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LEARNING APPROACHES TO APPLYING ROBOTICS IN SCIENCE EDUCATION

Heilo Altin,
Margus Pedaste

Abstract. *The methodology and ideas behind educational robotics arise from the 1960s, when the first hardware platforms together with computers were used in research studies in schools. Since the 1990s, the market for educational robotics has grown, and there are many solutions available to use in schools. Despite a wide variety of platform approaches for using robots in education, they are still based on ideas that are decades old. This study evaluates different approaches used nowadays to teach with robots. Problem-based, constructionist, and competition-based learning are identified as the most common uses of robots under observation. Each approach is analysed qualitatively based on the published literature. Each has positive and negative properties; though none have been studied thoroughly using quantitative methods. Results indicate that all these approaches are used in schools with robots interdisciplinary. The current reasons for using robots are based mostly on teachers' and students' impressions. However, robotics can be seen as a "tool" to create many approaches to science education, such as inquiry learning and problem solving.*

Key words: *constructionism, constructivism, educational robotics, inquiry learning, LEGO Mindstorms, problem solving.*

Heilo Altin, Margus Pedaste
University of Tartu, Estonia

Introduction

There has been a growing interest in using robots for science education in schools. This paper focuses mainly on robots used as tools to teach STEM (science, technology, engineering, math) subjects in school, e.g. according to K-12 curriculum (K-12 is a shortening of kindergarten through twelfth grade). Robotics used at universities is mostly object-based, which means that students learn robotics with robots. Robotics became an issue of education in the 1960s when Papert introduced the programming language LOGO and the floor turtle—a robot that can execute commanding directions by connecting to a computer (Papert, 1980). Turtle robot was able to draw its moving trajectory on the floor and because of that ability, it was possible to draw trigonometric shapes. Turtle robot was developed in cooperation with Marvin Minsky, who was the first to encourage children in the new MIT Children's Laboratory to learn to control a small robot (Minsky, 1986). Together they integrated a control system into LOGO. The target group of educational robotics was addressed in the 1980s by the Educational Products Department in the LEGO Group. Eventually, this department was renamed LEGO Dacta, whose purpose was to expand the educational possibilities of LEGO toys. Work on educational toys and especially robotics increased in 1998 when LEGO Education (formerly LEGO Dacta) released the educational pioneering concept Mindstorms. The core of Mindstorms was RCX, an intelligent and programmable LEGO brick. The successful start of educational robotics with RCX in first decade of the 21st century brought attention to other companies with educational robotics production, like FischerTehnik Computing, Robotis Bioloid, and Robotis Ollo. In 2007, LEGO Education released the next level of RCX, called NXT. Mindstorms NXT enabled users to use more sensors, newer motors, and more complicated programming languages like NXT-G and LabVIEW. In

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2013, the next platform, called EV3, was released. Updates included new communication channels such as WiFi and data recording on SD card. LEGO Mindstorms are not the only programmable toys in the education market, but they are some of the most used robots. Since the turtle robot there have been many methodologies used to teach with robots. These approaches are explained below:

- discovery learning;
- collaborative learning;
- problem solving;
- project-based learning;
- competition-based learning;
- compulsory learning.

A review of educational robots history shows that these methodologies are platform driven. Most of the educational robotics methodologies follow platforms—not vice versa. On the other hand, Sullivan claimed that most of the educational technology is based on Papert's theory of constructionism (Sullivan & Moriarty, 2009). Even from that point of view, usage of this technology in an educational context does not focus much on methodology. Alimisis (2012) found that the focus in educational robotics should be shifted from hardware to methodology. Based on the current studies, it can be concluded that robotics is not widely used in education (Papanikolaou, Frangou, & Alimisis, 2009), and therefore, advantages of robotics could be applied more (Bredenfeld, Hofmann, & Steinbauer, 2010).

Among many previously listed methodologies used to teach robotics, competition-based learning has been the most effective way of getting students to apply math, physics, and other subjects through robotics (Giannakopoulos, 2009). Competition-based learning is a methodology where learning outcomes are achieved through competitions. It has been successfully applied in several studies in the context of technology-enhanced science education (Pedaste & Sarapuu, 2006; Pedaste, Mäeots, Leijen, & Sarapuu, 2012). However, the competitions are only directed to a limited group of learners as robotics competitions are rather expensive to organise and the number of participants is limited financially. Because of that limitation, it is necessary to find effective ways of using robotics in classrooms by all learners in the fields of science (especially physics), technology, and engineering. In this case, the advantages of robotics can be applied to a much wider audience. These new methodologies that enable the use robots in classrooms are important. Students' interest in robotics is an important factor in the learning process and in achieving learning outcomes. If robotics is neither a part of a general curriculum nor a method or tool for acquiring outcomes of a curriculum, the effect is minimised. So robotics ought to be included in the curriculum in both ways—as a learning object and tool to learn other subjects.

These theory- and practice-based ideas for implementing robotics as a tool in curriculum-based education need further study. This research proposes a theoretical and methodological model of applying robotics through the inquiry approach to learning physics. For that we analyse most of the methodologies used to teach with robots. Modern model of educational robotics platform is described and its best use through inquiry learning is found. Two research questions are set up:

- What methods and platforms of robotics have been used in science education?
- Which new trends could be integrated to use robots as a tool in science education?

