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Thus a village may not even be sufficient to make a dent in this huge problem.
In the last few years, robotics has been proposed in Universities and High Schools as an innovative tool to teach scientific subjects. Scientific education is greatly improved when classroom teaching is supported by adequate laboratory courses and experiments following the *inquiry based learning* pedagogical approach. However, since the cost of laboratory equipment is an important issue, this approach has been seldom implemented until low cost robotic devices have allowed developing cost effective laboratory practices. Moreover, adequate teaching material should support the technological instruments, such as specific syllabi, introductory textbooks, evaluation instruments and so on. This supporting material is currently not available, thus leaving to the teachers a great deal of additional work. Lastly it would be advisable to have good communication and coordination between the various grades of education, and among institutions, to share educational material and to focus on ambitious goals that can be reached with difficulty by single institutions.
In this paper, we present the experience of several groups of dedicated teachers at various grade levels in using robotics to teach scientific subjects, including robotics itself. We briefly summarize the results of our sparse experiments from Elementary Schools, to academic teaching and adult education, and show the need, still unanswered, of synergy and coordination among institutions and within each course to transfer more excitement to the students about science and its importance in the society. We will start by describing the best developed tools, i.e. those developed for High School and academic activities, focusing on Kineplay, the learning environment developed using the LEGO© Mindstorm™ [9], and Eddy (Educational Device: Do it Yourself!), a low cost educational mobile robot [5]. Then, we describe the activities in Middle and Elementary Schools that have been carried out at Istituto Comprensivo Don Milani, in San Pietro di Lavagno (Verona) using the standard LEGO Mindstorm tool. Adult education and advanced subjects to technical High Schools have been funded by the Veneto Region, as a result of intensive lobbying efforts. Thus, in the last Section we address the need of creating a large support base in the public and in the various stake-holders, to raise awareness about the poor scientific competence of our students and its implications for the future. This efforts have been undertaken by the Verona branch of the Dante Alighieri Society, whose representatives have embarked in a series of scientific lectures to schools and institutions to illustrate this problem and present possible solutions.

2 Past work on robotic education

The multidisciplinary nature of robotics makes it a natural tool for science and engineering education at many levels. Robotics has been shown to be a superb tool for hands-on experimental learning, not only of robotics itself, but of general topics in Science, Technology, Engineering, and Mathematics (STEM). From a pedagogic point of view, robotic hands-on experiments follow the constructivism learning paradigm. These

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ideas go back to Piaget's pedagogical work, but take also into account the intuitions of Vygotskij on the proximal developmental area in which children acquire their knowledge primarily through social interaction, and Bauer's view of the importance of shared experience with teachers and other students. Constructivism was further refined by Papert in his paper [14], where he filled the gap between active learning and technology thus laying the foundation of the use of computers and mechanisms for education. Thus the ideal learning model should include a well balanced mixture of hands on experience, supported by the appropriate technology and mediated by teacher's account of past experience and explanation of theoretical background.

Depending on the students' grade, robotics can be the goal or the means of education. The former approach is followed in specifics courses at universities, while the latter is more related to K-12 education. Traditional and hands-on approaches to robotics teaching have been explored in several workshops [6] [17] and conference special sessions. In [12] the author describes the urgency of providing K-12 teachers new instruments and materials for their courses. However, the focus has been mostly on higher education, with only a few experiments reported on K-12 teaching. Even for High School and academic teaching, it is hard to find good tools to support laboratory activities. Furthermore, no material is available in Italian. In [15] an interesting virtual laboratory for kinematics is presented, but it is no longer available on-line. In [16] a computational construction kit is presented that encourages users to experiment and play with a collection of sensor, logic and actuator blocks, exposing them to a variety of advanced concepts including kinematics, feedback and distributed control. Finally, a recent initiative *RoboticsCourseWare.org* is collecting and organizing robotics courses from leading Universities in an open source, copyright free form, to give teacher worldwide enough material to develop courses specific to their needs. However, no such initiative is available for High and Middle School teachers, who are perhaps the ones most needing training and support.

