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Educational robotics as a powerful tool to create motivating activities in educational environments

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Abstract. Educational robotics is a suitable tool to create practical and motivating activities that can fuel interest and curiosity. In this paper we report some experiences conducted by researchers of the Italian National Institute for Astrophysics (INAF) and teachers in Italy sharing the desire to offer students innovative experiences with which to develop computational thinking, problem solving skills and team building attitude.

Key words. Educational robotics – Computational thinking – Problem solving

1. Introduction

It is widely agreed that coding and educational robotics are suitable tools to create practical and motivating activities that can fuel interest and curiosity (Eguchi (2010); Alimisis (2013)) and to ensure the involvement of those who experience a special educational need. As demonstrated by research conducted in this area (Resnick et al. (1996); Alimisis (2009)), robotics has entered not only rehabilitation contexts but also educational and school environments of all orders and grades, focusing each time on different perspectives: inclusive, interdisciplinary, specific to single subjects (Pennazio (2018)).

Here we present some experiences conducted by researchers of the National Institute for Astrophysics (INAF) and Italian teachers. Each section was written by the individual participants who presented their contributions to the "VR and AR Congress for the dissemination of Science", which are also available in the form of video memories (in Italian). The text has not been standardized in terms of style, in order to leave each author full autonomy on each section.

2. From μP to integrated and complex systems and their management. The role of educational robotics in the process of conscious learning

Participation in major international projects required the rapid training of personnel capable of supporting a large number of practical activities under the necessary careful, constant and very demanding guidance of the head of the INAF Technology Working Group in Naples. Direct field training emerged as the most rapid and challenging way to train operational personnel. It consists of conceptually nullifying the differences between all the technologies and methodologies that make up integrated systems. The method has been tested and improved for more than 20 years (Mancini (2002, 2019)), and since 2018 it has also been included in the Pathways for Transversal Skills and Orientation (PCTO) by the World Wide Laboratories of INAF Naples, achieving significant results in collaboration with high schools and technical institutes in Italy. Through designing and making robotic devices, students experiment practically, receiving the necessary information during the training process. The method enables students to discover and better understand their own aptitudes and consequently identify useful information to support possible future employment.

All aspects that make up an integrated system, whether social or technological, respond to the same basic principles and are necessary for the proper functioning of the system itself. The practical activities which simultaneously involve all components at the same level, minimize the difference between the various areas of knowledge, improving transversal skills and opening the mind to the concept of integrated systems. All components contribute substantially to the functioning of the system, which helps to reject any preconceptions and boundaries between different areas of knowledge. The method is applied to technological systems through the actual realization of robotic devices and allows participation in defining functional aspects such as, for example, choosing the optimal contribution of SW and HW according to the particular purpose of the project.

The fundamental concept that enables these results is that systems are built from the smallest elements such as microprocessors (μP), basic components of electronics and mechanics, which give the possibility of realizing increasingly complex devices, respecting the "micro to macro" concept. Modern microprocessors are characterized by low cost and are equipped with various interfaces that enable the rapid realization of very complex systems, without depending on pre-built and commercially available devices that limit the inventiveness and effectiveness of the educational approach. The management of the basic elements of a system and their interactions, i.e., both the physical components and their specific functions, are greatly simplified by practical application, and students are stimulated to delve independently into each aspect or peculiarity of the system according to the aptitudes that are manifested during the educational activities. The concepts of reliability, functionality, obsolescence, the analysis of the accessibility for further improvement, and maintenance are all covered during system implementation and become part of the integrated system view.

The method includes a management approach so that the training process is completed not only by producing the documentation but also by interacting with other institutions that may be involved in the same project, implementing different sections of the integrated system as shown in Fig. 1. The different project sections will then have to be integrated with each other while respecting time, quality and overall reliability targets of the integrated product. Interaction activities between different institutes take place through the management of ICDs (Interface Control Documents) and management tools such as WBS (Work Breakdown Structure), resource diagrams and gantt diagrams managed by a program manager cyclically identified among students. The management of interfaces between institutes is of paramount importance in the context of work activities because the mismanagement of interfaces between different operators is one of the most frequent causes of project failure. The QR code reported in Fig. 1 provides further information on the *Aprilamente* method and shows some of the activities in the field of educational robotics and other areas of advanced education.

