Advancing K12 education through Educational Robotics to shape the citizens of the future

L. Screpanti[1][0000-0003-4765-8427] *, L. Cesaretti[1, 2], M. Storti[2], E. Mazzieri[2], A. Longhi[3], M. Brandoni[3], D. Scaradozzi[1, 4][0000-0001-9346-2113]

[1] Università Politecnica delle Marche, Ancona, Italy
[2] TALENT srl, Osimo, Italy
[3] Istituto Comprensivo "G. Solari", Loreto, Italy
[4] LSIS, CNRS, UMR 7296, Marseille, France
*l.screpanti@pm.univpm.it

Abstract. Since the acronym STEM (Science, Technology, Engineering, Mathematics) was firstly introduced by the US National Science Foundation to bring technology and engineering into regular K-12 curriculum, Robotics has proven itself to be the sum of STEM disciplines. This paper presents an extra-curricular experience held in a formal environment with the aim to foster culture on technology and, in particular, on smart cities. Final assessment strategies included questionnaires and crossword puzzles to evaluate students' perception of activities and the knowledge they acquired. Data were processed and compared with the objectives of the project: increasing interest in learning school's subjects, stimulating students to work in team and transforming students' attitude towards ICT. Results showed that robotics engagingly teach traditional concepts while applying them to compelling real-world problems. Authors hope that this reported experience may give a useful contribution in favor of the introduction of Robotics in K12 education.

Keywords: Educational Robotics, STEM, Primary School, Lower Secondary School.

1 Introduction

The acronym STEM stands for Science, Technology, Engineering, and Mathematics and it has become a customary term since the National Science Foundation (NSF) used it for the first time. Actually, STEM education does not only refer to teaching and learning in STEM subjects, but it attempts to transform the typical teacher-centered classroom into a new approach which requires students to discover by themselves, to solve problems with a positive trial-and-error approach, actively engaging them in a project to explore and eventually find a solution to a given problem [1-2]. Experiences in the field carried out worldwide used Robotics as a learning tool in K12 education to realize an integrated STEM education. Such experiences gave some evidences of the actual multidisciplinary approach and effectiveness of Educational Robotics (ER) to foster the skills for the 21th century, Computational Thinking or to teach basic subject like Physics and Math [3-5]. An experience in a primary school of Rome, where Robotics is a curricular subject and aims at developing skills like logical reasoning and technological proficiency, reported that activities greatly engaged students and positively impacted teamwork. Moreover, students gained such confidence in programming that by the end of the primary school they were able to solve elementary problems by means of NI Labview, a professional development environment for a visual programming language commonly used by industries and universities [6]. Another study reported that robots in schools fostered collaboration and problem-solving skills, engaged students in deep reflection, as they solved problems and collaborated with their peers, and helped them in developing perseverance, motivation and responsiveness [7]. One study explored students' attitude and motivation during robotics' activities and it found out that environmental factors (gender, peers, parents and teachers) play an important role in positively influencing students' attitude and motivation during robotic activities [8]. The reasons why researchers are investigating what Robotics and STEM education are capable of can be found, partly at least, in the wide interest in preventing early school leaving (ESL) and fostering a technological literacy to help students to find a job in the future. At European level, in fact, the Digital Single Market strategy aims to open digital opportunities for people and businesses developing a digital talent pool. Today around 45% of Europeans have only basic digital skills, while 37% of the labor force, has insufficient digital skills [9]. In Italy, the Ministry of Education (MIUR) established a National Plan for Digital Schools (PNSD) to bring technology and digital education into school. The project presented in this paper was funded by MIUR under the call "Promotion of digital citizenship" (D.D. prot.n. 1227 of 16 november 2015), which aimed specifically to identify schools capable of fostering concepts and raising awareness on the topic of digital citizenship and digital culture (ICT technologies, OER, ICT literacy and online security). The school I.C. "G. Solari" identified the possible interventions on the didactic path of its students and chose to involve other organizations in the design of activities: the local municipality of Loreto, the Università Politecnica delle Marche and the innovative start-up TALENT srl. The project aimed at introducing primary and lower secondary school students to Smart Cities, Renewable energies, STEM and Educational Robotics. To assess the overall experience, the authors formulated two means of evaluation, a questionnaire and a crossword puzzle, that were intended to assess the three main objectives of the project:

1. increase interest in learning school's subjects (Obj. 1);
2. stimulating students to work in team, developing their autonomy as a group to cope with the difficulties of the task, helping each other to cover gaps in their basic knowledge (Obj. 2);
3. transforming students' attitude towards ICT world into a positive and proactive one (Obj. 3).

