Chapter 1

Constructionism and robotics in education

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1.1. Introduction

Over the last few years, interest in educational utilization of robotics has increased and several attempts have been made world-wide to introduce robotics in school education from Kindergarten to high secondary school, mostly in science and technology subjects. Nowadays, robotics is considered as a flexible medium for learning, offering opportunities for design and construction against short time and small funds. The newest version of educational robotic technologies, that is the programmable bricks, enable students to control the behavior of a tangible model by means of a virtual environment and make possible new types of science experiments, in which children investigate everyday phenomena in their lives (both in and out of the classroom) (Resnick et al, 1996).

However, the successful introduction of an educational innovation in school settings is not just a matter of access to new technologies. Technology alone cannot affect students' minds and cannot act directly on learning. Appropriate educational philosophy, curriculum and learning environment are some of the important factors leading any educational innovation to success. In view of the above, before teachers and educators at all levels rush to exploit robotics in education, appropriate teaching methods need to be formulated and incorporated in the school curricula, given that most schools and teachers lack not only experience and resources, but, also, in most cases, they have to operate under a directive school curriculum that does not favor educational innovation. As Martaric points out, although robotics seems to be an excellent tool for teaching and learning and a compelling topic for students of all ages, the pedagogy of teaching robotics (we would add the pedagogy of teaching *with* robotics as well) is still in its infancy (Mataric, 2004)

1.2 Controlling and constructing robots as a constructionist environment

Construction and control were the first powerful ideas on the use of computational media for learning (Papert, 1980). With respect to digital media, this idea involved the transition from black-box software to the design of transparent (white-box) digital artifacts where users could construct and deconstruct objects and relations and have a deep structural access to the artifacts themselves (diSessa, 2000, Resnick et al, 2000). It also involved the idea of distributed control where multiple users worked with the same digital artifact either in presence or remotely from different computer screens so that they would express their ideas in collectives rather than work individually (Mor et al, 2006).

However, the existence of such media did not bring about the envisaged radical changes in learning environments based on their use (Papert, 2002). Students fell onto ‘plateaus’, unable to progress beyond a certain point and found that they could not construct something very interesting when starting from scratch every time. To address this problem, black-and-white-box design perspectives provided users with generic black box artifacts which they could then use as building blocks for their constructions with exploratory digital media (Kynigos, 2004).

In the use of robotics, we saw a parallel transition from black box situations of pre-programmed pre-fabricated robots, aimed for the workplace, to white box designs, where children can construct and program robots from scratch. However, there has been little or no attention given to distributed control and black-and-white-box solutions, where students can start from something complex and interesting and then move on to learning by constructing robots and programs to control them.

So, what kinds of learning can be nurtured in learning environments based on the construction, programming and control of robots? What meanings and concepts can be understood in such environments? Do they afford added value to the fostering of creative thinking?

The main learning theory, which has been perceived as useful at addressing the questions, has been that of a special kind of constructivism termed ‘constructionism’ by Papert and his group at the Media Lab (Kafai and Resnick, 1996). Constructivism originated from Piaget and perceives learning as the generation of meanings from individuals as they eternally strive to bring some cohesion to the ways in which they see the world (Fosnot, 1997; Brooks and Brooks, 1993). Tangible concrete experiences with the physical and social environment are used to create generalizations, discriminate invariants and construct abstractions.

Constructionism can be seen as a special case of learning in situations where we make or tinker with an object or an entity. It was seen by Papert as one of the ways in which thinking can be manifested, made public. Constructing was seen as an emergent activity, where a lot of back and forth went on, where design is part of the process of building rather than a pre-requisite and where building involves de-construction and re-construction rather than just construction (Kynigos, 1995). In coining the term, Papert wanted to convey a slightly differing perception of learning than Piaget, i.e. that humans do not necessarily strive for cohesion, but are by nature engaged in questioning their view of the world.

Constructionism was elaborated in the early eighties at a time when individualistic cognitive theories were at the forefront and was thus associated with an individualistic perception of learning. However, notions of collaborating and communicating during constructivist activity were firstly articulated as far back as the mid eighties (Rogoff and Lave, 1984) and have since become more and more pertinent as digital technologies have made it possible for more than one students to have access to the same construction at the same time (Mor et al, 2006). This has not however happened yet with mechanical technologies and robotics.