Research Methodology

To answer the research questions, a literature review was conducted. Relevant research was selected and an analysis and synthesis was conducted on that. The articles were searched in the Thomson Reuters (ISI) Web of Knowledge, EBSCO, and Google Scholar databases. During the first stage of the search (see Table 1), the publishing period was set from 2000 to 2013 and the following keywords were used: (educational OR education) AND (robotics OR robots OR LEGO) AND (school OR K-12). Some results were not actual articles but rather commercial one-page reports on new robotics platforms. This was especially common in results from the EBSCO database. So the number of results from EBSCO was much higher than from ISI or Google Scholar. The next stage was to analyse all search results by title. If a title was confusing, the abstract was reviewed to identify whether the article discussed an educational robotic tool and robots used in schools as a part of a curriculum or extracurricular activity. During the third stage, articles were assessed in detail. To the final analysis were included only papers that met the following criteria:

- robots used as tools to teach science education, not the object itself;
- learning with robots through direct contact, not over the Internet;
- the study revealed quantitative or qualitative feedback.

Table 1. Number of Articles Found After Each Stage Applied in the Search Process.

Database*	Results after the first stage	Results after the second stage	Results after the third stage
Thomson Reuters (ISI) Web of Knowledge	50	12	3
EBSCO	261	20	2
Google Scholar	29	6	3

**Several duplicate articles were returned by all databases, the results in the third stage are unique.*

Research Results

Eight research papers were selected for analysis to answer the research questions formulated in the current study. The overview of these articles is presented in Table 2.

Table 2. Overview of the Articles Selected for the Analysis.

Thomson Reuters (ISI) Web of Knowledge	Authors	Methodology described
A constructivist methodology for teacher training in educational robotics: the TERECoP course in Greece through trainees' eyes	Alimisis, D (Alimisis, Dimitris); Frangou, S (Frangou, Stassini); Papanikolaou, K (Papanikolaou, Kyparissia)	Constructivist (project-based learning)
Teaching programming with robots: a case study on Greek secondary education	Maya Sartatzemi, Vassilios Dagdilelis, Katerina Kagani	Problem solving
Design, story-telling, and robots in Irish primary education	Fred G. Martin, Deirdre Butler, Wanda M. Gleason	Compulsory/story telling
EBSCO	**Authors**	**Methodology described**
Collaborative learning in an educational robotics environment	Brigitte Denis, Sylviane Hubert	Collaborative learning
Robotics and discovery learning: pedagogical beliefs, teacher practice, and technology integration	Florence R. Sullivan, Mary A. Moriarty	Discovery learning
Google Scholar	**Authors**	**Methodology described**
Robotics teaching in primary school education by project- based learning for supporting science and technology courses	Dilek Karahoca, Adem Karahoca, Hüseyin Uzunboylu	Project based, collaborative learning
The botball educational robotics program: engineering outreach for middle school, high school, and college students	Cathryne Stein	Competition-based learning
Enhance understanding of science concepts with technology-based learning tools (programming and hand-held device) in a LEGO robotics elementary after-school classroom	Daoquan Li, Insook Han, Seokmin Kang, Carol Lu, John Black	Problem solving

Learning Approaches Applied in Robotics Education

Approaches applied in the educational robotics context reflected in the articles found in the current study:

- discovery learning;
- collaborative learning;
- problem solving;
- project-based learning;
- competition-based learning;
- compulsory learning.

All these approaches follow the ideas of constructionism introduced by Papert and constructivism derived from Piaget's work (Papert, 1980). These are methodologically slightly different, but they could be thought of as a roof methodology that hosts many other methods used in the educational robotics context. For example, project-based learning is the implementation of constructivism (Frangou, 2009). Distinguishing between constructionism and constructivism requires a detailed knowledge of both methods and processes of knowledge construction. Constructionism by Papert was developed in the 1960s when Papert thought of the turtle as a good guide for pupils starting to learn math and numbers. The floor turtle robot was later replaced with a virtual turtle on the computer screen. One of the reasons was that virtual turtle was more accurate in its movement. Turtle did not follow an exact path due to errors. This was demotivating and confusing to the students if they did not get what was expected, even if they did everything correctly. Mechanical feedback of programming was lost and replaced with visual feedback. Papert's educational use of computers was to affect the way people think, learn, and access knowledge. LOGO fulfilled the goals as a tool for learning concepts like planning, problem solving, and experimentation.

Constructivist learning was used to help children to learn with computers (Papert, 1980). Constructivist theories according to Piaget states that people construct their knowledge based on experiences gained from real world and linked to personal pre-knowledge (Piaget & Garcia, 1991). Papert noted that computers play an important role in knowledge construction as tools to learn math and other subjects. Papert's idea of learning with LOGO was discovery-oriented. It means that LOGO enables the discovery of students' ideas through a personal search. On the other hand, Becker (1987) emphasised that the LOGO effect is raised when students are individually tutored. The same has been found in applying discovery or inquiry learning in science education. The discovery learning approach has been replaced by guided discovery or later with inquiry learning to increase the effect of the learning process. The effectiveness of solving problems through the discovery or inquiry learning approach depends on various characteristics of the learners and should be supported accordingly (Pedaste & Sarapuu, 2006). Inquiry learning will also be introduced in this section while it has emerged from the approaches applied earlier in robotics education and it is seen a promising new approach for combining these.