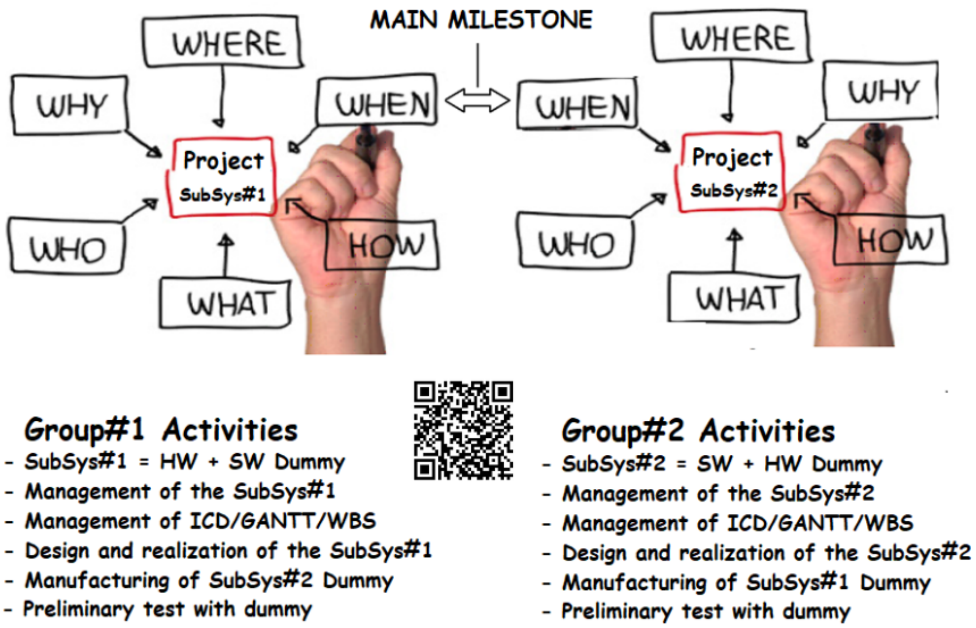

Fig. 1. Two groups of students carry out two sections of the same project that are integrated in compliance with milestones defined during project planning and controlled through ICD documents. Credits: INAF.

3. Play INAF: educational robotics resources for astrophysics

Educational robotics is prominently featured among the various resources offered by the National Institute for Astrophysics on its innovative teaching platform – `play.inaf.it`. Educational robotics is an approach to teaching based on the use of robots and aimed at making teaching for children and teenagers more effective and engaging. In line with the Third Mission of the institute, astronomy is the leitmotif of these activities, which include programming of small commercial robots.

3.1. mBot

One of the most used and low cost devices, simple to assemble, is mBot (Sáez-López et al. (2019)): an educational playmate for children who want to learn how to build and program robots, and an excellent educational aid for teachers in STEM (science, technology, engineering and mathematics) lessons. It gets children to engage both their hands and brain, encouraging them to exercise their interdisciplinary abilities while allowing them to experience the endless fun of creation at the same time. It can be programmed through mBlock, a programming environment based on Scratch – a high-level block-based visual programming language and website aimed primarily at children as an educational tool for programming, developed by the MIT Media Lab (Resnick et al. (2009)). Parallelism with Martian robots is very easy and allows students to approach some concepts related to space exploration, starting from various programming challenges that are presented on the Play INAF website: to drive the mBot by turning on the two lights; to make the mBot stop at an obstacle, using the ultrasonic sensor; to make the mBot follow a path, thanks to the infrared sensor; to program the mBot to move autonomously. To face these challenges, the students familiarize themselves with the sensors available in the mBot basic kit: the ultrasonic sensor (positioned in the robot's eyes, one eye is the ultrasound transmitter, the other is the receiver) and the two infrared sensors, located frontally and facing downwards. Furthermore, with mBot it is also possible to deal with the challenge of the remote control of a robot on Mars, linked to the fact that by sending a command from Earth, the robot will receive it only after several minutes, depending on the distance between the two planets at any time. It became clear that it is not practicable to pilot the robot from Earth, because the control would not be timely: the robot would risk colliding with the obstacles it encounters along its path. The students thus understand that it is essential to instruct the robot so that it can figure out for itself what to do when it encounters an obstacle. In other words, they need to program it, i.e. to create a code and transfer it to its internal memory, so that it can execute commands without any human control, even on Mars (Sandri et al. (2022)).

