The environments of educational robotics in Early Childhood Education: towards a didactical analysis

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ABSTRACT
This article consist an analysis of educational robotics environments for early childhood and first primary education. Firstly generally presented a problematic for the role of these environments in educational contexts for young children and examined the main research in the area. Then it is developed a framework of didactical analysis of two main categories of educational robotics environments: a) building competencies when constructing and robots and b) constructing computational thinking. Finally, based on this framework the most known educational robotics environments are analysed.

KEYWORDS
Educational robotics, visual programming, didactical analysis, early childhood education, computational thinking

RÉSUMÉ
L'article comporte une analyse concernant les environnements éducatifs de robotique pour l'école primaire. D'abord nous présentons la problématique sur le rôle de ces environnements dans un contexte éducatif pour les jeunes enfants et nous examinons en bref la recherche dans ce champ. Ensuite, nous développons un cadre d'analyse didactique de deux catégories principales d'environnements de robotique éducative : a) construire des compétences en construisant des robots et b) construire la pensée informatique en programmant des robots. Enfin, dans ce cadre nous analysons les environnements robotiques les plus connus.

MOTS-CLÉS
Robotique éducative, programmation visuelle, analyse didactique, éducation primaire, pensée computationnelle

INTRODUCTION

Current approaches for the programs of study (curricula) relating to preschool and first school age, approaching the digital technologies both as object of new literacies (technology fluency, creative thinking, understanding of the role of technology in community and culture) and as cognitive tools with many implications across the disciplines (problem solving, team-work, inquiry, discovery, experimentation, creativity, critical thinking, communication, cooperation). In this context the educational robotics environments constitute a cognitive tool, which on the one hand supports the development of digital literacy to children and on the other hand can be used as a cognitive tool in a variety of curriculum subjects, such as in the area of STEM (Science, Technology, Engineering and Mathematics), or in literacy but even more in constructing high level cognitive abilities (problem solving, critical thinking, decision making, modeling, etc.).

The term "Educational Robotics" refers to the pedagogical approach which the students use the robots to construct knowledge with the help of or for the robots themselves (Papert, 1980). This approach appeared in the 1960s through the educational movement of the Logo programming language (Papert, 1980). Within this context educational robotics consists of a teaching and learning strategy which recruits programmable devices to improve the learning process through project-based learning. As it was pointed out by many researchers, the use of digital technologies involves its own affordances for observation, analysis, modelling and control of various physical procedures (Depover, Karsenti & Komis, 2007; Misirli & Komis, 2014). The pedagogical approach of educational robotics mediating for procedural thinking processes such as: to define a plan, to organize and find a specific solution to the given problem exchanging one's opinion with those of others (Denis & Baron, 1993). At the same time promotes the development of key components of computational thinking such as algorithmic thinking, programming abilities and modelling (Wing, 2006).

The implementation of educational robotics in early childhood education is seen as a way for introducing different concepts and developing different competencies such as the metacognitive ability, with which the children reflect on the followed cognitive process, improving the ability of problem solving and promoting the ability of spatial orientation (Clements & Nastasi, 1999; Clements & Sarama, 2002). In this article we will deal with robotics environments that have been developed specifically for early childhood education and can favour either learning robotic concepts or skills development of computational thinking using control technologies and automata programming.

CONTROL TECHNOLOGY AND ROBOTICS IN EARLY CHILDHOOD EDUCATION

The current pedagogical approaches for early childhood education support the ability of the child to have control of his activities, while the active participation constitutes one of the basic parameters for the construction of knowledge. Control technologies and robotics applications in particular but also programming and computers are a suitable educational framework within which it is possible to develop high-level cognitive skills, such as: problem solving, critical thinking, algorithmic thinking, team-work, creativity, logical and linguistics abilities, etc (Benitti, 2012).