In any case, these perceptions of learning seem to fit very well with the activities of constructing robots and programs to control them. The robotics industry aims at humans using pre-programmed pre-fabricated robots to do arduous, repetitive, mundane, fast, precise, dangerous or physically impossible things from them. The ways in which the robots are made and programmed is a black box for their users. It is the same paradigm with which many technologies are constructed from hardware to software and digital tools. It is also compatible with the traditional educational paradigm of the teacher or the curriculum book revealing and explaining ready-made, ratified and, thus, unquestioned information.

In the framework of progressive and contemporary educational paradigms, construction and programming of robots have been made transparent so that individuals can engage in building and in programming robots themselves. Two main technologies have been so far designed and built for students to engage in robotics, the Lego-Mindstorms and the Pico-Crickets kits from the Media Lab at MIT (Resnick et al, 1996; Resnick et al, 2006). This white-box metaphor for construction and programming has generated a lot of creative thinking and involvement in learners, mainly in informal educational settings.

However, as in the case of digital media, there seems to be a plateau which learners reach with respect to what kind of robots they make and what they can program them to do. It quickly becomes very difficult for anyone to construct a technically robust and interesting robot and to program it to do complicated and interesting things. This was noticed some time ago, as in the case of Pico-crickets, where there was an expansion of the kinds of sensors and the kinds of constructions students could make (Martin et al, 2000) in order to enhance, for instance, the interest of female students.

An important part of learning with robots, apart from constructing and programming them, is controlling them or their environment in play. This has been rather under-exploited from an educational point of view precisely because of the white-box metaphor of starting from scratch with robotics. Controlling robots, however, can provide an avenue for black-and-white-box perspectives, where students can have distributed control of specific robots amongst others. This is seen as part of a complex learning environment likewise embedding the construction of robots and programs to control them as usually, but different in that there is also emphasis on interesting learning activity with robot control.

We consider robot control as an integral part of constructionism. We suggest that robot control can be perceived as an integral part of constructivist engagement with robotics and that given devices and setups, where control is designed to be interesting, students can learn from the kinds of feedback they get from their activities and intentions to control the robots or their environment and from the kinds of representations available to them for control.

Robotics is an integral part of control technology. The ways~~,~~ in which humans control machines, the semantics of the interfaces through which they control them and the discrimination of what is what they control in a certain machine behavior are becoming more and more pertinent for people to understand. The number and variety of automated machines that we control in our everyday lives is increasing continually and rapidly. Think of automatic doors, alarms set by motion detectors, lights put on by clapping. We interact with them all the time but have little idea of how they work. On the other hand, these are devices designed for our everyday lives, the workplace, the home, the public places, such as airports etc.

Consider devices set up for humans to learn things as they control them in order to do something interesting. For instance, the ways in which robots respond to changes in the environment and those changes to which they respond are very important concepts. Discriminating the kinds of things we can control robots to do and, by consequence, gaining insight into the way they are programmed in situations which are more complex than those in which they can be constructed by typical construction kits, has also been overlooked. The means by which we can control robots and the semantics of the devices we use to control them can operate as mechanisms through which we express our thinking, as expressive media. We do not need to wait for learners to build their own programmed robots in order to address these issues.

1.3 Robotic technologies: from floor Logo turtles to Lego Mindstorms

Research in the field of educational robotics has for years placed emphasis on the interplay between the invention of new technologies and the development of innovative ways of learning: new pedagogical ideas can lead to new technologies, and vice-versa (Martin et al. 2000). Since the late 1960’s, research has been developed for robotic construction kits for children focusing on the invention of construction kits and programming tools that children will find easy to understand and control, thus becoming active participants in their learning and creators of their own technological artefacts instead of being just users of devices that others have made for them (Martin et al. 2000).