3.2. Ozobot

Another small robot used by INAF to introduce relevant astronomical concepts is Ozobot, which is equipped with optical sensors that make it able to distinguish colors and move on surfaces by following color paths (Balaton et al. (2021)). Ozobot can be programmed in two ways: either using color codes or using the dedicated platform, OzoBlockly. In the first case, it is not even necessary to know how to read or write: it is sufficient to color sectors of the path using appropriate color codes so that the robot understands how to move. For this reason, Ozobot is especially suitable for younger children. In the astronomical framework, on the Play INAF website there are resources available that employ Ozobot to explain the two main methods that astronomers use to find exoplanets (the transit method and the radial velocity method), or to demonstrate the Moon phases and the so-called "super Moon".

3.3. INAF Escape Room

Based on this extensive experience with robotics in astronomy education, INAF designed an escape room based on unplugged coding (Bell et al. (2009)) and educational robotics, which premiered during the 2022 Genova Science Festival (see Fig. 2): "A cavallo di un fotone" (in English: *Aboard a photon*), an interactive serious game experience that traces the long journey of photons (the particles of light) from inside the Sun to the planets of the Solar System, where they are reflected all the way to the telescopes on Earth that capture them to produce images of these planets. The challenges in the game are three: first, get out of the Sun and understand in which direction to go; second, reach the correct planet where photons are reflected; and finally, find the right telescope on Earth where each photon arrives. The first challenge concerns programming a Bee-Bot or Blue-Bot – an educational robot designed specifically for use by young children (Schina et al. (2021)) – on a custom-design carpet showing the Sun, inside which a labyrinth has been created. Players have to follow instructions provided in coding language to exit the Sun: if the photon (robot) is programmed to exit the labyrinth correctly, the covered path reveals the password to open an encoded locking device called cryptex. Inside the cryptex is another code that, through pixel art, leads to one among the eight planets. At each planet station, the players find a locked treasure chest, which can be unlocked by solving a series of quizzes about that particular planet. Inside the box are various objects: if combined appropriately, it is possible to derive terrestrial coordinates that, thanks to a map, allow players to locate their final destination: a telescope on Earth. In the final challenge, players must program an Ozobot through a maze that leads to all different telescopes, enabling the robot to reach the right destination. Finally, upon reaching the telescope, the players receive a key that opens a box containing postcards that feature the image of the planet seen from that telescope. The path of the photon, born in the Sun and reflected by the planet, thus

Fig. 2. The INAF escape room "A cavallo di un fotone" (in English: Aboard a photon) presented during the 2022 Genova Science Festival, in Italy. Credits: INAF.

ends and remains impressed in a beautiful image.

At the time of writing, more than 2000 students have participated in this escape room, leaving enthusiastic comments about the experience, which are currently being analysed for further evaluation. The instructions to play, as well as all files necessary to the installation presented at the festival, are available on the Play INAF website.

4. ChangeMakers: mind-renovations in first grade school

The early approach to computer programming is considered essential for the development of digital skills, which might help students to be more oriented in the world of technologies, the network in a critical and aware way, turning themselves from simple "computer consumers" into "makers of their own future". Talking about coding at school doesn't mean just writing a code, but rather the acquisition of basic capabilities that contribute to reach "problem solving" competences. The goal goes beyond the simple training of future programmers, but aims to educate the pupils to computational thinking, which is the ability to solve problems – even complex ones – by applying logic, reasoning step by step on the best strategy to reach the solution.

The approach to the new experience takes place in a playful and creative way, through simple paths responding to algorithm programming commands. This methodology has a transversal nature (these activities pervade the disciplines) and is going to be carried out using unplugged digital methods and with the aid of educational robotics. What follows are some examples of activities conducted at a primary school in Alcamo, Italy (the goal is to develop different and more autonomous learning processes):

- games about directionality, laterality and orientation in space;
- orientation games into the classroom space with Cody Roby's cards purpose built for specific use on mobile chessboard;
- algorithms programming on graph paper;
- movements in the classroom space by written and oral instructions from classmates, following indications of a shared iconic symbology and QR codes;
- graphical representations and verbalization of routes;
- writing an algorithm using a set of predefined commands to lead classmates in replicating a drawing/route with reflection on everyday life and virtual reality;
- thought on what could be differently done, starting from well-known programmable objects already done;
- thought on which and how non-programmable objects could become programmable.