The high-level cognitive abilities that are developed in early childhood with the use of robotics have been studied since the introduction of the Logo pedagogical approach. The Logo-like programmable robots constitute a distinct category of educational robotics which is appropriate in early childhood and primary education. These games are based on programmable robots which are controlled by the child for the respective movement or path they are ordered to execute. In certain cases the connection with the computer or the tablet may be used. The child conceives and defines the commands which are introduced into the robot following the principles of the Logo like programming language.

The pedagogical approach followed in the case of control technologies is based on development and technical description situations grounded on fundamental command languages, associated in turn with the use of simple (e.g. joysticks) or more complex (e.g. programmable robot) devices. In particular, in the case of programmable robot it is necessary the use of a programming language. The emergence of developmental appropriate robotic devices (like Bee-Bot™ and Thymio) adapted to the abilities of early childhood children enrolled in this perspective. With the inclusion of programmable robots in the curriculum, younger students are introducing to control technology and approaching programming concepts. Then, using programming languages that often accompany imported into more complex concepts approaching this algorithmic approach as a key component of computational thinking.

The domain of robotics is multidisciplinary, including various subjects such as engineering, electronics systems, finite automata, control technology, communication, vision, computing, and systems design. In early childhood education many of the previous concepts may be introduced and delivered through the curriculum. Educational robotics constitutes an appropriate framework for developing key skills (e.g., teamwork, critical thinking, planning, scientific observation, and record keeping). There is a growing emphasis on using educational robotics to support science activities, for example by providing programmable (and often mobile) data-logging platforms.

It is worth mentioning that robotics is an educational approach with a variable dimension, which it can be easily integrated in various educational settings (Bers & Horn, 2010). Moreover, educational robotics may be implemented from early childhood education to develop knowledge in many disciplines. Simple robotics tools permit young children to engage with mathematical processes from an early age such as transformational geometry, unit measure and semiotic processing (Highfield, Mulligan & Hedberg, 2008). Robotics is a cognitive tool through which children have the possibility to approach mathematical concepts, applying strategies such as problem-solving, inquiry and experimentation (Rogers & Portsmore, 2004). Furthermore teaching about and through computer programming and robotics using developmentally appropriate approaches, increases children's sequencing abilities and high order competencies such as problem-solving strategies, abstraction, logical thinking (Kazakoff, Sullivan & Bers, 2013). During the planning and constructing procedure of a robotic model, children of early childhood put into action cognitive abilities which are under development (Papert, 1980). Programming concepts which may be developed within computing environments are not always consisted with cognitive abilities of children of early childhood. There are usually environments which require users to develop the ability of abstract thought (Misirli & Komis, 2014).

Finally, it should be mentioned that several research findings focusing on initial education and teachers' training while developing appropriate teaching interventions for early childhood education (Bers et al., 2002; Bers & Portsmore, 2005; Misirli & Komis, 2014; Kim et al., 2015).

THE ENVIRONMENTS OF EDUCATIONAL ROBOTICS IN EARLY CHILDHOOD

The approach of educational robotics comes directly from the constructionist approach of Logo (Papert, 1980). This approach makes use of a variety of micro-worlds (that require construction or automatic handling with most typical the example of programmable robot 'turtle'), which are used in various teaching situations through meaningful oriented activities for the students. In particular, the pedagogical objectives of robotics can be divided into two main categories: a) handling robots and b) build a robot (Benitti, 2012). Educational robotics in early childhood education is mainly about handling and not building robots and endorses an alternative way of learning programming, through developing initial thinking component that is to move objects in space. But simple constructions of robots can favour the development of other skills associated with the mechanical and control technologies. Educational robots allow, among other things, the exploration of space "from a distance", without intervention of the body, the exact and logical command language, through an encoding, the prediction of the acts and an algorithmic construction of paths. The educational robotics in first school age makes use of various environments that allow either a simple construction and/or handling robotics. In this context we can distinguish two major types of contexts for early childhood and first school age (table 1): a) the robotics construction kits, Lego-Logo like environments (Kibo, LEGO®-WeDo™) allows construction and programming of the robot and b) programmable robots Logo-like environments (Bee-Bot™, Pro-Bot™, Constucta-Bot™).