Early work, led by Seymour Papert, included the development of the Logo programming language (Papert, 1980). A popular use of Logo involved a “floor turtle," a simple mechanical robot connected to a computer by a log cord. With pens mounted in their bodies, floor turtles made drawings on paper, commanded by Logo programs. In the late 1970's, influenced by the increasing production of personal computers, the focus was shifted to screen turtles, which were found to be faster and more accurate than floor ones, while offering opportunities for children to investigate and solve more complex mathematical problems. In the 1980's, Papert's vision of computing, in which children explore ideas by constructing their own computer programs (Papert, 1980), came into being as the first microcomputers entered schools. Many of these activities involved, as a matter of fact, robotic design activities before a general-purpose robotic construction kit for children was made available.

In the mid-1980's, the LEGO/Logo technology, the first true robotic construction kit ever made available widely, appeared, combining the popular LEGO construction kit with the Logo programming language. Lego/Logo integrated two different types of design activities (Resnick & Ocko, 1991; Resnick, 1993). Children start by building machines out of LEGO pieces, using the traditional LEGO building bricks and newer pieces like gears, motors, and sensors as well. Whereas traditional construction kits enable children to construct structures and mechanisms, LEGO/Logo goes further by enabling children to construct behaviours for their artefacts connecting their LEGO constructions to a computer and writing computer programs with a version of Logo (Resnick , 1998).

LEGO/Logo might be seen like a return to the past, since it brings the turtle from the screen back to the real world. But LEGO/Logo compared with the early Logo floor turtles offer some key advantages: students can use LEGO/Logo not as ready-made mechanical turtles but they have to build their own constructions before programming them; in addition to that, children can use LEGO/Logo to build and program, not only turtles, but a wide variety of creative machines.

A serious problem encountered with the LEGO/Logo technology was the nuisance (not only in technical but also in conceptual terms) caused by the wires connecting the robot to a computer, which made it difficult for children to create autonomous and mobile robots. Programmable LEGO Bricks, which appeared in late 1980's, offered a solution to that problem since they run without wires providing in this way autonomous function to children's mechanical constructions. Children can build Programmable Bricks directly into their LEGO constructions, embedding accordingly computation directly into their constructions. Programmable LEGO Bricks expanded significantly the design and learning possibilities for children in 1990's (Martin, 1996; Resnick et al, 1996).

These first generations of robotic technologies served as the foundation for the development of the LEGO Mindstorms kits (http://www.legoeducation.com), a line of Lego sets combining programmable bricks with electric motors, sensors, Lego bricks, and Lego Technic pieces (a line of Lego interconnecting plastic rods and parts, such as gears, axles, and beams). Lego Mindstorms, named after Papert's *Mindstorms: Children, Computers, and Powerful Ideas* (Papert, 1980), are based on research and ideas from the Lifelong Kindergarten group at the MIT Media Lab (Resnick, 1998) and are already being used world-wide in both elementary and secondary education as well as in higher education.

The LEGO RCX Brick, the first retail version of Lego Mindstorms released in 1998 and marketed commercially as the Robotics Invention System (RIS), included motor outputs, sensor inputs, and an LCD screen. The educational version of the product, called *Lego Mindstorms for Schools*, came with ROBOLAB, a graphical user interface-based programming software developed at Tufts University (http://www.ceeo.tufts.edu) using the *National Instruments Lab VIEW* as an engine. The current version (Lego Mindstorms NXT) was released in 2006 and comes with servo-motors, new sensors and the NXT-G iconic programming software but can also be supported by a variety of other programming languages (such as NXC, NBC, leJOS NXJ, and RobotC).

Crickets are another robotic technology, developed in parallel with Lego Mindstorms, aimed at enabling children to learn important math, science, and engineering ideas through the creation of musical sculptures, interactive jewelry, dancing creatures, and other artistic inventions (http://www.picocricket.com/). Crickets have also been intended to engage children in new ways of learning in connection with their interests and passions, and to provide a deeper and more concrete understanding of scientific ideas and a richer sense of the interplay between science and technology (Resnick, 1998). A plurality of Cricket designs has been developed ("Display Cricket", "MIDI Cricket", "Science Cricket", "Cricket Bus system") that provide true analog-to-digital converters on the sensor inputs allowing the use of a greater variety of sensor devices, all of which can communicate with a standard cricket design.

