Robotics in Education: A Smart and Innovative Approach to the Challenges of the 21st Century

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Abstract Robotics in Education (RiE) is a broad term that refers to a variety of applications. Robots can enhance learning and teaching, but they can also help overcome impairments, whether physical or social. Even though the advantages of bringing new technologies into schools are clear, the lack of a well-established set of good practices, assessment of experiences, and tools slows down their adoption. This chapter aims to highlight the key points that emerge from the recent enhancements in RiE. First, the market and research are continuously developing new tools for school to try to meet needs and tailor products. Second, there is a wealth of formal and non-formal experiences, both in the literature and in school activities. Third, research is still validating tools and methodologies that will assess the impact of introducing robotics into education. Despite the wide availability of tools and experiences, there is still a certain degree of uncertainty about how to cope with technology in education and how to evaluate the outcomes of such activities. The increasing cross-pollination between schools and researchers from different fields is producing valuable experiences that will soon close the gap.

Keywords Educational robotics · Social robotics · Assistive robotics · STEM · Digital skills

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1 Introduction

Technology has always been the key to any human's achievement and progress. Modern technologies are becoming increasingly complex and connected. Dealing with such technologies requires a lot more than numeracy and literacy skills. Local and national governments are taking measures to empower citizens with the key competencies they need to live and work in the society of today and tomorrow. Thus, one challenge is to train people in enabling technologies to ensure a workforce that is skilled in them. Another challenge is to transform education so that everyone masters technology rather than simply using it. In order to solve this last issue, governments have set up more comprehensive strategies. For example, Italy's National Plan for Digital Education (PNSD) is a long-term plan aimed at introducing digital infrastructure, digital skills and robotics into schools.

Supported by governments and welcomed by teachers with a mixture of enthusiasm and mistrust, technologies and robotics have filtered out of research laboratories and industry and have finally entered schools. Some of these technologies are intended to be used in the classroom to overcome impairments and to assist the teaching–learning process. Others are intended to be "objects to think with" [1].

This chapter aims to highlight the key points that emerge from the recent enhancements in Robotics in Education (RiE).

2 Robotics in Education

Many fields have greatly benefitted from achievements in the field of robotics. Education has a variety of challenges that tools and methods from robotics can help solve [2]. Specifically, robotics provides a unique learning experience, with helpful solutions for every student's learning needs. As such, RiE encompasses a variety of well-established sub-areas of robotics. Considering the applications of robotic devices in the field of education, it is possible to identify four main areas: assistive robotics, social robotics, socially assistive robotics, and educational robotics (ER) [3]. Each of these areas is applied in the field of education for different purposes. Assistive robotics in education can help overcome physical impairments that might prevent learning and teaching, thereby contributing to well-being and inclusiveness [4, 5]. Social robots in education are either students' tutors or companions, engaging their interest and transforming lessons into interactive and connected learning environments. Socially assistive robots help students reduce a social impairment, assisting users through social rather than physical interaction [6]. Founded on constructionism and using re-programmable robotic kits—usually consisting of several unassembled components—ER helps students develop many technology- and subject-related competences [7]. Hard skills and soft skills (i.e., communication, teamwork) can both be developed through ER activities.

The wealth of robotic devices brings many opportunities but also new challenges. An effort should be made to evaluate their effectiveness in engaging learners and developing competences [2, 8] and to train teachers in pedagogical and technological aspects [9]. Technological transparency may be regarded as an advantage in social and assistive robots, as it enables end users to easily manage and seamlessly accept their device. On the contrary, it can be a disadvantage when it comes to ER [3, 10].

3 Trends and Perspectives

Parts V and VI of this book propose many interesting ideas and perspectives about RiE, emphasizing three key points: good practices, assessment of experiences, and development of tools.

3.1 Good Practices

Good practices for robotics as an educational methodology should be a reference for other experiences. They should consist of a set of common features that can be compared (i.e., age of participants, learning environment, etc.). Many of the activities described in parts V and VI of this book have been done at schools as an occasional or short-term project [11–13] or as a comprehensive, organic experience [14, 15].