Obj. 1 is connected to preventing ESL. To turn the activities of the project into meaningful experiences, learning concepts related to the Smart Cities was linked directly with the city in which students live in and with what they learn at school. This meant that students got the active role in learning, designing, building, programming and disseminating their artefact. This aspect was investigated in the questionnaire by analysing the dimension of well-being in the classroom, which is an environmental factor influencing the positive attitude towards STEM [8]. Obj. 2 relates to training teamwork skills, like autonomy, communication, creative problem-solving and conflict resolution between members of the team. This is one of the most investigated skill in this kind of experiences, according to [5]. Lastly, concepts and tools from the ICT world, like robotics, coding and renewable energies, in the present project are connected to motivating, expressive, gratifying, meaningful and authorial experiences, thus fostering a positive attitude toward the ICT world. Obj. 3 is one of the general objectives of PNSD and one of the most investigated aspect in literature [5,7-8]. Similar objectives can be found also in [10], where students from an upper secondary school were involved in a School-Work turnover programme with ER. Along with these three main objectives a set of abilities and meaningful context adaptations had been set out:

- stimulating students to develop computational thinking, to learn coding, robotics and digital technology fundamentals;
- fostering the development of soft skills, especially critical thinking, analytical skills, design capacity, problem solving, teamwork and communication skills;
- increasing the effectiveness of the educational methods through innovation of techniques and tools and through specific teachers' training;
- promoting active participation between students since an early age to the local community and raising awareness to environmental issues (i.e. source of energy, pollution, communication network…);
- forwarding a network composed by the different partner above mentioned with the aim to improve quality in teaching and learning processes.

2 Tools and Methods

2.1 Participants

The school I. C. "G. Solari" of Loreto (AN) decided to involve 8 classes, 6 from primary school and 2 from lower secondary school, in a 2 months period of activities. The total number of participants to the project was 165: 123 students from Primary school (59 students from class III, 19 students from class IV, 45 from class V) and 42 students from Lower Secondary school. All the students had no previous experience with Robotics.

2.2 Educational Approaches

25 teachers from I.C. "G. Solari" took part in a training course (21 hours). They were presented with the constructionist approach [11] and with tools like Scratch [12], Lego WeDo and waste materials. Lessons were designed in accordance with the Università Politecnica delle Marche and delivered by TALENT srl along with the teacher from I.C. "G. Solari". Moreover, the local municipality was involved in the project to bring

students the possibility to know better their hometown and the gratification of being active citizens in the community they belong to. On the other side, thanks to this project, the local community had the chance to reflect on some aspects of its everyday life. In the classroom educators acted as facilitators, fostering construction and reconstruction of mental representations more than a transmission of knowledge [13-14]. Thus, students were encouraged to follow their own ideas exploring their personal way of learning and of cooperating with others. Project based learning emphasized the cooperative research of feasible and effective solutions to an initial problem given by the educator. The “learning-by-doing” approach [15] and the “theory of multiple intelligence” [16] helped the project in empowering students with knowledge and competences by means of different learning modalities that draw from different intelligences, thus developing them (especially if some is lacking) and, at the same time, letting the peculiarities stand out. The intervention in the classroom, unleashed the potential of student to create and to bring forth their own way of producing tangible artifacts through the rework of what they had previously learnt. This is a way to promote self-awareness in students and awareness about them for the teacher. “Peer tutoring” was used in the classrooms letting older students tutor the younger ones.

2.3 Description of Activities

First of all, each class autonomously thought about how to improve their hometown, so that in the future it will become a Smart City. This activity was carried out in the classroom by teachers through brainstorming with students (at the elementary level) and trough a writing assignment (at the lower secondary school). This brief reflection led to acknowledge that technology is very useful to improve the quality of life. After this activity, students attended 4 introductive lessons to Robotics and 2 lessons on the application of Robotics to make their town smarter. The focus of each lesson was on:

1. The roles in robotic design.
2. Differences and similarities between humans and machines. Useful and useless machines.
3. Differences and similarities between machines and robots.
4. Introduction to coding.
5. Designing, assembling and programming a smart city element.
6. Improving the smart city element: how can we make it smarter?