Discovery learning

Sullivan and Moriarty (2009) conducted an experiment with teachers to use the discovery learning approach with robots. According to their description, the discovery method takes more time than other methods described here. Problems arose based on the discovery approach. As it was open and almost guidance free, it was difficult for the teachers to stay away from struggling pupils without giving direct guidance because pupils were free in their search and were supposed to find out how "things work" by themselves. Teachers were expected to use the Socratic method, which does not give direct answers to inquiries but rather guides students towards their own answers. In many cases, pupils had problems with simple things, like getting the robot to move. This experiment caused frustration among teachers as they did not have fast progress and felt helpless. In some cases, teachers did not know the answers, so the discovery approach was replaced with collaborative learning. However, despite negative feedback, Sullivan and Moriarty (2009) claimed that the discovery approach could be effective even when teachers cannot witness an actual increase in pupils' mental functioning and resulting stability due to new knowledge. The discovery approach takes more time than normal in the context of the curriculum.

Collaborative learning

Collaborative learning could be organised in combination with any other approach used in educational robotics if pupils are allowed to communicate during the learning process. Denis and Hubert (2001) focused on collaboration to develop common robotics education projects along with problem solving theory. Their goal was not to only acquire knowledge of robotics but also to develop strategic and dynamic skills. Educational robotics was a tool to achieve collaborative learning. Denis and Hubert targeted collaboration within groups of two to four and distributed cooperation between learners. They noted that collaboration is defined as actors sharing the same goal of task realisation. Based on their approach, distributed cooperation includes subtasks with a common goal first distributed among different actors. Groups usually have two members, and one is responsible for hardware and the other for software by agreement. Collaboration in that context means sharing knowledge, skills, and strategies between groups. Hubert and Denis stated that collaborative learning reduces the gap between teachers and pupils as the educator will be involved in learners' interactions. When teachers do not know the answers, they are often on the same knowledge level with pupils and will learn with them. This creates a community that shares information, which enhances educational robotics (Denis & Hubert, 2001).

Problem solving

Sartatzemi, Dagdilelis, and Kagani (2005) performed a study on using robots to teach programming. The aim was related to the knowledge and skills of problem solving and the design of algorithms. Robots first did what their users commanded, not what was expected. The process involved problem solving. Jonassen (2000) called it debugging. Sartatzemi, Dagdilelis, and Kagani (2005) noted that professional programming languages offer many complex statements. Understanding these statements requires some pre-knowledge. When facing problems, users tend to focus on the use of language rather than focus on the actual problem. The authors noticed that students test their solutions to the problem with the execution of the program on the robot. The robot reflects their commands, and the students see if the problem is solved. If the problem still exists, it is not the same state as before. A new program created a new situation, which students take as a new starting point for further trials, or they retrieve their last changes in the program and return to a previous state. After that, they try out a new solution.

So the use of robots could be considered a learning methodology for novice programmers to develop debugging skills as when debugging on a computer. This is derived from constructionism and the physical reflection of the program in the real world. Learning with physical objects enhances a learner's cognition. Sartatzemi, Dagdilelis, and Kagani (2005) concluded that Mindstorms were easy for students to understand and control. We find this rather important because students expect immediate results t when handling other types of ICT tools (e.g., mobile phones and computers). This is in accordance with comparing experiences from workshops with intuitive robotic kits. Students get frustrated while dealing with robots when they struggle with problems related to lack of knowledge about the programming environment (rather than programming itself) (Sartatzemi et al., 2005).

Project-based learning

According to Karahoca, Karahoca, and Uzunboylu (2011), project-based learning (PBL) tasks are assigned to students organised in teams for group work. Tasks could involve investigation or are based on searches for problems. Collaboration is also supported in this type of work as students try to refine questions, think critically, collect and analyse data, draw conclusions, and share their findings

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with others. These authors combined PBL with collaborative learning to organise science courses in electrical circuits (Karahoca et al., 2011). They divided students into groups and assigned each team a coach. The classes followed a learning scenario consisting of eight stages of PBL. Several teams did not complete the electronics project. The average rate of completion over four teams was 68%. Some of the problems with PBL were derived from collaboration. Communication and dividing work within teams was crucial. Karahoca, Karahoca, and Uzunboylu (2011) noted that in some teams, curious and enthusiastic students did most of the work. Groups with better communication and enthusiastic students had more ideas and better results. So teamwork is important in the context of PBL.

PBL was also used to train teachers on the TERECoP project (Alimisis, Frangou, & Papanikolaou, 2009). It was an implementation of constructivist learning theory targeting teachers' use of the methodology. Teachers teach students as they were taught in training—not as they were told (Arlegui & Pina, 2009). This methodology was applied in teacher training during three meetings, and each meeting played an important role in the context of PBL. The fourth and fifth meetings developed teachers' own projects, and the evaluated results were tested on the students. PBL (exploration, experimentation, and creation features) used in training was a positive experience.

Competition-based learning

Another approach to teaching STEM subjects (Science, Technology, Engineering, and Math) with robots is competition-based learning (CBL). Students take part in robotics competitions. They prepare for the competition by building hardware and software. This process involves debugging as students will face problems. While trying to find a solution to the problem, students have to obtain or regain knowledge from subjects like math, physics, programming, and science subjects. Preparing for competition could be generally motivating as participants are motivated by the competition. Knowledge and skills obtained through this learning method are memorised and understood better than with fact-based learning (Papert, 1993). Competition-based learning has been the most effective way of getting students to apply math, physics, and other subjects through robotics (Giannakopoulos, 2009).