Robotics construction kits

A robotics construction kit is an environment in which the robot is made of building blocks, Lego type typically represents the most typical example of educational robotics, as it combines both the construction and the programming section of this pedagogical approach. The robotics construction kits may be used to teach robotics concepts (first-order uses) or as analogical tools for learning in other domains (second-order uses) (Sullivan & Heffernan, 2016). A robotics construction kit is a microworld, which consists of physical interfaces and a symbolic language, and allows the study and creation of articulated robot guided by machine. In this context constructions that are created have an engine, which works either via a special interface with your computer, such as in LEGO® WeDo™ environment, either independently, as in Kibo or Cubelets. The movements of these constructions are made either directly (with remote control), or from small programs or processes that the user has created with the help of appropriate software. These environments make possible additional routes to learning through the provision of immediate feedback and the dual modes of representation (physical and symbolic). The robots can be fitted with sensors and send appropriate messages on the computer, which can then be analyzed and responded based on a program. The user should therefore in principle to build the robot and the plan afterwards. Robotic engineering environments constitute the most complete/appropriate developmental framework for a user to construct robotics knowledge. In addition, engineering robotics offers an educational framework to import concepts from various cognitive areas such as science, technology, engineering and mathematics (STEM). Through the programming language, students can build algorithmic concepts, programming and to develop abilities of computational thinking. As noted by Sullivan & Heffernan (2016), programming environments support a computational thinking learning progression beginning with a lower level of sequencing and finishing with a high level of systems thinking, while concurrently support evolving problem-solving abilities along a continuum, ranging from trial and error to heuristic methods associated with robotics study.

In this category we find robots that follow the approach of tangible programming, and designed specifically for young children like KIBO. KIBO is a robotics construction kit specifically designed for children aged 4-7 years old. Children construct their own robot with KIBO, program it to do what they want, and decorate it. KIBO gives children the opportunity to express their ideas by a physical and tangible way without requiring screen time from computers, tablets or smartphones. KIBO allows children to simulate engineers by constructing robots using motors, sensors and craft materials. Also, it is notable that children are becoming programmers by exploring programming concepts such as sequences, loops and variables (Sullivan, Elkin, & Bers, 2015).

TABLE 1

Robotics construction kits for early childhood and first school age

Robotics system	Concepts	Competencies	Age
Cubelets	Sensors, motion, input-output, actions, parallelism	Construction, algorithmic thinking, tangible programming	5+
Kibo	Sequence, motion, repeat, selection, sensors, algorithm	Construction, tangible programming, computational thinking	4+
LEGO® WeDo™	Sequence, repeat, selection, sensors, motor	Construction, computational thinking, programming	7+
Poppy Ergo Jr	Humanoid, degrees of freedom	Construction, movement comprehension	6+

Moreover, we can find and most complex construction robotics kits, which can be used in early childhood education like LEGO® WeDo™. The particular robotic system follows the approach developed by Resnick, Ocko and Papert (1988): LEGO/Logo links the LEGO constructions with the Logo programming approach. In using LEGO/Logo, students start by building robots out of LEGO pieces, using not only the traditional LEGO building bricks but pieces like gears, motors and sensors. Then they connect their robots to a computer and 'write' computer programs to control their robots (Resnick, Ocko & Papert, 1988). In this category there are no robotics kits which have anthropomorphic characteristics besides Poppy Ergo Jr (Roy & Oudeyer, 2016). The Poppy robotic platform allows printing robots in 3D, like the Poppy Ergo. It is about a robotic arm who planned to perform moves and allows the introduction to programming, plus studying anthropomorphic systems etc.

Programmable robots

The Logo-like programmable robots are prefabricated floor robots, which are programmed by the user to execute a programme (movement or path in space) (Misirli & Komis, 2014). The user designs and specifies the set of commands entered into the robots, on occasion, using the commands of a language, which is a subset of the Logo programming language. It is a ready-made robots that have a simple to use interface with command buttons, which represent basic Logo commands and allow for tangible programming, which is done directly to the robot controller, which makes them relatively easy to use even by pre-schoolers (table 2).