At the end of the project a final exhibition provided the opportunity for students to share their knowledge and project-work regarding smart cities, renewable energy and basic concepts about Robotics with the local community. Sharing ideas was very important for this project. The last 15 minutes of each lesson were dedicated to debriefing, students could express their feelings about activities and teamwork, proposing sometimes personal or collective suggestions for improvement. They also explained their creations and ideas to other pupils, listening to advices and constructive critiques during the discussion. Moreover, during the final exhibition, they showed to parents, citizens, teachers and institutions their ideas, dreams and knowledge by presenting a scale model of their future smart city, realized with recycled materials integrated with the technological tools. These sharing opportunities were part of the constructionist approach [13]. An Italian version of the description of activities and some pictures of the project can be found at [17]. One of the key points of the activities was to divide the group assigning a role to each member of the group: a designer (responsible for the project and coordinator of the team, his/her task was to communicate to the others members of the group the building instructions of the robot), a warehouse worker (responsible of the robotic kit, his/her task was to look for the Lego pieces inside the box), the technical-assembler (responsible of the robot assembling, his/her task was to build the robot receiving instructions from the designer and Lego pieces from the technical-assembler) and the validator (responsible for the check of the robot assembly, observing the instructions on the computer). During Activity 1 students were presented with roles. They practiced by building an Alligator with Lego WeDo kit switching roles every 8-10 minutes. After that the educator showed some examples of Scratch programming that any teams could replicate and start, without exploring the meaning of the blocks sequences (objective of the fourth lesson). Activity 2 explained the differences and similarities between humans and machines. The description of a useless machine was provided observing some works of Bruno Munari [18], and students faced the challenge of building a useless machine using up to 8 Lego pieces chosen from the WeDo kit and writing its building instructions. Groups exchanged their products. They had to rebuild the machine of another group following the provided instructions in 15 minutes. This trained students to explain to others a personal creation in a clear and effective manner and to choose a strategy to do it (is it better to draw, write or a combination of them?). Activity 3 dealt with differences and similarities between machines and robots: students were guided in the construction of simple machine (a motor and a rotational element, like a fan), programmed in Scratch with a ON-OFF logic. Students noticed that there wasn't a real intelligence in that. Then, students built and programmed a more complex robot (the lion robot). Educators showed an algorithm which acquired data from sensors and took consequent decisions. Thus, students discovered the difference between machine and robots, namely the intelligence (deriving from programming) that characterizes robots. Activity 4 was dedicated to introducing some main concepts of programming, using Scratch. After building a new model of robot, educator proposed some coding challenges to primary students about sequential and loop execution of instructions, while secondary students also explored conditional execution of instructions. Activity 5 and 6 were dedicated to designing, building and programming a smart element, starting from the ideas emerged during the initial brainstorming activity. Some example of what students built are: wind turbines, cleaner robots, electric cars, cableways that allow tourists to reach popular landmarks of the town and so on. All these smart objects were programmed in Scratch so that they could interact with environment adequately.

2.4 Evaluation methods

Bearing in mind the objectives stated in the Introduction, authors designed questionnaires and crossword puzzles to measure two different dimensions of students' experience. Questionnaires assessed the appreciation for the activities and engaged children in a metacognitive activity, stimulating students to think both about their knowledge and the process they employed to acquire the knowledge, reflecting on the level of interest and satisfaction with the le lessons, the relationship with proposed technologies, with educators and with other pupils. Two different scales for respondents were provided: a 3-point Likert scale for primary school and a 5-point Likert scale for lower secondary school [19]. Questions were related to:

- Student's interest in activities (level of interest, their opinion about the educator, their well-being during the lessons): item Q1 (Did you understand correctly the instructions the teachers gave you?), item Q2 (Did the teachers listened when you asked him something?), item Q3 (Did you feel comfortable enough in the classroom?);
- Student's attitude towards technological devices (both hardware and software): item Q4 (Was it easy to build a robot in class working in a group?); item Q5 (Was it easy to use the software while working in a group?);
- Student's experience during team working (collaboration in the group, quality of the relationship with the classmates): item Q6 (Did you like this kind of activity in the laboratory?), item Q7 (Did you have fun with your group?), item Q8 (Did you work together with your group?), item Q9 (Did you find out new things about you or your classmate?).