The planned activities for pupils of Junior High School also approach what is defined as an "authentic reality task", being aimed at the production of an actual product, although simple, digitally distributable and usable. The students are involved in their "product" creation,

Fig. 3. Some examples of programming activities. Credits: IC Bagolino.

starting from a predefined goal or a problem to be solved. The programming activities extend to the interaction with real robots, both moving on wheels and flying ones, which can be made and used to carry out the most varied tasks and paths, thus inviting the learner to identify solutions to very practical problems (e.g. following a specific path, avoid obstacles, etc). Problem solving activities overlap with those of coding, with positive effects both from the development of logical skills point of view and from the actual programming one (see Fig. 3).

One of the merits of these program drafting activities is their adaptability and scalability, according to children's different abilities: therefore, it is possible to operate in visual mode only, or directly on the programming language. At the same time, mere manual activities are also developed, steadily decreasing nowadays: the assembly/disassembly of the robots, preparatory to the subsequent interaction via software, also permit a better understanding of the functioning of the devices themselves. The activities may concern:

- creation of rudimentary videogames, conceived, programmed and realized (digital product and mechanical/digital object) by the students;
- creation of algorithms for the representation of physical phenomena;
- creation of programs for digital storytelling with themes and content designed by students.

5. The ProgramMarte project

The *ProgramMarte* project is a set of activities created to teach kids astrophysics using coding as a teaching tool. Born from an idea of researchers from the INAF Rome Observatory and two teachers from the Gianelli Institute in Rome, it was developed for the 2019-20 school year but interrupted due to the COVID-19 pandemic. It was later re-proposed in the following school year and then a second time in the 2021-22 school year in a new form, supporting the evolution of the coding skills of the children involved. Thanks to a fruitful collaboration between researchers and teachers, it has been possible, year after year, to develop new codes, develop new programming strategies, exploit the characteristics of the hardware better and better and put the students to new challenges that allowed them to increase expertise in programming knowledge.

The primary purpose of the project is to talk about Astronomy. Mars was chosen as the main topic due to the enormous interest aroused in the kids not only for the imaginary inspired by the Red planet but also for the great echo that the various Martian missions had in recent years. So it was decided to use coding as an educational and inclusive tool. The watchword was: no one stays out. In fact, the activities involved all the classes of the school, from kindergarten classes to primary and lower secondary classes. For the younger children, educational labs have been created, whereas for children from 4-th grade (primary) to 11-th grade (secondary) schools a coding course using first Scratch and then mBlock were employed. Furthermore, to stimulate the interest of the children, the coding courses always included a final competition. The kindergarten classes participated in some educational experience on space exploration, rockets and comets. The first three classes of the primary school instead worked on the environment. In collaboration with a parallel program carried out by the technology teacher, they explored in depth the themes related to living, environment, infrastructures and the livability of urban spaces. This allowed to develop the basic concepts related to the construction of a base on a hostile planet like Mars by identifying the fundamental elements of a Martian base and the needs of human crews in an extraterrestrial environment. At the same time, the older children of the secondary school classes created some models of hypothetical housing units for Mars which were then assembled together in a large 3×3 meter surface model which was then used as a competition field for the robots (see Fig. 4).

Children from 4-th grade (primary) to 11-th grade (secondary) schools focused on coding. In each class, the students were divided into teams that followed a Scratch course. At the end of the course, a Scratch competition was held in each class to identify the best teams who had the opportunity to participate in a subsequent mBlock course aimed at programming the movements of mBot Ranger robots. In the first edition of *ProgramMarte* the optical sensors that equip the robots were used to identify obstacles. Each obstacle was marked by continuous black lines. The robots therefore had to identify these lines and consequently go around the obstacle to continue the march.

The teams tested their code in a race to identify the finish line as quickly as possible while avoiding all the obstacles on the layout. After the success of the first edition of the *ProgramMarte* project, the activity was scheduled again for the following school year 2021-22. In this second edition, the teams had become more experienced both in programming and in the mBot Rangers sensors. So, they were asked to realise more complex robots code that no longer use optical sensors to identify obstacles but instead ultrasonic sensors. The competition field was a labyrinth: the aim of the race was to cover the route from the entrance to the exit in the shortest possible time avoiding the obstacles included in the route.

Fig. 4. The playing field for the robot race: the Martian base (upper panel). The robot setup (lower panel). Credits: INAF, IP Gianelli.

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