We can distinguish two major categories of programmable robots, suitable for early childhood and first school age. The first one is entirely inscribed to the tradition of Logo and is represented by ~~at~~ the following robots: the Bee-Bot, the Blue-Bot (that is the evolution of basic Bee-Bot adding programmability via mobile device), the Pro-Bot and the Roamer Turtle Robot. The second category is a special robot family represented by Thymio, a robot which takes full advantage of the possibilities of multiple sensors (motion detection, distance, volume, etc.) for carrying out actions in the field. On a technical level both categories function mainly through tangible programming while on a conceptual level, the first one follows the principles of structured programming and the second of event-driven programming. Both from research evidences and educational point of view, the most popular robots are the Bee-Bot and Thymio. The Bee-Bot, which embodies the turtle Logo, is externally represented by an animal (bee) and based on principles of programming language for controlling floor robots. Kids can program complex paths on the floor to solve open-ended problems (Misirli, 2015). The planning of movements is located at the top of the robot and consists of a set of coloured keys (commands). Children by pressing on the substance type a series of commands for movement and rotation of the robot. Therefore, the Bee-Bot allows the use of basic commands of Logo and especially the structure of the sequence. The Pro-Bot car format, with its main feature a full numeric keypad, support structures and sequence repeat (Repeat), creating procedures and through touch sensor may implement the control structure.

TABLE 2

Programmable robots for early childhood and first school age

Robotics system	Concepts	Competencies	Age
Bee-Bot / BlueBot	Sequence, motion, algorithm	Algorithmic thinking, tangible programming	4+
Pro-Bot	Sequence, motion, repeat, algorithm, procedure	Algorithmic thinking, tangible programming	6+
Roamer Turtle Robot	Sequence, motion, repeat, algorithm, procedure	Algorithmic thinking, tangible programming	6+
Thymio	Sequence, motion, condition, finite-state machine, sensors, events	Algorithmic thinking, tangible programming, computational thinking, problem-solving thinking	6+

The Thymio robot introduces a new programming approach, the event-driven programming. The robot is pre-programmed with six different behaviors: follows an object at a certain distance, explores the space while avoiding obstacles, detect strokes and the direction of gravity, detects and tracks color differences, obey in joysticks, listens and distinguish certain sounds. In addition, through a visual programming language with programming features to handle events, the developer arranges events and actions, defines what will happen when an event takes place. Each pair of "event – action" provides a transition from a situation to another and thus helps us to introduce a very strong concept of Informatics, the finite-state machine.

TEACHING AND LEARNING PERSPECTIVES OF EDUCATIONAL ROBOTICS

The programmable robots constitute the first learning environment through which young children can be introduced and be familiar with basic concepts of robotics and programming. In particular, the environments delivering tangible programming features while introducing the concept of robots, sensors and automation. Robotics engineering environments provide an educational environment to import concepts from various cognitive areas such as motion sensors, which serve as inputs or outputs, mechanical construction, automated actions and implementation of algorithms. With the use of such an environment favoured the development of metacognitive ability, when children reflect on their thought processes that have followed, problem-solving ability is improved and promoted the ability of spatial orientation and awareness. In addition, since children are dealing to a programming language thus they are integrated to a developmentally appropriate educational environment, where evolution of algorithmic and computational thinking takes place.

Tangible programming / visual programming and programming structures

The basic feature of all robotic systems discussed in this article, except for the LEGO ® WeDo ™, whose programming is carried out via the computer, is running through (or by) tangible programming. The Bee-Bot only works with tangible programming, Blue-Bot and the Bot-Pro are based on tangible programming while can be programmed and digitally (with portable device or computer), the software is programmed Thymio (language/VPL Aseba) but on basic functions work. Tangible programming characterized by physical/tactile relationship developer with the programmable system, with all the cognitive dimensions that this relationship involves the level of early childhood education (Bers & Horn, 2009). At the same time, all the programming languages that come with programmable robot follow the example of the visual programming, which lets the child create programs through the virtual handling programming elements.