Whether addressing the needs of higher education of those of Elementary Schools pupils, it is important to give students many simple robots that are cheap, safe, easy to use and in some cases even prone to be broken to let students explore all the implications of their actions. Unfortunately, since the cost of a robotic laboratory is high, inexpensive robotic devices must be developed either from scratch or using the available construction kits. A particular interest is on using low cost commercial platforms, i.e. adding sensors and boards to the iRobot device [13] and adding parts to standard LEGO Mindstorm kits as described in [17].

It must also be noted that while the material on robotics education at various grades and competence levels is rather abundant, very little is available on using the robotic kits to teach general scientific subjects. This need has motivated part of the work described in the following Sections, where we present the steps undertaken to establish general science education curricula using robots.

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3 High School Tools: Kineplay and Eddy

Kineplay is the name of the curriculum that we have developed to teach elementary concepts of fixed manipulators using LEGO Mindstorm sets to High School students
Traditional robotics classes cover concepts such as rigid body transformations, forward and inverse kinematics, velocities and Jacobian of linkages, mechanical design aspects and programming of robots. Although many of these notions are complex, basic kinematics is rather simple, especially if it is explained with the aid of laboratory sessions. To set up the laboratory exercises we overcame two misconceptions about the LEGO robotic kit. First, that it is not a serious tool for school courses, and second that it is only suitable for teaching simple concept of mobile robots. On the contrary, the LEGO kit allows to design and build a fully operational fixed robot, a task can be hardly done with other laboratory equipment of the same price range.
In this course, we apply the constructivism paradigm to the way kinematics concepts are taught. We provide a quick overview of the basic concepts in the frontal lectures, and then we let the students carry out the laboratory experience by interacting with the tutors to clarify the supposedly known mathematical foundations, such as geometry, matrix algebra and trigonometry. The frontal lectures are done partly in the High School, to refresh the basic mathematic and geometry concepts, and partly at the University, to introduce the kinematics tools. Usually these two parts are organized into two sections of 10 hours each. Then 12 hours are devoted to laboratory practice, to apply these concepts to building and operating a robot made with LEGO bricks.
We are still using the old RCX version of the LEGO kit, because the new NXT series is less flexible in building kinematic structures and forces the students into a set of pre-determined mechanical configurations.

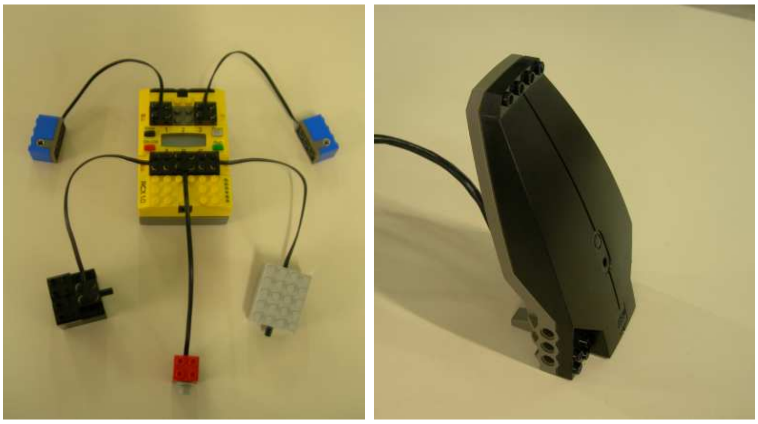

Fig. 1. RCX with actuators and sensors and infrared tower for communication

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3.1 The Kineplay Environment

To enhance the flexibility of the LEGO kit, we used *brickOs*, a firmware directly installed on the LEGO controller RCX. Thanks to this firmware the RCX can be programmed directly in C or C++ and the only limitation is given by the amount of memory available in the system. The compilation of the programs on a PC is easy because the RCX processor is a standard Hitachi 8300, for which several cross compilers are available. To complete the laboratory set up, we have installed six low end PC running the cross compiler and equipped with the USB support for the LEGO infrared tower. PCs are equipped with Slackware Linux Kernel 2.6, which has a built-in driver for the infrared link. Figure 1 shows the standard RCX LEGO processor and the infrared communication tower. We run programs directly on the RCX brick so that students can better understand the problems related to embedded system design. To simplify software development and to let students focus on the robotics problems, we developed a basic software infrastructure subdivided into three main parts: drivers, communication, and manipulator control.