An example of CBL is the Botball Educational Robotics Program in the United States, which involves designing, building, and programming robots to get middle and high school students to apply knowledge from science, technology, math, and engineering (Stein, 2004). In this competition, teams include 5-15 or more students. The Botball approach consists of many stages: research, workshop, designing, building, and programming projects, finalizing through competitions, and conference. Botball first targeted only middle and high school students but later targeted university students. Organisers aimed to offer challenges to university students through hands-on engineering. A survey conducted on Botball participants reflected that Botball affected career choice for one third, and most of them (94%) wanted to continue in a career in a technical or engineering field.

Compulsory learning

The work done in the field of robotics education is mainly still on the "interest level" and is not widely used as a part of compulsory education in general schools (Barbero, Demo, & Vaschetto, 2011). Although there are some positive examples of robotics being used in school curricula, these are mainly pilot studies. One of these studies conducted from 2002 to 2003 in Sweden (Hussain, Lindh, & Shukur, 2006) demonstrated several positive effects of using robotics in a classroom on the cognitive development of grade 5 students. They found that it was difficult to confirm the hypothesis of LEGO generally having a positive effect on student cognitive development. More studies should be done to draw conclusions with high validity (Hussain et al., 2006). Robots were compulsory in the curriculum. Robots were used eight hours a month. Activities were related to ordinary schoolwork, in which teachers integrated robotics with their lessons, such as math and technology. In this study, compulsory learning was one possible reason for a more negative attitude towards LEGO robots.

Another example of using robots as a compulsory part of education is in Ireland, where in cooperation with MIT Media Laboratory, four Irish Primary Schools used Mindstorms in children's technology projects (Martin, Butler, & Gleason, 2000). Robotics was included in the curriculum to teach technological concepts. Eight projects were organised in the classroom, and the traditional curricular content was studied through creative expression. Authors concluded that children conceived and implemented successfully skills and knowledge of crafts, mechanics, sensing, control, and programming.

Inquiry learning

Inquiry learning cab be seen as a new promising approach to increase the applicability of robotics in learning science. Inquiry learning has its roots in scientific discovery learning (Bruner, 1961). It is a highly self-directed constructivist approach of learning and discovering through experiments or observation (De Jong & Van Joolingen, 1998). However, the effect of inquiry learning does not depend only on the actual level or support of students' transformative inquiry skills but also on the level and support of students' regulative skills (Mäeots, Pedaste, & Sarapuu, 2008). Students have to plan, monitor, and evaluate their processes of identifying problems, formulating research questions and hypotheses, planning and carrying out experiments, analysing and interpreting results, and drawing conclusions. In a virtual environment, the immediate responses of programs can give feedback and support to the students to help them be effective learners in inquiry settings. Robots, however, can provide students with immediate visualised and tactile feedback that would even increase the attractiveness of inquiry learning – it helps to build a blended learning situation from computer-based and real activities.

Robotic Systems for Science Education

Out of all educational robotic platforms, according to Alimisis (2012), it is not important what exact platform is used in a classroom. The focus should be on the methods that are used while learning with robots. Educational robotic platforms should be built using logic (Figure 1). Robots are mainly composed from three functional elements and in some part act as humans. Sensors are for sensing the environment; decisions are made on the basis of that information by the brain function, and there are also motors as actuators for interacting with the environment.

A similar structure has been used in the context of science studies, which could provide input for robotics in the future. For example, the latest work with artificial muscles is promising to displace motors in the future (Kruusamae et al., 2010). An actuator's function has moved towards accurate controlling of motor rotation. Sensors available for educational robots allow robots to sense the environment beyond human senses (Beetz, 2008). The simple movement of turtle has expanded. Robots have more complicated sensors while motor functions remain on a basic level. There has been much research towards getting robots to act more naturally in terms of coordination and motion principle (Zhang, Liu, Chu, & Guo, 2008). There are also examples of using robots in visual simulation (Abiyev, Ibrahim, & Erin, 2010). Using a simulation is cheaper and more accurate, but according to constructionism theories, where users enhance their cognition with objects they can feel with their senses, visualisation uses fewer senses than real, physical objects. There is another method in robotics education between physical contact and visual simulation – remote/virtual lab. It enables users to control the robot over the internet (Sell & Seiler, 2012).

Complicated robotic solutions that try to act more like humans are developed with textual programming environments. For beginners starting to program a robot like NXT, programming is not the primary objective. The key purpose is to get the robot moving and to understand its brain-sensor-motor function. That is one reason why programming is made simple and visual for beginners. For developing their programming skills, more complicated environments can be used. When it comes to learning programming, robots can make it easier to understand ("LEGO Education," 2013).

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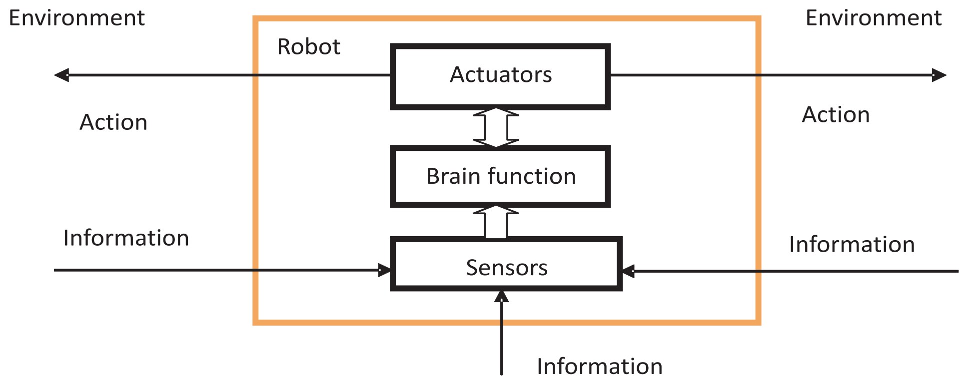

Figure 1: The schema of educational robotic systems. Robots consist of sensors, controllers and actuators that interact with the environment through information collection and actions (based on Alimisis, 2012).