At the same time, all the programming languages that come with programmable robot follow the example of the visual programming, which lets the child create programs through the virtual handling programming elements. Since the program flow represented virtual, but writing and understanding/correction programs is relatively easy process. Some environments, such as the Pro-Bot, support and basic iterative structure (repeat) while most, through sensors, can simulate control structures. The programming environment of the LEGO ® WeDo ™ is more complex because of basic programming structures allows the handling of motor and sensors, which convert the construction into a multi-purpose and automatic capabilities.

Sensors (input-output)

The sensors, devices that detect physical sizes and produce from these measurable outputs, are one of the most important functionalities in a programmable robot. Moreover, it is the most essential element that distinguishes a robotic device from a common computer system. Sensors have been introduced, without always being perceived, in the children's environment, and constitute for them part of their daily life in means such as motion sensors, light, touch, sound, distance, etc. In some robotic systems such as Thymio, sensors are the primary means of communication with the robot since receiving inputs/information from users or ~~to~~ the environment and convert it into actions of the robotic device. In other robotic systems such as LEGO® WeDo™, the sensors are accessories which extend the scope or actions of robotic device. The understanding of the role, function and basic settings of sensors for the automatic handling is now part of the broader knowledge ~~you~~ students are gaining within the context of educational robotics.

Engineering construction - Motor / motion

Handling of a robot allows the analysis of motion that it develops in space and time and of its partial synchronization. By that side robots are introducing the concept of logic thinking for handling the fulfilment of a project or achieving a goal. When constructing a robot a user/child is approaching the problems of transmission and transformation of movements. A user develops the skill to copy a given mechanism or discover another to carry out a given motion.

The user/child may develop different kinds of manipulation depending on the type of robot: a) as a ‘puppet’ or object for play when representing its moves to pragmatic and semantic language (manual control), b) direct with the help of a controller (analog controller) and c) planning his moves on the keyboard of a computer or directly on it (logic controller-use of a code language).

SYNOPSIS: A FRAMEWORK TO DEVELOP PROGRAMMING AND ROBOTICS CONCEPTS IN EARLY CHILDHOOD AND PRIMARY EDUCATION

In this article we studied robotics educational environments that can be used at early childhood and first primary classes of education aimed at building knowledge and competencies development of computational thinking and robotics. There was a brief didactic and cognitive analysis of nine environments (programmable robots and robotics kits). These environments have varied characteristics, with the main feature the ability to support basic or more advanced programming concepts and to generate a framework through which children are introduced to control technology and robotics if accompanied by appropriate didactic and pedagogical approach.

The educational robotics offers a developmentally appropriate educational context where various knowledge and competencies may be developed and enhanced. In the present study emphasis was given to the knowledge and competencies concerning programming and robotics rather to the abilities developed by learning fields supported by science, technology, engineering and mathematics (STEM). In this context two large categories of competencies are emerged: a) those regarding construction and manipulation of a robot and b) those oriented to programming knowledge. In particular the development and evolution of programming competencies comprises of skills mostly on algorithmic thinking, tangible programming and visual programming, basic programming structures rather on more complex concepts such as even-driven programming. Therefore, environments like Thymio promoting modern programming concepts, which deserves to be studied in early childhood and in first years of primary education. Additionally most competencies of computational thinking may be constructed under the umbrella these two main categories of educational robotics (construction kits, programmable robots).

In robotics, the studied environments allow us to deal with concepts and competencies associated with the move (and hence with the direction and orientation), with the sensors as input and output devices of information but also to build a robot and its engineering issues.

It is obvious that this research area requires more research, either at the level of theoretical approach, either at the level of the development of new tools, and either at the level of implementation in the classroom.

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