The authors in [12] describe how primary school students built a game about escaping safely from an earthquake and saving their town's cultural heritage. Robotic kits, coding platforms, and QR codes can all help to boost school performance, motivation, interest in science, technology, engineering, and mathematics (STEM), and teamwork. Most importantly, students learned how to behave during an earthquake and got to know their local culture. Not only can robotics be used to gamify learning, it can also introduce students to other school subjects. The authors in [11] describe how to introduce primary school students to music, science, mathematics, geography, critical thinking and technology through Nintendo Labo technology and many other materials from the real world. This helped enhance the "spiral of creative learning," not only through immersive technology or prefabricated robotic kits, but also through specially designed authentic learning and tinkering activities that take place in innovative learning environments. Similarly, [13] describes an ER activity for developing logic, mathematics and physics skills. Starting from an analysis of a story by Dino Buzzati, students are asked to use the information retrieved from the text to model the behaviors of characters and to solve simple prediction problems. Interestingly, the author observes three approaches to the problem: empirical (simulating on paper the possible strategy to solve the problem), algebraic (looking for a relationship between two variables), and physical-algebraic (using notions from both mathematics and physics).

Many schools are enlisting robotics in their usual activities to bring a new approach to teaching STEM subjects, and to increase knowledge and competitiveness in scientific and technological fields. Notably, the authors in [14] promoted the culture of technology and science across Europe, improving achievement and motivation, right from primary school. To this end, secondary school students developed the mobile "Robot for Geometry" (R4G) for teaching mathematics, geometry, and fractions to younger students. Furthermore, the authors in [15] report a unique experience in Italy in which robotics is introduced as a primary school subject, and describe the learning objectives, lesson plans, and robotic devices involved. Notably, this curriculum has already been through its first phase of validation and has also been improved. Moreover, topics like the Internet of Things and distributed control were added to update the educational path.

Outreach activities complement formal learning in a variety of ways. Examples in parts V and VI of this book include a coding club [16], a global robotics contest [17], and an international project [18].

The author in [16] describes the experience of the Pomezia CoderDojo, where the MBot is used not only for educational purposes, but also for improving collaborative and social skills. The experience looks at the Seymour Papert learning-by-doing methodology as the best way to deploy the potential of coding and ER.

The authors in [17] aim to fill the gap between the world of scientific and educational competitions, focusing on participants, their knowledge of robotics and the hardware involved. The RoboCup@Home Education Project has created a new set of organization rules and standardized courseware and platforms that users have access to. Notably, organizers scaled up the project around the world and are now getting deeper into schools, providing self-paced training for teachers and setting up a community for the exchange of good practices.

Finally, the authors in [18] present the preliminary results of a comparative research on robotics education from a media education point of view. High school students from Italy and the Democratic Republic of the Congo performed a SWOT analysis of robotics after a lecture they received on the European recommendations to the Commission on civil law rules on robotics. This analysis is the starting point for a more comprehensive look into what robotics means for their lives and for society at large.

3.2 Assessment

Robotics was employed in several projects to develop knowledge of a wide range of subjects, hard and soft skills, and even complex competencies, or to raise awareness about social and environmental issues. Despite this wealth of robotic applications in education, many stakeholders at different levels advocate for measurable indexes of the effectiveness of RiE. The authors in [19] begin by acknowledging the results corroborating the enthusiasm with which new learning theories and methodologies have been met in schools. They then move on to highlight the lack or underuse of models and tools for assessing relatively new educational activities, like robotics, coding, making, tinkering. Hence, teachers and educators should be trained not only in pedagogical matters and educational paradigms but also in assessment models, to empower them with suitable tools for the digital context. Furthermore, the study carried out by the authors in [20], whose aim is to evaluate the effect of learning platforms, highlights that modern pedagogy should look for ways to bridge the gap between how students learn and how teachers teach. New and innovative teaching methods and learning environments are necessary for preparing students for life in a constantly changing society.

An automated evaluation system is the proposal of the authors in [21], to support teachers by seamlessly collecting data from an ER activity, and autonomously assessing how students cope with it. Exploring a machine learning approach and data mining techniques, they analyze real-world data and find three main behaviors: "Mathematical strategy", "Incremental Tinkering approach" and "Irregular Tinkering approach", which are closely linked to the "planner scientist" and "bricoleur scientist" [22] and echo the results observed by [13].

Teachers can also benefit from collaboration with universities. Cross-pollination between school education and academic research can lead to sound research design and a stronger educational experience. This is the case for the authors in [23], who report an example of a cross-pollination project in a lower secondary school. The Bricks for Kidz (B4K) methodology and ER are brought into a curricular setting and used to propose didactic and cross-curricular targets and define criteria for assessing student performance. The results of the research highlight the strong need for teacher training in pedagogical and didactic methodologies. The authors in [24] show how the number and the quality of social relationships can be analyzed in a formal learning environment during ER using quantitative techniques, like sociograms and questionnaires. The findings of this study report the effectiveness of short ER activities for stimulating social skills, but they also highlight that more studies are needed to explore the complex world of student relations.