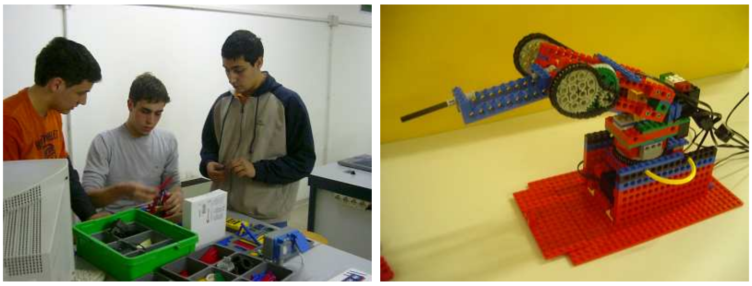

Fig. 2. Some of our students at work and one of the robots built by the students.

The laboratory is organized into three phases. The initial phase is the manipulator design that allows students to get acquainted in a fun way to various aspects of technical design, team work, and time constraints. None of the concepts related to mechanical design were introduced during the frontal lectures, and students learn first hand the importance of mass balance and static stability. Figure 2 shows a group of students at work and one of the robots built by the students.
The second phase of the laboratory is the kinematic analysis. Students use different approaches to solve the inverse kinematic problem. Some of them use the standard approach discussed during theory lectures and follow step by step the examples given. Other students more confident with the computation of matrix transformations develop more advanced solutions.
During implementation, students have only to insert functional and structural parameters in the robot program. They do not have to do any real programming, because the background in computer science of students

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from different High Schools would have required too much time for this phase.
Once the robot has been fabricated and programmed, the students can verify the correctness of their implementation by displaying on the RCX block the Cartesian value of the end effector position. Motion resolution is basically comparable to the size of a LEGO brick that becomes the position measurement unit.

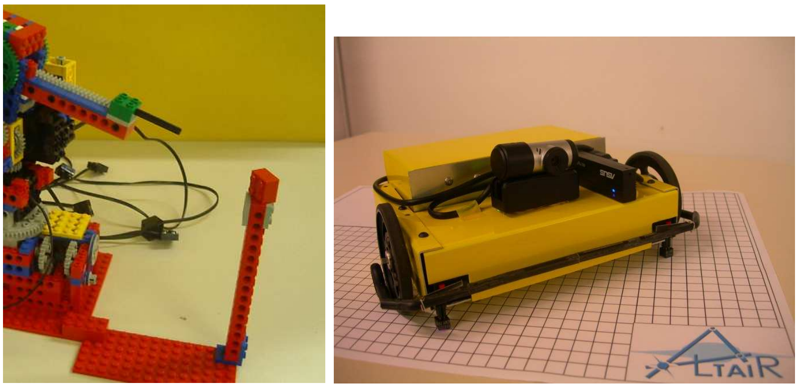

Fig. 3. The left figure shows the "Drop the Brick!" final test, and the right side shows the Eddy Robot.

The final phase consists of throwing away a LEGO brick from a tower whose coordinates are given in advance to the students, as shown in Figure 3. We called this task "Drop the Brick!". We also put some static obstacle on the manipulator path introducing complexity in the task.
Since the beginning, this approach to teach robotics has shown many positive results. Students are very enthusiastic, they learn to work in team in the design phase dividing tasks among themselves and scheduling their work. We repeated the Kineplay experience several times: High School students are recruited by the Tandem project, a collaboration between the University of Verona and High Schools, and also with our own students. More than 200 students from 10 schools have already attended these robotics courses, with very satisfactory results from the students' personal point of view. It is of course very difficult to assess whether this course has any direct impact on the student interest in sciences and on their future academic career. Attending students belong to the last two years of High School and no long term measurements were taken. Furthermore, the data on their academic career are not available to us.