In accordance with teachers it was decided to design an assessment tool which focused on concepts, key words and their relative meanings learnt by students. This tool was meant to be both a playful and educational. Two Crossword puzzles, one for primary (18 definitions) and one for secondary school (22 definitions) were delivered to students and performed like a summative test in 30 minutes. Theoretical concepts addressed during the project were the solutions to fill the empty boxes. Definitions can be grouped into 4 categories. For primary school:

- Concepts related to software functions (Scratch): 8,11,12;
- Concepts related to Robotics and hardware (kit Lego Wedo): 1,2,3,7,13,16,17;
- Concepts related to Energy issues: 4,5,9,14,15;
- Aspects regarding teamwork: 6,10,18.

For lower secondary school:

- Concepts related to software functions (Scratch): 1,6 across, 6 down, 14, 16;
- Concepts related to Robotics and hardware (kit Lego Wedo): 2,4,8,9,12,17,18;
- Concepts related to Energy issues: 5,13,15,20,21;
- Aspects regarding teamwork: 3,7,10,11,19

Both questionnaires and crosswords puzzles were delivered to students at the completion of the project. All data were processed using MS Excel. No data was discarded.

3 Results

Fig. 1 shows results from questionnaires comparing Primary and Lower Secondary school. Mean values were computed per each question in each of the two level of education, then normalized to the highest value of the range (3 for the Elementary school and 5 for the Lower Secondary School) and multiplied by 100 to obtain the percentage value.

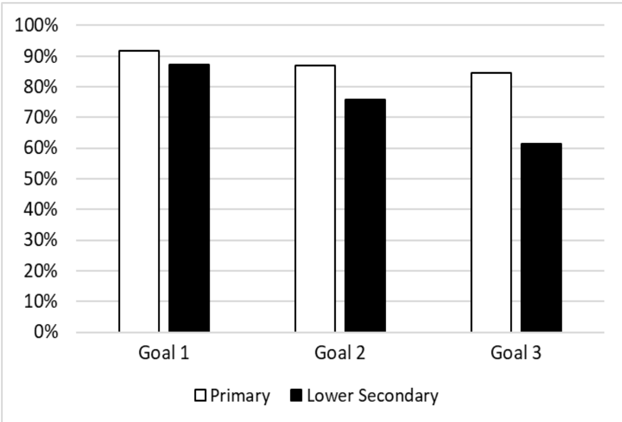

Fig. 1. Results of the Questionnaires grouped per goals.

Fig. 2 and Fig. 3 show the results from the crossword puzzles scored by primary and lower secondary school, respectively, and grouped by the four main areas of knowledge listed in subsection 2.4.

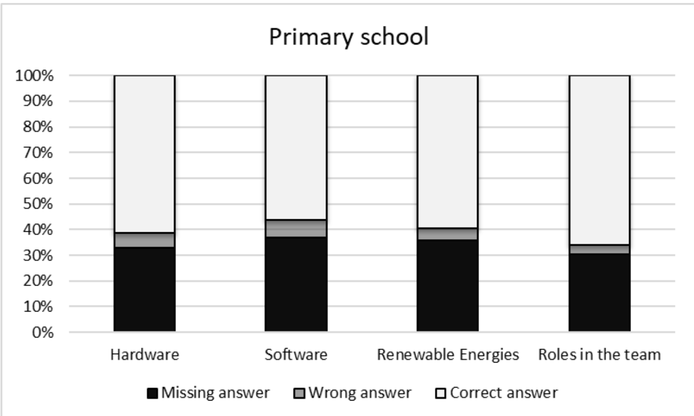

Fig. 2. Results of the crossword puzzle tests administered to primary school students. Each category represents an area of knowledge investigated by a set of questions.

