Educational robotics: Open questions and new challenges

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Abstract. This paper investigates the current situation in the field of educational robotics and identifies new challenges and trends focusing on the use of robotic technologies as a tool that will support creativity and other 21st-century learning skills. Finally, conclusions and proposals are presented for promoting cooperation and networking of researchers and teachers in Europe that might support the further development of the robotics movement in education.

Keywords: educational robotics, constructionism, creativity

Introduction

During the last decade robotics has attracted the high interest of teachers and researchers as a valuable tool to develop cognitive and social skills for students from pre-school to high school and to support learning in science, mathematics, technology, informatics and other school subjects or interdisciplinary learning activities.

This paper is based on ideas presented and discussed in the frame of a special discussion panel held during the International Workshop "Teaching Robotics, Teaching with Robotics" (TRTWR, 2012), which focused on the current situation in educational robotics at European level and examined ways for driving ahead the community and the robotics movement in education.

The paper starts with an investigation of the state of the art in the field of educational robotics; then, existing problems and new challenges are discussed; finally, some proposals are presented for aligning robotic technology with learning theories, namely constructivism and constructionism, for promoting cooperation and networking of researchers and teachers and for building the educational robotics community in Europe.

Investigation of the field

Review of literature reveals that Educational Robotics is a growing field with the potential to significantly impact the nature of science and technology education at all levels, from kindergarten to university. Educational Robotics has been emerged as a unique learning tool that can offer hands-on, fun activities in an attractive learning environment feeding students interest and curiosity (Eguchi, 2010).

The main theories behind Educational Robotics are constructivism and constructionism. Piaget argues that manipulating artefacts is a key for children to construct their knowledge (Piaget, 1974). Papert added the idea that knowledge construction happens especially effectively in a context where the leaner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a technological artefact (Papert, 1980). Educators' role is to offer opportunities for children to engage in hands-on explorations and to provide tools for children to construct knowledge in the classroom environment. Educational Robotics creates a learning environment in which children can interact with their environment and work with real-world problems; in this sense Educational Robotics can be a great tool for children to have constructionist learning experiences. Studies in the field (e.g. Eguchi, 2010; Benitti, 2012) report that robotics have a potential impact on student's learning in different subject areas (Physics, Mathematics, Engineering, Informatics and more) and on personal development including cognitive, meta-cognitive and social skills, such as: research skills, creative thinking, decision making, problem solving, communication and team working skills, all of them being essential skills necessary in the workplace of the 21st century.

Three different approaches to Educational Robotics are reported in the literature (Eguchi, 2010):

- Theme-Based Curriculum Approach: curriculum areas are integrated around a special topic for learning and studied mostly through inquiry and communication (e.g. Detsikas & Alimisis, 2011; Litinas &Alimisis, 2013)
- Project-Based Approach: students work in groups to explore real-world problems; this is for example the case proposed in the methodology developed by the European project *TERECoP*, *Teacher Education in Robotics-enhanced Constructivist Pedagogical Methods*, www.terecop.eu) (Alimisis, 2009).
- Goal-Oriented Approach: children compete in challenges in Robotics Tournaments taking place mostly out of school, such as FIRST Lego League (http://www.firstlegoleague.org),RoboCupJunior (http://www.robocupjunior.org), Trophée de robotique in France (http://www.planete-sciences.org/robot), World Robotics Olympiad in Greece (http://wrohellas.gr) and more.

At the same time there is an increasing number of actions and events in Europe that might be categorized in thematic workshops (e.g. the pre-mentioned series "Teaching Robotics - Teaching with Robotics"), regional conferences (e.g. "Robotics in Education", www.rie2013.eu), regional or national tournaments, training courses for teachers such as TERECoP (www.terecop.eu), Roberta Teacher Training (www.iais.fraunhofer.de/roberta-teacher-training.html), local or regional networks, e.g. Robot@scuola in Italy (www.scuoladirobotica.it/en/RobotAtScuola/index.html), CENTROBOT in Austria and Slovakia (http://www.centrobot.eu) and more.

On the other hand, there is no systematic introduction of robotics in school curricula within the European school systems. However, a plethora of constructionist robotic toolkits created and deployed in the 2000s with improved and friendlier designs (LEGO Mindstorms NXT, Arduino, Crickets and more) have prepared the ground for the popularity of robotics among students of all ages. Pioneering efforts in school classes during last decade have shown that children are enthusiastically involved in robotics projects achieving learning goals and/or developing new skills (e.g. Detsikas & Alimisis, 2011; Litinas &Alimisis, 2013).

Open questions and new challenges

Educational robotics, considered as a branch of the educational technology, suffers from the same old problems well known in the latter. In the next sections, some critical current problems and the consequent emerging challenges for educational robotics community are identified and discussed.