3.2 Eddy

The Kineplay experience was positive for us, but we realize that when the robotic course was over, there was no motivation for the students to

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continue working on robots, and no long term project could be started with the High Schools. Thus, we decided to build a small mobile robot that schools can use for year-long projects, without the limitations imposed by the LEGO kits.
A few companies have started producing small robots for education but it is difficult to find robots that are cheap enough to be affordable for High Schools and highly configurable to adapt to specific educational goals. Khepera [11] robots are well-known, modular and robust but their cost is not affordable for schools. Those considerations held also for many commercial and research product [7,8]. Others valuable devices are related to a specific application field [10] or more oriented toward an evolutionary approach, where robots are used as a network of semi-intelligent sensors, such as [1] and [2].
To overcome these problems we developed Eddy, a robotic platform for education, that students and teachers can build together shown in Figure 3. Our aim is to provide an inexpensive mobile platform with highly customizable sensor capability. We follow the Open Hardware Paradigm [5], and provide all schematics and source code to let students build, enhance and use their own robot [4]. The overall cost of the robot parts is about 300 Euro, which is affordable to most Italian High Schools.
Eddy is a small robot; however, it is not just a micro-controller that may act as a "proxy" for the sensors, like most of the economic systems, such as Fischertechnik, Basic STAMP, or Scribbler. By using a fairly standard CPU with a stripped-down version of a GNU/Linux distribution, the only limits are the device support (on *kernel side*) and the amount of memory available for applications. With this system, in few hours it was possible to develop a very simple software (running on Eddy) to control the robot with a standard Bluetooth USB device and a Nintendo® *wiimote*, using one of the many open source Linux libraries already available [3].
Following the encouraging results we obtained with Kineplay we are working on the development of easy software tools for Eddy, to make the users concentrate on the learning aspects, rather than dealing with software and hardware development.

4 Middle and Elementary Schools: A Two Prong Approach

At Universities and High Schools it is possible (after a long search) to find teachers who take upon themselves to learn new teaching tools and apply them in the classroom. However, in Middle and Elementary School, teachers are seriously worried about their ability to learn new tools and to be outsmarted by their students. Thus it is not possible to address only the students needs, but special attention must be given to train the teachers to the new tools.
In this context, the learning objective for the students is to stimulate their *active thinking*, i.e. the ability to find and build their own know-how by trail and error, acquiring new information when needed and experimenting until an appropriate solution is found. The goal is towards

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new and emerging technologies, so robotics in itself is important, but space must be given also to energy and environmental issues, just to mention two. Furthermore, the comparison with the solutions proposed by the other students, and the evaluation of the different performance will provide the evaluation of the work, better than any grade assigned by the teacher. In this case the teacher is not asked to provide "the" solution to a problem, rather to act as a facilitator, helping and stimulating the student to find a solution and learning him or herself when, as it is often the case, the student is faster than the teacher.
However, this is the main difficulty of bringing new learning tools, and in particular robotics, to Elementary and Middle Schools, i.e. teachers are afraid of looking bad in front of their students. To overcome this problem, we organized a year long program to give teachers the self confidence and the technical knowledge required. The first step was a short course at the University of Verona, in which about 20 teacher from various Middle and Elementary Schools of the province of Verona were taught the basic concepts of robotics and of using the LEGO NXT kit. The lectures first aimed at introducing teachers to the various aspects of robotics and to their future impact and current relevance. Then, the focus switched to providing teachers with the practical knowledge of using the LEGO NXT sets, by executing the basic examples in the kit. The second phase of the program consisted of a series of self guided meeting, in which the teacher applied these basic concepts to develop learning units on various scientific subjects using a LEGO laboratory. Specifically, the objectives of these meetings were:

- Attract the attention of the education establishment towards the importance of science and technology in everyday life.
- Help growing the scientific and technological culture of the students, by means of higher quality teachings.
- Stimulate the practical understanding of mathematical concepts.
- Develop learning models following the social constructivism paradigm.
- Start a virtuous circle by which students become the builders of their own knowledge.
- Address the issue of intelligent machines: from design to fabrication.
- Rethink the curricula design, and develop new laboratory learning units.
- Develop the new teaching model of *teacher-researcher*, who is able to acquire new competences and able to promote innovation in teaching.
- Start robotic classes in the Elementary School, to establish a science and technology learning path, from earlier grades.
- Develop, within each school, robotics laboratories.

Currently, eight schools are involved in this program, with about 20 teachers developing scientific learning units based on robotic tools. The program received the support of the Education Administration of Verona, and a small financial support to cover teachers' expenses. The result of this work will form the core of a curriculum that will be distributed on the Internet for other schools to use. However, some difficulties are emerging with respect to the autonomy of the teachers. In fact, after carefully following the course and acquiring the tools and material to add new teaching material to the curriculum, there has been a slow down in activities and some lack of creativity, which we hope will be soon overcome.

5 Lobbying for Education

Of course, without enough "political" support, initiative such as the one described above cannot have a wide diffusion and cannot be adopted by a large enough number of schools to make an impact. Therefore, the Verona branch of the Dante Alighieri Society took upon itself to carry out the lobbying efforts. The Society representatives contacted the Administration of the Verona School District, possible donors, and institutions interested in improving science education to coordinate a city wide effort to disseminate the educational experiments described above.
Many other lobbying efforts were started, in particular by technical High Schools, desiring to improve the quality of their offering. A first result of these efforts was the establishment of a Robotics District in the city of Verona (sponsored by the Veneto Region), that supported the creation of after-hour lectures on robotics to students and to adults as well. These lectures were organized in courses ranging from Control Theory, to Robotics, to CAD, to advanced computer programming. The courses allowed the participant to achieve a good understanding of these advanced subjects and to receive a certificate of participation after a final examination.
The results of the new science and robotics activities will be demonstrated with a year long series of events, involving several schools of the Verona district. A number of teachers will volunteer to bring experiments and new lectures to various schools and to mentor both teachers and students who will start year-long science projects. The projects will be first presented at the beginning of the school year in a workshop opened to students and teachers, and demonstrated at the end of the year in a science festival coordinated with the Museum of Natural Sciences of Rovereto. Since 2001, The Museum of Rovereto organizes the science festival *Discovery on Film*, showcasing various aspects of technology, and demonstrating students projects that have been carried out during the previous months. We plan to organize a similar festival in Verona, which will also help attract industry and local institutions to our educational efforts.

6 Conclusions

In this paper we describe the approach taken in the School District of the city of Verona to attempt at increasing the student competence in science subjects. We started by developing curricula for High Schools by teaching robotics, taking advantage of the appeal of this subject on the students. However, it was rather evident that robotic devices could also be useful tools for teaching other subjects and at other student grades. Thus, encouraged by the interest of teachers and their results

with students, we started adapting the tools and lectures for teachers as well as students of a number of different schools.
We developed two tools for teaching robotics at the High School level, which have now been used with more than 200 students, with excellent results. We have started a small teaching program for Middle and Elementary School teachers, which has now spurred the development of science curricula specifically dedicated to the needs of lower grade students. Finally, realizing the importance of a global effort to impact science status in the society at large, we started lobbying various institutions and local administrations to try raising their awareness and interest to scientific culture in our society.
Whether robotics is the goal or robotics is the medium used to teach other subjects, it is important to have the correct evaluation instruments to verify that the students learn what we want them to learn. While it is easy to assess the enthusiasm of the students and their efforts to correctly finish the activity or win a contest, it is more complex to verify that the notions they learn will endure after the course. At the moment we think that this is the big issue about robotics *in* and *for* education together with teacher training (especially in K-12 courses), and the availability of ready-to-use robotics tools and textbooks.

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