Sartatzemi, Dagdilelis, and Kagani (2005) described how they researched ninth and tenth grades (14- to 16-year-olds) and the effect of Robolab programming with LEGO MINDSTORMS RCX. They demonstrated that the understanding and correct use of the basic programming concepts was easier with robotic systems. But these concepts (such as the creation and use of random numbers) were difficult for novice programmers to understand, whereas for others (such as repetition structures), nothing could be declared with certainty. It could be concluded that use of robots for learning programming has better outcomes on students programming skills compared to learning programming in traditional only computer based way.

New Approaches to Applying Robots in Science Education

New methods of using robotics in science education are still related to hardware capabilities and methodological possibilities. RCX, the first widespread LEGO Educational product, was designed according to constructionism. NXT and EV3 (LEGO Educational robotics platforms) mainly enhance RCX's hardware capabilities but still rely on constructionism.

Relating the hands-on aspect to pupils' interaction with the programmable construction materials means that the pupils' individual knowledge develops continuously in building constructions of LEGO products. In situated cognition (theory that states knowing is inseparable from doing), the importance of the situation or the context of learning is emphasised. Individuals participate and become absorbed in social and cultural activities. Learning is a part of these activities, which contributes to the meaningful knowledge of its carrier. Communication is a key concept as it mediates the individual and his/her context (social situation).

There have been discussions about two main methodologies of applying educational robotics. Becker (1987) emphasised the importance of testable consequences in research on LOGO in discussions of advantages and disadvantages. Becker examined two types of research methodologies: the treatment methodology and computer criticism. Several researchers, including Becker (1987), stressed that the main evidence showing that LOGO can produce measurable learning outcomes when used in discovery classes has been obtained in situations like individual tutoring. They confirmed that in normal-sized classes, the evidence clearly showed the need for direct instruction in the concepts and skills to be learned from LOGO, as well as further direct instruction to enable students to generalise what they have learned to other situations. But this is in complete opposition to Papert's concept of the discovery approach to LOGO. Pea (1985) argued about human mental functioning and the two roles of a computer. The choice of the role of computers was between an amplifier of cognition and a re-organiser of human minds. This problem is applicable to the LEGO environment. The issue is whether tutoring should be close to students or more intuitive to allow students to work more independently.

Robotics also supports students' self-reflection (see Runnel, Pedaste, & Leijen, 2013). As students program a robot to complete a task, they are putting themselves into a situation where the robot is acting. Students are trying to "think" like a robot and reflecting on their thoughts on how a task should be completed. In particular, they should apply all reflection activities: describing of their work, critiquing and evaluating it, and discussing it from different perspectives. Robots and collaborative teams of students can provide support in this process.

In conclusion, the results of the analysis of the reviewed articles about using robots in education showed the advantages of applying robotics in the context of inquiry learning. However, in previous studies, there has been no strong evidence of the development of students' regulative skills. There is statistically significant improvement in transformative inquiry skills that depend on the regulative skills, but the regulative skills have not been significantly increased as a result of various treatments (Mäeots, Pedaste, & Sarapuu, 2009). But different advantages in supporting the development of regulative inquiry skills can be seen in the case of robotics. The programming environment can act as a medium for planning the actions of a real robot that can easily be monitored by a learner, and the outcome or success of the learning process can be evaluated by analysing the movements of the robot. So robotics has real potential for solving problems of virtual environments and developing students' regulative inquiry skills.

Discussion

As there are few quantitative studies conducted in the field of educational robotics, it is difficult to come to conclusions about the effectiveness of the methodology applied to robotics in educational settings. Quantitative analysis does not always provide evidence of using robots (Benitti, 2012). Generally, the results of studies on using robotics in classrooms are positive, but they emphasise the need for further study. Hussain et al. (2006) concluded that it is difficult to confirm the hypothesis that LEGO has a generally positive effect on cognitive development. Their studies indicate that certain positive effects can be shown for groups/categories of students. Pedersen (1998) argued that the teacher's role in achieving the positive results in K-12 is a crucial one. It is the teacher who also has considerable influence over the way in which these tools are received by the pupils. Beisser (2006) found that both genders are thriving in the Lego/Logo environment, and both groups view computer use as important for completing schoolwork and for future job or career roles. The teacher's role is not seen as important only while using robots, but when using any information and communication technologies (ICT) tools in science education. Robotics is in some ways also a part of ICT used in schools. ICT covers a wide range of techniques, instruments, and methods that allow users to obtain, transmit, reproduce, and obtain information (Martinez, 2000). Robots address similar principles, and as an extension of computers, they collect information from the environment, make decisions, and act (sensor-controller-actuator systems). This process is based on a student's algorithmical thinking; students make robot do what they want through programming. ICT technologies and robotics have a similar effect on student skills (Kim, Choi, Han, & So, 2012). Applying ICT technologies in schools depends on teachers and their abilities (Cavas, 2011).