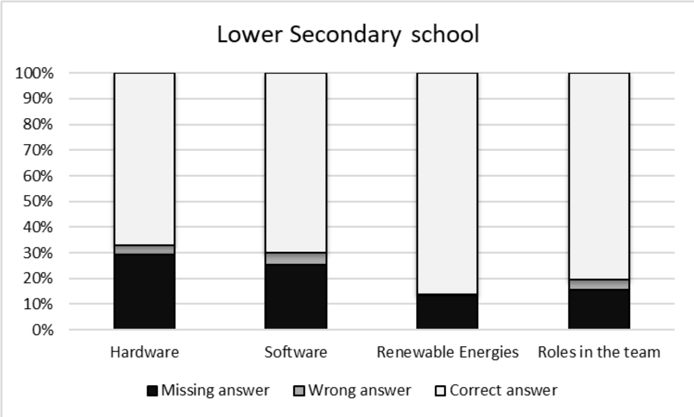

Fig. 3. Results of the crossword puzzle tests administered to lower secondary school students. Each category represents an area of knowledge investigated by a set of questions.

Results from the crossword puzzles were processed assigning each answer to one of the following categories: missing answer, wrong answer, correct answer. Then, percentage of each categories were computed and divided into four categories relating to four areas of knowledge addressed by the activities: hardware, software, renewable energies and roles in the robotic activity. To examine to which extent the didactic objectives concerning these four areas of knowledge have been achieved, a threshold of 80% was set to see how many students answered correctly to this level. This threshold is suggested by [20] as a reference point to measure the success of the activities. Results from this kind of analysis are shown in Table 1.

Table 1. percentage of students who scored above or below the threshold expressed as the percentage of correct answers. Rows present the percentage of students above the threshold (>80%), below the threshold (<80%) and the sum of these shares (Tot.). Columns present percentages related to the overall result in the test (Tot), to Hardware (Hw), to Software (Sw), to Renewable Energies (En) and to Roles in the Group (RG).

Threshold	Primary school					Lower Secondary school				
	Tot	Hw	Sw	En	RG	Tot	Hw	Sw	En	RG
>80%	33	33	39	45	35	40	29	62	86	79
<80%	67	67	61	55	65	60	71	38	14	21
Tot.	100	100	100	100	100	100	100	100	100	100

4 Discussion and Conclusions

Tools and methods employed in this project represented a new experience for students as it was different from the everyday teaching approach, both in the relation with the place around them (the different spatial distribution of the desks or the possibility to use even the floor to build and test) and in the approach to the learning activity (for example the peer tutoring technique, educator acting as a facilitator rather than a deliverer of notions). Fig. 1 shows overall positive results for Obj. 1 which led to believe that this new approach has proved to be successful. But this is no surprise because most of the literature reports great enthusiasm towards robots in the classroom and new approaches to learning. Fig. 1 highlights also that activities yielded positive results at the primary school, but checking answers to Q1 the 42% answered that they experienced a little difficulty in understanding the instructions the educator gave. Answers to Q4 and Q5 seems to show that they really felt as they faced some difficulties in building and programming. In the lower secondary school, Q1 reports higher scores if compared with primary school. Higher scores in Q1, Q2 and Q3 are counterbalanced by the presence of few totally negative scores, which affects in Fig. 1 the final percentage for Goal1. For Obj. 1 there is an overall positive result, as the column in Fig. 1 are above an 80% threshold, thus depicting a scenario in which students seemed to perceive as positive the new approach to learning. Fig. 1 shows an overall positive result for the experience of working in team, both for primary and lower secondary school, even though there is a slight difference in scores (87% for primary school and 76% for lower secondary school). Results seems to show that they did not get to know something more about the other team mates. Possible causes could be the short time dedicated to activities which would require more time to fully exploit its potential or the fact that students were already used to work in group. Looking at Fig. 2 and Fig. 3 we can see that there are more missing answers than wrong answers. This can relate to the peculiarity of the test, because it seems likely that a student not knowing the answer, would seek to match the possible words coming to his/her mind with the boxes in the crossword and if the word didn't fit, he/she would discard the answer leaving the boxes blank. It should be considered that crossword puzzles could be an easier way to answer a question, because they give hints on the length of answers and sometimes even on some letters. Maybe, if students were presented with open questions, they probably would have ventured more to give tentative answer. In general, it seems that lower secondary school presents more positive results in Crosswords puzzle test. In Fig. 2 we can see that the test scored an average 40% of missing/wrong answers, whereas in the lower secondary school the average missing/wrong answer is considerably inferior (about 25%). Looking at Table 1, we can see that in the field of Renewable energies at the lower secondary school 86% of the students are above threshold, whereas at the primary school only the 45%. Another curious result is that with a share of 79% at the lower secondary school, students clearly recalled the roles they were assigned during the project, whereas at the primary school only the 35%. This gives credit to the possible side effect of technology. Robots are very attractive to children, but they can draw attention on themselves, to the detriment of contents they are supposed to convey. In fact, even if Robotics is a useful aid to raise interest toward STEM subjects in schools and it has the potential to change the way students learn STEM subjects, technology by itself do not necessarily translate into better learning.