"Technology is everywhere, except in schools"

Research by legislative bodies (such as the United Nations Economic Commission for Europe, the International Federation of Robotics, and the Japan Robotics Association) indicates that the market growth for personal robots, including those used for entertainment and educational purposes, has been tremendous and this trend may continue over the coming decades (Benitti, 2011). However, as a recent OECD report remarked "technology is everywhere, except in schools" (OECD, 2008). While experts are optimistic concerning the development of technology-enhanced learning opportunities, skepticism prevails concerning the ability of formal education systems and institutions to keep pace with change and become more flexible and dynamic. These difficulties are not irrelevant to findings of current surveys of school students' attitudes to Science and Technology (see for example: TISME, The Targeted Initiative on Science and Mathematics Education 2012, http://tisme-scienceandmaths.org), which witness declining interest and engagement in technological fields of study (Nourbakhsh et al., 2006).

Although there have been some directives issued by national education authorities (e.g. by the Italian Ministry of Education, n. 93 30/11/2009) encouraging the development of projects on educational robotics in schools, and some new school curricula are being enriched with robotics projects e.g. the curriculum for informatics literacy in the lower secondary school of Greece (Jimoyiannis, 2012), educational robotics (and other digital technologies as well) has not been introduced in the European school curricula. Most of the experiments involving robotics activities are not integrated into regular classroom activities; they take place in after-school programs, in weekends or in summer camps (Benitti, 2011).

Although exceptions have been reported by teachers who have been able to integrate robotics in ordinary teaching (e.g. Litinas & Alimisis 2013, Detsikas & Alimisis 2011), teachers who implemented robotics activities in schools witness that they felt after-school classes or special in-school activities only for certain students are more convenient (Sullivan & Moriarty, 2009). Obstacles to implementing robotics as part of the regular school curriculum appear to be the time consuming nature of the robotic activities, the cost of the equipment needed and the practical work required from teachers to cope with the mess resulting in class and to keep all the pieces in the right place in their kits. The problem becomes worst when paired with perceptions that robotics, similarly to other science and technology subjects, is hard, highly gender-biased (only for boys!) and not inviting for most students (Blikstein, 2013).

Proposals have appeared in the recent years for a roadmap by which robotics applications can enliven technology education and capture the interest of students (Nourbakhsh et al., 2006). Movements like the so-called "digital fabrication and making in education" movement (Gershenfeld, 2007; Blikstein, 2013) have appeared aspiring (and working) to overcome bias inherit within the educational systems and to link the intellectual work in the classroom with students' experiences in 'making' and building things either with their parents and friends or in jobs in garages, in construction companies etc.

Technologies in schools today do not support the 21st-century learning skills

Promoting excellence in education and skills development is one of the key elements within the "Innovation Union" Flagship Initiative (2012) under Europe 2020 strategy. The "Innovation Union" communication recognizes that weaknesses remain with science teaching; the skills for future responsible innovators/researchers as well as for "science-active" citizens have to be built starting from early age including scientific reasoning, as well as transversal competences such as critical thinking, problem solving, creativity, teamwork and communication skills.

Nowadays there are calls in education in Europe and world-wide for educational approaches that will foster creativity and inventiveness (e.g. Resnick, 2007; Blikstein, 2013). Today's students are growing up in a world that is very different from the world of their parents and grandparents. To succeed in today's "Creative Society" (Resnick, 2007) students must learn to think creatively, plan systematically, analyze critically, collaboratively, communicate clearly, design iteratively, and learn continuously. Appropriate learning methodologies such as Constructivism/Constructionism and Inquiry-Based Science Education (Demo et al., 2012) can strongly contribute to the development of these skills. European Commission call often (see for example European Commission, 2011) for actions aimed to achieve the more widespread use of problem and inquiry-based science teaching in primary and secondary schools.

However, most uses of technologies (including robotics) in schools today do not support the pre-mentioned 21st century learning skills. In many cases, new technologies are simply reinforcing old ways of teaching and learning. Current typical school science labs seem not appropriate for fostering critical thinking, problem solving, creativity, and teamwork and communication skills since they are architected for rigorous, disciplined, and scripted experiences (Blikstein, 2013) in which students are guided usually through recipe-style guides towards the "discovery" of predefined concepts.