Learning with robots is currently more project-based (Arlegui & Pina, 2009). Students solve real-life technological problems because they are interesting and motivating. This assesses students' thinking and problem solving skills, but more studies are needed to decide whether robotics should be a compulsory aid for school subjects rather than an instrument that applies pedagogical methods and increases motivation.

Another way of motivating students to use robotics and is competitions, which are great motivators but sometimes do more harm. Based on experience with the World Robot Olympiad (WRO, 2009) competition, students are strongly motivated by competition (Giannakopoulos, 2009). Robotics' teams and robotics' tasks are similar to those in sports such as football or basketball. The robotics' courts and the competition rules were very close to students' favourite sports.

One example of using competitions to teach robotics in Estonia is a robotics introduction pro-

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gramme where three to four university students take the necessary equipment and go to schools to let the children try out programming robots. Usually 45 minutes is allocated to teaching programming and completing a small task of moving a robot around obstacles. The methodology used to complete the task is mainly trial and error. More successful are those students who follow this path of separating the track into smaller objectives. Others who try to complete the task completely with one programming cycle via computer will not complete the task as quickly as others. In the end, there is always a competition between students. The idea of a competition is motivating but may result in disappointment if students do not succeed as expected.

Another example of demotivation derives from the FIRST LEGO League (FLL) competition (FIRST LEGO League, 2013). As the accuracy of NXT robots is not at the level expected by the robot game field in FLL, students are disappointed when the robot does not achieve the same goals in the competition field compared to the situation on the home field. It is unclear if this disappointment decreases interest in robotics even when competition is in the last step in CBL learning or whether it discourages further participation. From competitions to more curriculum-oriented learning, Giannakopoulos (2009) elicited from the introduction of robotics in high school education that a curriculum of robotics could involve the students in activities where theory and knowledge from math, informatics, and physics are applied. In this way, robotics' lessons could support traditional lessons or be elective course using multimedia such as networks or computer applications. The similarity of robotics to informatics and its use in the field of applying real algorithms renders robotics a very useful tool that could be used for understanding various lessons. The use of robotics in programming lessons helps students to understand and use correctly primary programming concepts (Sartatzemi et al., 2005).

As programming itself would be a narrow outcome for educational robotics, robotic resources should be evaluated to support other subjects such as physics. Studies on robotics supporting physics should show effects and outcomes of using LEGO kits for that purpose. Robotics is in this case not an object; it is an instrument for learning physics. It may be difficult to use robotics in all domains of a physics curriculum, but there are topics that are difficult for students for which LEGO could be used as an experimental tool. These topics in Estonia can be retrieved from the national examinations in physics. There are many misconceptions in physics among students (Krikmann, Susi, & Voolaid, 2004). Such topics include impulse, Newton II law, and fluctuation (waves). Educational robotics could be one suitable methodology to support learning in these domains.

The development of inquiry skills (transformative and regulative) should be a new target of applying robotics. If robotics and inquiry learning have both shown their efficiency in developing problem-solving skills, a combination of these approaches could contribute to even better learning outcomes. Further empirical study is required (see Figure 2). Educational robotics has been mostly used in the context of extracurricular activities and has not changed much in the last thirty years. Inquiry learning has been heavily involved but not often applied in schools. Methods of engaging inquiry learning in schools are being researched. Robotics as a tool and inquiry learning as a method would create, according to the theoretical discussion, a powerful and mutually beneficial synergy.

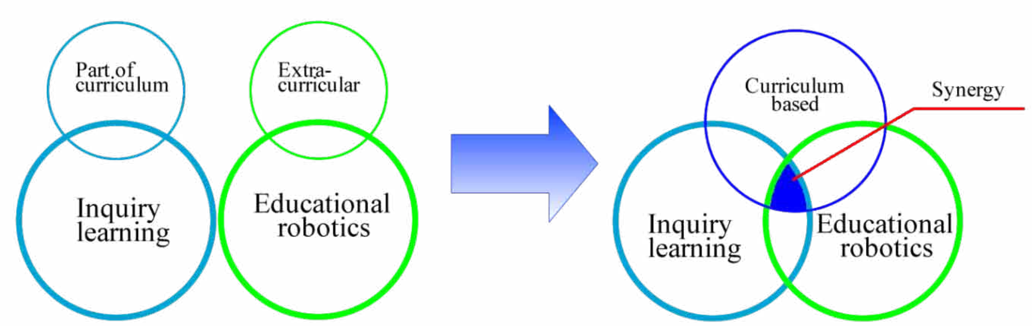

Figure 2: How inquiry-based curriculum and extra-curricular robotics education could benefit from a merge.

In general, in the approach of inquiry-based robotics education, LEGO robots access human knowledge similarly to LOGO computer language. LEGO Mindstorms are more advanced in technology and allow students to reflect their thoughts on a more complicated level than simple movement. Using more sensors to detect environment beyond human senses could be a promising support for STEM subjects. Through hands-on learning, students construct their knowledge and link it with pre-knowledge because robots give new meaning. Robots support constructivist learning but the question of tutoring remains. Future studies are needed to clarify how learning with robots should be supported and to what extent the students should have the freedom to discover robots more independently. LEGO Mindstorms with close tutoring will help students link their work on robots with the real world and better understand real world processes. This type of tutoring requires more teachers with comprehensive knowledge in science and technology generally, but particularly in robotics science.