The design of Crickets was heavily influenced by the Beyond Black Boxes (BBB) project, a science-education initiative (Resnick et al, 2000) which provided a theoretical framework and a collection of project ideas for a constructionist approach to science education. Crickets are aimed, among other goals, at enabling children (and educators) to design their own scientific instruments for investigations which they personally find meaningful. Through designing their own instruments, children are expected to gain a deeper appreciation and understanding of many scientific concepts (Martin et al, 2000)

There have also been interesting explorations with other "digital manipulatives" (Resnick, 1998), where computation is added to traditional children's toys embedding either a Cricket inside of a ball (Bitballs Project) or built-in microprocessor and LED (Digital Beads Project) or built-in electronics and infrared communication (Thinking Tags Project). All theses projects are aimed at engaging children in new ways of learning in connection with their own interests and passions: BitBalls can be used mainly in scientific investigations, Digital Beads to engage children in creating dynamic patterns and Thinking Tags to experiment with people's behaviour at social gatherings (Resnick, 1998).

1.4 Robotics in School Settings

Robotics projects and activities in school settings might be classified in two separate categories, according to the role that robotics play in the learning process:

- Robotics as *learning object*: This first category includes educational activities where robotics is being studied as a subject on its own. It includes educational activities aimed at configuring a learning environment that will actively involve learners in the solution of authentic problems focusing on Robotics-related subjects, such as robot construction, robot programming and artificial intelligence.

- Robotics as *learning tool*: In the frame of this second category, robotics is proposed as a tool for teaching and learning other school subjects at different school levels. Robotics as learning tool is usually seen as an interdisciplinary, project-based learning activity drawing mostly on Science, Maths, Informatics and Technology and offering major new benefits to education in general at all levels.

However, this classification is not always easy and clear. Even in the cases, when robotics is introduced as an autonomous learning object, it covers multiple educational aspects and serves objectives beyond those stated in the relevant curriculum extended to the development of problem-solving skills, creativity, critical thinking, collaborative skills etc. In the process of designing and programming robots, students learn important engineering, math, and computer science concepts (Druin and Hendler, 2000, Arlegui et al, 2008a). Robotics can enhance learners' research attitudes, allow learners to make assumptions, carry out experiments and develop their abstracting skills. So, learning constructed through robotics (seen as learning object) is also valuable for other cognitive areas belonging to the broader spectrum of the school subjects.

Over the last few years, several educational projects and initiatives have been developed in the field involving universities, schools or other educational and research institutions. A typical sample of them is presented shortly in the following lines just to offer a sense of the pluralism of thematic areas, educational objectives, learning approaches, topics and diverse audiences involved in past and current applications of robotics in the broader school settings.

The *Lifelong Kindergarten* group at the MIT Media Lab (Resnick, 1998 and 2008) has developed several robotics projects extending from the exploration of the fundamentals of mechanical motion (*Learning About Motion*) to a suite of tools and activities to introduce artists into robotic/electronic media (*Robotic Art Studio)* and to *Learning Engineering by Designing Robots (*for a full list of projects see http://llk.media.mit.edu/projects.php)

Fiorini et al. (2008) describe the efforts undertaken by a small community of teachers concerned with boosting science education in the school district of Verona (Italy) by promoting constructivism with the help of various configurations of robotic devices. These efforts have been going on for the last eight years, slowly gaining momentum and impact. They emphasise that the most striking difficulties have been encountered with the educational environment rather than with students themselves.

The network *Robot@Scuola* of Italian Schools works to gather into a unique national network schools from Primary to Secondary Professional and Vocational education, which use robotics in their educational processes (http://www.scuoladirobotica.it/progettieng.htm). *The Roberta-Goes-EU* project (http://www.iais.fraunhofer.de/3845.html) aspires to encourage young people, and especially girls, through Robotics to take up engineering studies, providing training courses and comprehensive teaching materials to teachers and others who wish to increase students' enthusiasm for technical professions.

The PIONEER (PIedmOnt NEt for Educational Robotics) is an Italian School-Net for the Educational use of robotics in school classes. Its goal is to promote Papert's constructionism in a cooperative environment setting up a model of minirobot programming experiences that can support the standard curricula for school years K-12 (De Michele et al, 2008).