Assessing students' relationships and expectations is very important when it comes to the gender issue. Based on data collected during ER and coding activities throughout Europe, the authors of [25] find that only a small percentage of female students pursue a career or studies in computer science and technology. According to their analysis, the barriers to such careers can be found in girls' self-limiting beliefs. These, in turn, stem from the low expectations of parents, peer groups, the school system, and society, and eventually lead many to choose secondary schools on the basis of perceived possibilities for working while taking care of their families. A job in a technical or scientific field is seen as being in conflict with the ability to care for a family. Coding and robotics activities might not be the solutions to the problem, but they can be used to build self-confidence and problem-solving abilities, which in turn can help to evaluate one's inner strengths.

3.3 Technological Development

Industry 4.0, Society 5.0, Education 2.0 are all broad terms that point to the deep impact of technology on every aspect of human life. Technological developments are at the core of the change in perspective that many fields are witnessing. Low costs and wide availability allow teachers to bring affordable instruments into schools for innovative activities at different levels.

Flying robots, for example, and quad-rotor micro aerial vehicles (MAVs), in particular, are the most appealing vehicles recently introduced as inexpensive, straightforward educational platforms for teaching the behavior and control of MAVs to students in primary schools (Tynker and Blocky), secondary schools and universities (JavaScript and Python, MATLAB & Simulink). As shown in [26], it can even support a robust nonlinear control algorithm (sliding mode control), thus demonstrating the flexibility and versatility of this novel educational ecosystem.

Mobile robots like the one described in [27] bring several applications into the classroom, enabling students to explore several aspects of technology, from the design of functional hardware to the development of sophisticated software. The fully open source and open hardware robot based on the Arduino platform and Robotic Operating System can explore the environment and can track and recognize objects via machine learning software.

The degree of complexity and transparency of the tools brought to students can vary according to age, grade, competence level, learning objective, and funding availability. The same open-source low-cost single-board microcontroller, Arduino, can improve laboratory practice in upper secondary schools and change students' attitudes towards STEM subjects. The authors in [28] report a series of experiments using this platform as an interface for data acquisition and for building a simple prototype of a rover.

Teachers need to keep track of all the different tools available, to choose the most suitable for their needs, and create an activity that can target the intended outcome, whether it is computational thinking or teamwork, communication, and mathematics. All of this work requires teachers to improve their digital skills and to enhance pedagogical and didactic innovation. The Weturtle.org platform presented in [29] draws on the concept of "Community of Practice" and the Technological Pedagogical Content Knowledge (TPCK) model to promote active use of the community, the training of teachers, and to enable more experienced teachers to become trainers themselves.

Both teachers and students increase their interest in robotics when they understand that it can help themselves or others to reduce a barrier. In fact, students can use robots not only as platforms on which to learn robotics, but also for assistance during the learning process. Assistive robotics provides particular benefits for education, as it can reduce the impact of impairments and increase autonomy. The authors in [30] present a proof of concept for a smart wheelchair with localization and navigation capabilities, which can be integrated with an academic management system to enable students who cannot walk on their own to reach any academic building or room on a university campus autonomously.

4 Conclusions

The picture that emerges of Robotics in Education is one of a wide variety of applications available to help students and teachers in their everyday lives. Plenty of technological tools and systems are available to help meet the needs of different tasks and age levels.

This means that teachers can create student-tailored and student-centered activities, often with a hands-on learning approach. In order to learn how to exploit technology in education, teachers need to be trained, not only in the technology itself, but also in integrating technology into their educational practice, for both instructional design and docimology. Some support comes from the technology itself, with platforms for online learning and communities of practice, where materials can be shared without time and geographical restrictions. Moreover, cutting-edge research that combines learning analytics and educational data mining is providing further insight into the learning process, and, eventually, it can provide teachers with a decision support system grounded in evidence-based education.

Despite the wide availability of tools, there is still a certain degree of uncertainty about how to deal with technology in classrooms and how to evaluate the outcomes of such activities. In fact, even if the technological developments are driving the digital revolution in education, the lack of guidelines on how to integrate robotics into education, and the difficulty assessing the complex competencies that such new practices bring forth are preventing teachers and schools from fully exploiting and exploring the benefits that technology could bring. On the other hand, the increasing cross-pollination between schools and researchers from different fields is producing valuable experiences in technology-enhanced teaching.

In conclusion, schools and stakeholders in education are still exploring how best to exploit the benefits of new technological developments. Tech developers, in turn, are working closely with pedagogical experts to meet the needs of teachers, students, and educators. In today's hyper-connected, digitized society, education cannot neglect to include new forms of literacy that will increase students' knowledge, skills, attitudes and values helping them to fulfil their potential and contribute to the well-being of their communities and environment.

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