Most robotics education approaches should not be used alone as these methodologies support and enhance each other. Collaborative or inquiry learning could help students share information, knowledge, and experiences and improve learning outcomes. All these methodologies rely on constructivism and therefore can be easily combined. Nearly all the methodologies have positive and negative properties, but educators have to find the best way to react to these by combining them to meet today's educational needs. More research is necessary to make a decision on how these approaches should be combined. Qualitative judgment of teachers and students based on experience in applying robotics in education is scientifically not strong evidence. So both application of the approaches described in the current analysis as well as their combination should be supported with much stronger empirical results.

Conclusion

Educational robotics is used widely in schools. The main reasons for using robots are found in the qualitative statements by teachers and students. There are few quantitative studies showing the effectiveness of using robots and even those few often conclude by stating the need for further studies. Thus, there is not enough quantitative evidence for applying robots in curricula to achieve educational goals. However, the educational robotics market is saturated with different robotic platforms as many companies see a possibility to earn profits in education.

In the context of science education these platforms could have wide applicability but in this case a review of successful methods is needed. Based on the literature found in the current analysis, the following approaches have been used in educational robotics: discovery learning, collaborative learning, problem solving, project-based learning, competition-based learning, and compulsory learning. All robotic platforms on the market could be used with this variety of approaches developed since 1960's. More or less, these approaches have remained same and they have to face the need of modern society. For instance, discovery learning is one of the approaches used for educational robotics, but it is very time consuming and therefore expensive. Students nowadays expect fast results and when teachers cannot give them direct answers, they get bored and frustrated. These approaches need reshaping towards the context of modern society. Some approaches are developed from previous approaches because of a changing educational world. Inquiry learning is considered to be one of the new approaches in science education that improves students' inquiry skills. However, it is not implemented very widely in classrooms. As a result of the current study there is proposed a way to use robotics as a tool for learning physics through experiments that are set up according to inquiry learning stages (setting research questions, hypothesizing, planning experiments, collecting data, analysing, making conclusions). Physics is just one example in the current study, robotics and inquiry learning could be used in other STEM subjects as well. The applicability of inquiry learning in using robots in different domains needs further study.

References

Abiyev, R., Ibrahim, D., & Erin, B. (2010). EDURobot: An Educational computer simulation program for navigation of mobile robots in the presence of obstacles. *International Journal of Engineering Education, 26* (1), 18-29.

Alimisis, D. (2012). *Robotics in Education & education in robotics: Shifting focus from technology to pedagogy.* Paper presented at the Robotics in Education, Praha.

ISSN 1648–3898

Alimisis, D., Frangou, S., & Papanikolaou, K. (2009). A constructivist methodology for teacher training in educational robotics: the TERECoP Course in Greece through trainees' eyes. *Icalt: 2009 Ieee International Conference on Advanced Learning Technologies*, 24-28.

Arlegui, J., & Pina, A. (2009). *Teacher training in the scientific field through robotic activities.* Paper presented at the Lessons Learnt from the TERECoP Project and New Pathways into Educational Robotics across Europe Athens.

Barbero, A., Demo, B., & Vaschetto, F. (2011). *A contribution to the discussion on informatics and robotics in secondary schools.* Paper presented at the Proceedings of 2nd international conference on Robotics in education (RiE 2011). INNOC–Austrian Society for Innovative Computer Sciences, Vienna, Austria, September.

Becker, J. H. (1987). The importance of a methodology that maximizes falsifiability: Its applicability to research about Logo. *Educational Researcher, 16* (5), 11-16.

Beetz, M. (2008). *Cognition, control, and learning for everyday manipulation tasks in human environments.* Paper presented at the Robot and Human Interactive Communication, 2008. RO-MAN 2008. The 17th IEEE International Symposium on.

Beisser, S. R. (2006). An examination of gender differences in elementary constructionist classrooms using Lego/Logo instruction. *Computers in the Schools, 22* (3-4), 7-19.

Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education, 58* (3), 978-988.

Bredenfeld, A., Hofmann, A., & Steinbauer, G. (2010). *Robotics in education initiatives in Europe--Status, shortcomings and open questions.* Paper presented at the Workshop Teaching Robotics, Teaching with Robotics, Darmstadt, Germany.

Bruner, J. S. (1961). The act of discovery. *Harvard Educational Review*.

Cavas, B. (2011). The use of information and communication technologies in science education. *Journal of Baltic Science Education, 10* (2), 72-72.

De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68* (2), 179-201.

Denis, B., & Hubert, S. (2001). Collaborative learning in an educational robotics environment. *Computers in Human Behavior, 17*, 465-480.

FIRST LEGO League (2013). Retrieved from http://www.firstlegoleague.org

Frangou, K. P. S. (2009). Teacher education on robotics-enhanced constructivist pedagogical methods. In D. Alimisis (Ed.). Athens: School of Pedagogical and Technological Education.

Giannakopoulos, N. (2009). *Experiences from WRO 2009 competition and verifications about the robotics incorporation in the school* Paper presented at the Lessons Learnt from the TERECoP Project and New Pathways into Educational Robotics across Europe Athens.