Bers and Urrea (2000) in the framework of a research program at the MIT Media Laboratory, called Con-science, attempted to integrate learning about technology and values in a hands-on way, by involving families, as well as teachers, in the design and programming of robotic creations that represent their most cherished values.

Kärnä-Lin et al (2006) note that although robotics is used worldwide in education as a learning tool, surprisingly it happens only rarely in special education. Through qualitative action research they have identified various advantages that educational robotics can bring into learning in the field of special education: the robotic technologies make it possible for students to practice and learn many necessary skills, such as collaboration, cognitive skills, self-confidence, perception, and spatial understanding.

Dias et al. (2005) presented the challenges and benefits of three higher education initiatives in Sri Lanka, Ghana, and the USA that focused on innovating and implementing robotic technologies for developing communities, examined the potential intersections of robotic technologies with education and sustainable development and the factors that contributed to the success of such educational initiatives designed specially for developing communities.

Mitnik et al. (2009) describe a robotics-based educational project and compare it with a similar computer-simulated activity. The project was aimed at developing graph construction and graph interpretation skills and at reinforcing learning of kinematics concepts. The activity was carried out by means of a set of handhelds and a robot wirelessly interconnected. Results showed that students through the robotic activity achieved a significant increase in their graph interpreting skills that proved to be almost twice as effective as compared with the computer-simulated activity. Moreover, the robotic activity proved to be highly motivating for the students and fostered collaboration among them.

The Science, Engineering, NASA Site Of Remote Sensing (SENSORS) project (Portsmore et al. 2004) was intended to help bring remote sensing and tele-robotics to upper elementary and middle school audiences. Via the web, users remotely control LEGO RCX - based rovers by submitting programs that instruct the creation to complete a or collect data.

Other research efforts have focused on the integration of Robotics in Early Childhood Education developing attractive activities and effective practice for learning with digital technologies at preschool age (Bers et al,. 2002; Pekarova, 2008), while others focus on technical and vocational school students engaging them in designing, building and programming a robotic device that allowed them to explore phenomena of mechanics like the gear-aided transmission of motion (Alimisis et al, 2005) or the gear function and mechanical advantage (Chambers and Carbonaro, 2008). Carbonaro et al. (2004) describe a project-based learning environment in which various robotic construction tasks based on LEGO Mindstorms have been undertaken by middle-school students and highlight some sample products of their work.

1.5 Educational Robotics beyond School Settings: Competitions and other Events

In addition to the activities that take place in school settings, many other robotic events run in informal education contexts, structured as competitions or exhibitions. Each year, several robotics-related associations announce challenges with certain rules, and thousands of teams of young (and older!) people compete in national and international events. The mission of the competitions is usually to engage young people in exciting mentor-based training that builds science, engineering and technology skills, inspire innovation, and foster self-confidence and communication skills. Robotics contests and the relevant project work appear as a very suitable platform to support team-based learning, which is often undervalued in the current school systems (Petrovič and Balogh 2008).

Robotics competitions are growing rapidly in size and popularity and have proven to be very motivating for young people (Sklar et al, 2003). For example, the FIRST

(**F**or **I**nspiration and **R**ecognition of **S**cience and **T**echnology) LEGO League robot challenge, open to student ages 9–14, grew from 200 student teams in the US in 1998 to more than 4,600 student teams in the US in 2006 and more than 2,800 student teams elsewhere in the world (http://www.usfirst.org). RoboCup and RoboCup Junior contest (http://www.robocup.org/) is another international event. Its goal is to foster artificial intelligence and robotics research by providing a standard problem where a wide range of technologies can be examined and integrated (Sklar et al. 2003).