Riferimenti bibliografici

1. Gonzalez, H.B., Kuenzi, J.: Science, Technology, Engineering, and Mathematics (STEM) Education: A Primer. Congressional Research Service (2012). Also available online at http://www.stemedcoalition.org/wp-content/uploads/2010/05/STEMEducation-Primer.pdf
2. Hoeg, D. G., Bencze, J. L.: Values Underpinning STEM Education in the USA: An Analysis of the Next Generation Science, Science Education. Science Education 101(2), 278–301 (2017).
3. Eteokleous N., Ktoridou D.: Educational robotics as learning tools within the teaching and learning practice. In: 2014 IEEE Global Engineering Education Conference (EDUCON), Istanbul, 1055-1058 (2014).
4. Eguchi, A.: Robotics as a Learning Tool for Educational Transformation. In: Proceeding of 4th International Workshop Teaching Robotics, Teaching with Robotics & 5th International Conference Robotics in Education, Padova (Italy) July 18, 2014.
5. Benitti, F. B. V.: Exploring the educational potential of robotics in schools: A systematic review. Computers & Education, 58(3), 978-988 (2012).
6. Scaradozzi, D., Sorbi, L., Pedale, A., Valzano, M., Vergine, C.: Teaching Robotics at the Primary School: An Innovative Approach. Procedia - Social and Behavioral Sciences, 174, 3838-3846 (2015).
7. Toh, L. P. E., Causo, A., Tzuo, P. W., Chen, I., Yeo, S. H.: A review on the use of robots in education and young children. Journal of Educational Technology & Society, 19(2), 148 (2016).
8. Kaloti-Hallak, F., Armoni, M., & Ben-Ari, M. M.: Students' Attitudes and Motivation During Robotics Activities. In Proceedings of the Workshop in Primary and Secondary Computing Education, pp. 102-110. ACM (2015).
9. European Commission, Education and Training website. https://ec.europa.eu/education/policy/school/early-school-leavers_en, last accessed 2018/03/10.
10. Cesaretti, L., Storti, M., Mazzieri, E., Screpanti, L., Paesani, A., Principi, P., Scaradozzi D.: An innovative approach to School-Work turnover programme with Educational Robotics. Mondo Digitale. Associazione Italiana per l'Informatica ed il Calcolo Automatico (2017).
11. Papert S.: Constructionism: a new opportunity for elementary Science Education. MIT Media Laboratory, 1986.
12. Scratch webpage. https://scratch.mit.edu/, last accessed 2018/04/03.
13. Ackermann, E.: Piaget’s constructivism, Papert’s constructionism: What’s the difference. Future of learning group publication, 5(3), 438 (2001).
14. Abdal-Haqq, I.: Constructivism in Teacher Education: Considerations for Those Who Would Link Practice to Theory. ERIC Digest (1998). Also in http://ericae.net/edo/ed426986.htm.
15. Dewey, J.: Democracy and education: An introduction to the philosophy of education. New York: Macmillan (1916).
16. Gardner, H.: Frames of mind: The theory of multiple intelligences. New York, NY: Basic Books (1983).
17. Italian version of the description of the activities. https://www.weturtle.org/dettaglio-progetti/31/rethink-loreto-we-build-our-smart-city.html, last accessed 2018/03/10.
18. Munari, B. (1942). Le macchine di Munari. Einaudi.
19. Likert R.: Technique for the measure of attitudes. Arch. Psycho. 22(140), (1932).
20. Calvani A., Menichetti L.: Come fare un progetto didattico. Carocci Faber (2015).