In line with the above questioning, an important distinction emerges between "technical competence", that is in-depth knowledge necessary for professional engineers and scientists to do their work, and "technological fluency or literacy", meaning knowledge, skills and attitudes valuable for every citizen (Papert, 1987; diSessa, 2000). In accordance with the pre-mentioned discussion for the so-called 21st century skills, current societal developments call for a shift in educational technology from technical (or computer) skills towards technological and computational fluency or literacy. For the field of educational robotics it dictates a move from just using it to offer vocational skills for future science, technology, engineering and mathematics workers towards fluency or literacy with robotic technology making its intellectual and manual advantages available for every future citizen. If robotic technologies are used in line with the above perspective, have an important role to play: they can provide constructionist learning experiences, promote essential skills necessary in the workplace of the 21st century and equip new generations with a sound "technological literacy" for their better preparation for life in the "Creative Society".

Is Robotics just the servant of other subjects? Need for new and broader perspectives

If the reasoning of the previous section is adopted then a need for broadening robotics audiences and target groups emerges. The way robotics is currently introduced in educational settings is unnecessarily narrow (Rusk et al., 2008). Till now most of the applications of robotic technologies in education have focused on supporting the teaching of subjects that are closely related to the robotics field, such as robot programming, robot construction or mechatronics (Benitti, 2011).

If we wish to address larger target groups of learners (ideally all the children!), broader perspective projects are needed. A wider range of possible robotic applications has the potential to engage young people with a wider range of interests. Pursuing this challenge we need to develop new and innovative ways to increase the attractiveness and learning profits of robotics projects. Rusk et al. (2008) suggest four strategies for engaging a broad range of learners in robotics: projects focusing on themes, not just challenges; projects combining art and engineering; projects encouraging storytelling; organizing exhibitions, rather than competitions. Young people who are not interested in traditional approaches to robotics become motivated when robotics activities are introduced as a way to tell a story (for example, creating a mechanical puppet show), or in connection with other disciplines and interest areas, such as music and art (Resnick, 1991; Rusk et al., 2008). Different students are attracted to different types of robotics activities; students interested in cars are likely to be motivated to create motorized vehicles, while students with interests in art or music are likely to be more motivated to make artistic robotic creations (Benitti, 2011).

Embodiment is another new and innovative way that might be introduced in robotics activities to make them more meaningful for children. Embodied experiences with robotics can be realised when students physically move their own bodies and then program robots to perform a certain task. In such a case learning develops from personal embodiment to embodiment through surrogate robots (Lu et al., 2011). Another way to facilitate embodied learning with robotics is to make the learners embody the robotic system, for example by asking learners to reenact or follow movements of robots through gesturing (De Koning & Tabbers, 2011). Embodiment within robotics seems a promising path for further research based on current theories of embodied cognition.

Shifting from "black box" to "white box" paradigm: learners as "makers" rather than just consumers

The robotics industry so far mainly aims at humans using pre-programmed pre-fabricated robots. The ways in which the robots are made and programmed is a "black box" for their users. Unfortunately, the same "black box" method is followed very often within educational robotic applications where the robot has been constructed or programmed in advance and is introduced in the learning activity as an end or a passive tool (Mitnik, Nussbaum & Soto, 2008).

The reasoning behind the "black box" method is often based on the perception that construction and programming of a robot is a highly demanding task for children. However, perceived difficulties of robotics tasks have been found to be due to deficient design rather than learners' cognitive deficiencies (Blikstein, 2013). Whatever is the underlying misconception, the "black box" metaphor is compatible with the traditional educational paradigm of the teacher or of the curriculum book revealing and explaining ready-made ratified and thus unquestioned information.

Very differently from this approach, constructivism/constructionism methodologies require the transition to the design of transparent ("white-box") robots where users can construct and deconstruct objects, can program robots from scratch and have a deep structural access to the artefacts themselves rather than just consume ready-made technological products. The white-box metaphor for construction and programming might generate a lot of creative thinking and involvement in learners (Resnick, Berg & Eisenberg, 2000).

However, students often fall onto "plateaus", unable to progress beyond a certain point and find that they cannot construct something very interesting when starting from scratch every time. So, compromises to transparency in the design of robotics kits for learning have been suggested resulting in the so-called "black-and-white-box" perspectives, so that children can engage in meaningful, interesting and challenging constructivist activity through the control of robots and/or their environment (Kynigos, 2008). This is for example the case when teachers wish to focus on programming concepts in their class without having time available for students to construct their robots; in this case teachers have to bring in class the robots constructed in advance to save teaching time and to offer opportunities for their students to program and control the robots in a transparent way (e.g. Detsikas & Alimisis, 2011).

Finally, the dilemma between "white-box" and "black-and-white-box" metaphor seems that should be answered by teachers and educators according to their learning objectives when they introduce robotics in their class and, more importantly, according to their students' learning interests and needs.