Hussain, S., Lindh, J., & Shukur, G. (2006). The effect of LEGO Training on pupils' school performance in Mathematics, Problem Solving Ability and Attitude: Swedish Data *Educational Technology & Society, 9* (3), 182-194.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48* (4), 63-85.

Karahoca, D., Karahoca, A., & Uzunboylu, H. (2011). Robotics teaching in primary school education by project based learning for supporting science and technology courses. *World Conference on Information Technology (Wcit-2010), 3*. doi: DOI 10.1016/j.procs.2011.01.025

Kim, H., Choi, H., Han, J., & So, H. J. (2012). Enhancing teachers' ICT capacity for the 21st century learning environment: Three cases of teacher education in Korea. *Australasian Journal of Educational Technology, 28* (6), 965-982.

Krikmann, O., Susi, J., & Voolaid, H. (2004). *Dependence on usage of physics misconceptions by year of study among Estonian students.* Paper presented at the Annual Symposium of the Finnish Mathematics and Science Education Research Association, Helsinki.

Kruusamae, K., Brunetto, P., Graziani, S., Punning, A., Di Pasquale, G., & Aabloo, A. (2010). Self-sensing ionic polymer-metal composite actuating device with patterned surface electrodes. *Polymer International, 59* (3), 300-304. doi: Doi 10.1002/Pi.2752

LEGO Education. (2013). Retrieved from http://education.lego.com

Martin, F. G., Butler, D., & Gleason, W. M. (2000). Design, story-telling, and robots in Irish primary education. *Smc 2000 Conference Proceedings: 2000 Ieee International Conference on Systems, Man & Cybernetics, 1-5*, 730-735.

Martinez, J. A. D. (2000). Social trends of the information and communication technologies in Spain. *Futures, 32* (7), 669-678.

Minsky, M. L. (1986) *The Society of Mind*, Simon and Schuster, New York

Mäeots, M., Pedaste, M., & Sarapuu, T. (2008). *Transforming students' inquiry skills with computer-based simulations.* Paper presented at the 8th IEEE International Conference on Advanced Learning Technologies.

Mäeots, M., Pedaste, M., & Sarapuu, T. (2009). *Developing students' transformative and regulative inquiry skills in a computer-based simulation.* Paper presented at the Proc. of the Eighth IASTED International Conference on Web-based Education (WBE 2009).

Papanikolaou, K., Frangou, S., & Alimisis, D. (2009). *Challenges and achievements of the TERECoP project: the Hellenic experience.* Paper presented at the Lessons Learnt from the TERECoP Project and New Pathways Into Educational Robotics Across Europe, Aspete, N. Heraklion, Athens.

Papert, S. (1980). *Mindstorms--Children, computers, and powerful ideas*. New York: Basic Books.

Papert, S. (1993). *The children's machine: Rethinking school in the age of the computer*. New York: Basic Books.

Pea, R. D. (1985). Beyond amplification: Using the computer to reorganize mental functioning. *Educational Psychologist, 20* (4), 167-182. doi: DOI 10.1207/s15326985ep2004_2

Pedaste, M., Mäeots, M., Leijen, Ä., & Sarapuu, T. (2012). Improving students' inquiry skills through reflection and self-regulation scaffolds. *Technology, Instruction, Cognition and Learning*, *9* (1-2), 81-95.

Pedaste, M., & Sarapuu, T. (2006). Developing an effective support system for inquiry learning in a Web-based environment. *Journal of Computer Assisted Learning, 22* (1), 47-62. doi: 10.1111/j.1365-2729.2006.00159.x

Pedersen, J. (1998). Informationstekniken i skolan. *En forskningsöversikt*.

Piaget, J., & Garcia, R. (1991). *Toward a logic of meanings*. Hillsdale: Lawrence Erlbaum.

Runnel, M. I., Pedaste, M., & Leijen, Ä. (2013). Model for guiding reflection in the context of inquiry-based science education. *Journal of Baltic Science Education*, *12* (1), 107-118.

Sartatzemi, M., Dagdilelis, V., & Kagani, K. (2005). Teaching programming with robots: A case study on Greek secondary education. *Advances in Informatics, Proceedings, 3746*, 502-512.

Sell, R., Seiler, S. (2012). Improvements of Multidisciplinary Engineering Study by Exploiting Design-centric Approach, Supported by Remote and Virtual Labs. *International Journal of Engineering Education, 28 (4),* 759-766.

Stein, C. (2004). The botball educational robotics program: Engineering outreach for middle school, high school and college students. Retrieved 27.04.2013 from http://www.asee.org/documents/sections/midwest/2004/Botball_Educational_Robotics_Program.pdf

Sullivan, F. S., & Moriarty, M. A. (2009). Robotics and discovery learning: Pedagogical Beliefs, teacher practice, and technology integration. *Technology and Teacher Education, 17* (1), 109-142.

Zhang, M., Liu, X., Chu, D., & Guo, S. (2008). *The principle of turtle motion and bio-mechanism of its four limbs research.* Paper presented at the Computational Intelligence and Industrial Application, 2008. PACIIA'08. Pacific-Asia Workshop on.

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Heilo Altin	MSc, PhD Student, University of Tartu, Faculty of Science and Technology, 1 Nooruse Street, 51009 Tartu, Estonia. E-mail: heiloaltin@gmail.com
Margus Pedaste	PhD, Professor, University of Tartu, Faculty of Social Sciences and Education, 1a Salme Street, 50103 Tartu, Estonia. E-mail: margus.pedaste@ut.ee