Is Robotics just a fashion? Calls for validation of the impact of robotics

It is clear that while robots have positive educational potential, they are no panacea. In the literature there have been studies reporting non significant impact on learners observed in some cases (Benitti, 2011). In any case, the impact of the robotics in promoting student learning and in developing skills needs to be validated through research evidence. Without validation of the direct impact of robotics on students' learning and personal development, robotics activities might be just a fashion. However, there is a lack of systematic evaluations and reliable experimental designs in educational robotics. Benitti (2011) highlights that most of the literature on the use of robotics in education is descriptive in nature and is based on reports of teachers achieving positive outcomes with individual, small scale initiatives.

A criticism emerges within the robotics community in recent years claiming that there is a clear lack of quantitative research on how robotics can increase learning achievements in students. Bredenfeld et al. (2010) point out lack of a systematic examination of the robotic projects and of a significant evaluation of the impact of the approaches or if they meet their goals. In other cases the expected benefits have not been clearly measured and defined because there is not a system of indicators and a standardized evaluation methodology for them (Ortiz, Bustos & Rios, 2011). Despite the usually positive educational and motivational benefits, studies suggest that rigorous quantitative research is missing from the literature. Research involving robotics in the classroom very often provide results dependent on teacher or student perceptions rather than rigorous research designs based on student achievement data (Barker & Ansorge, 2007).

Research needs to prove in each robotic project or course if the learning goals were reached, if more children become interested in science and technology or develop significantly better cognitive or social skills. In addition to that, we need to know if a robotic course for young children has its impact on their further educational career, which requires longitudinal evaluation projects (Kandlhofer et al., 2012). However, during a robotics class students' work in developing their projects or in problem solving takes usually diverse and unpredictable paths making difficult for evaluators to follow students' progress. Monitoring environments have been proposed to allow the teacher to monitor and model the learning process based on the data coming from the under evaluation learning situation. Data mining methods were tested with authentic data collected from a robotics class and produced useful and interpretable information about the students' progress (Jormanainen & Sutinen, 2012).

Conclusions and proposals

In the light of the above discussion it is obvious that a need for rethinking our approaches in Educational Robotics emerges. Robotics has much potential to offer in education, however, the benefits in learning are not guaranteed for students just by the simple introduction of robotics in the classroom, as there are several factors that can determine the outcome; technology alone cannot affect minds. Robots are not the end point for improving learning; the real fundamental issue is not the robot itself; rather, it is the curriculum. Robots are just another tool, and it is the curriculum that will determine the learning result and the alignment of technology with sound theories of learning. An appropriate educational philosophy, namely constructivism and constructionism, the curriculum and the learning environment are some of the important elements that can lead robotics innovation to success. The emphasis should be shifted from the technology towards partnership with learning theories putting the emphasis on the curriculum than on the technology. The curriculum is the keystone in educational robotics and it is necessary to incorporate the basic principles of learning and to set qualitative and quantitative performance metrics for expected outcomes and for validation of the curriculum.

The role of Educational Robotics should be seen as a tool to foster essential life skills (cognitive and personal development, team working) through which people can develop their potential to use their imagination, to express themselves and make original and valued choices in their lives. Robotics benefits are relevant for all children; the target groups in robotics projects and courses should include the whole class and not only the talented in science and technology children.

To this end, broader perspective projects are needed to foster the above emphasised creativity skills for all the children, no matter their school orientation or gender. Different strategies for introducing students to robotics technologies and concepts should be employed by teachers and educators to provide multiple pathways into robotics and to ensure that there are entry points to engage young people with diverse interests and learning styles (Rusk et al., 2008). An iterative plan is necessary for the validation of the different strategies and methodologies whereby implementations of the robotics curricula will take place in practice followed by testing, refinement and continuous improvements. Testing should be based on a system of indicators and a standardized evaluation methodology for clearly measured and defined benefits.

Finally, the realisation of the above proposals requires the development of a vibrant and active European community in educational robotics that will promote further networking of researchers, teachers and learners. The existing local and regional networks in educational robotics in Europe, mostly built around current or past project partnerships, remain still small size and isolated groups suffering from lack of coordination. However, these pioneering efforts are considered as development of a high potential if these networks link together and synchronize their actions into a European network (Bredenfeld et al., 2010) that will offer well-organized and coordinated collective actions at European level focusing on the following objectives:

- To create and share open educational and technological products and practices (curriculum and resources) for both formal and informal learning environments in a way that reflects the best pedagogical practices and educational research in the field.
- To promote communication and collaborative networking between researchers, teachers, and learners establishing fora for the community to share experiences, products and expertise
- To support teacher education establishing and running schools for teachers
- To encourage and support practical implementations of robotics curricula in schools
- To test and validate curricula and methodologies in both teacher education and school class level
- To form Special Interest Groups to study specific issues in Educational Robotics.
- To provide a reference point for education authorities, academics, teachers, parents and children on the latest developments in the domain of educational robotics.

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