Some of the many other local, national or international competitions carried out across Europe are listed below:

- *RoboParty* by the Robotics Group at University of Minho (Guimarães, Portugal) (http://www.robotica.dei.uminho.pt), where participants build robots from scratch
- *CEABOT* (http://www.robot.uji.es/research/events/ceabot08), a nationwide little humanoid robots competition by the RoboticsLab, University Carlos III de Madrid–Spain
- *RobotChallenge* (http://www.robotchallenge.at) for self-made, autonomous, and mobile robots, hosted in Vienna by the Austrian Society for Innovative Computer Science
- *Istrobot* held at the Slovak Technical University (http://www.robotika.sk) by the association Robotika.SK

A series of interactive exhibits, designed for learners to control in interesting game situations, have recently been made available at a special informal serious games centre in Athens called 'Polymechanon', which runs in informal education contexts without the constraints of the schooling system (Kynigos 2008). In Polymechanon, visitors can be directly immersed in collaborative games, where the more they understand what they control and how the robots respond to environmental change the better players they become. The concepts behind the games are robot's behaviors and aspects of the robot's environment that the human can control, the kind of control they have on these behaviors, the robot's responses to aspects of its environment and the consistent or changing roles of robots in the game at hand.

1.6 Competitions or Exhibitions?

Although competitions are motivating and beneficial in many aspects for students, exhibitions are suggested as an alternative approach that can support more collaboration and less antagonism. Exhibitions offer young people the opportunity to display their work to the public without the need to compete their schoolmates. If students are deeply involved in the design of their robotic projects, as well as in the design of the exhibition event itself, exhibitions can provide the same level of motivation and engagement, as compared with competitions (Rusk et al. 2007). Students and school community members of all ages can be invited in an exhibition to informally join and interact with each project and its creators. The open-ended nature of an exhibition format, while maintaining the motivational benefits of a public display of student projects, accommodates a wider range of abilities and offers room for a greater variety of creative expression (Turbak and Berg 2002).

1.7 The role of teachers and the TERECoP project

Athough the role of teachers in the effective introduction and use of robotics in the educational process is particularly important, only few projects have tackled the problem of teacher training in designing and implementing robotics in classroom settings. For example, Bers et al. (2002) present a methodology for teaching pre-service teachers to integrate technology in classroom following a constructionist approach. They describe experiences in which pre-service teachers design robotic projects to engage their students in exploring and learning new concepts and ways of thinking. The Student Teacher Outreach Mentorship Program (STOMP) at Tufts University (Portsmore et al. 2003) brought engineering students to educational settings as a support mechanism for teachers who were not familiar with robotics and engineering concepts, helping students with hands-on projects, resolving technical issues with equipment etc. Chambers and Carbonaro (2003) report a case study of a pilot teacher education course in robotic technology intended to design and develop a course that provides teachers with a solid understanding of robot design, construction, and programming, as well as of teaching using constructionist pedagogical strategies.

The **TERECoP** project (*Teacher Education on Robotics-Enhanced Constructivist Pedagogical Methods*, www.terecop.eu), involving 8 educational institutions from 6 European countries, is being activated in the field of teacher training in educational robotics. In the framework of the TERECoP project, a constructivist methodology meant to enable teachers to introduce robotics into their classrooms as learning tool in a constructivist context, was designed, implemented and evaluated in pilot training courses held in each of the 6 participating European countries (Alimisis et al, 2007; Alimisis, 2008; Papanikolaou et al, 2008; Arlegui et al, 2008b; Fava et al 2009).

Based on the premise that the use of robotics as learning tool requires from teachers a conceptual change from the idea of learning from technology, predominant in traditional computer-assisted instructional models, towards learning *with* technology in project-based learning environments (Carbonaro et al. 2004) and believing in the educator's axiom *"teachers teach as they are taught, not as they are told to teach"*, we designed a training methodology for future and in-service teachers aimed at engaging them in robotic activities that they could implement in a creative way with their own students. Pursuing the constructivist professional development of teachers, our course curriculum is inspired by the same constructivist spirit that we would like our trainees to foster in their school classes. Keeping line with the proposed use of robotics as a tool of constructivist learning, our course curriculum is meant to train teachers in the very way in which they are expected to educate their school students.

The idea of "learning by design" is central in our pedagogy supported by a project-based learning approach. The learning tasks of the course are organized as small or large scale robotics projects encouraging trainees to design and develop their own products. As Rusk et al (2008) point out, the way robotics is currently introduced in educational settings is unnecessarily narrow and they suggest that designing activities, focused on *themes* and not just on *challenges,* helps to engage wide and diverse audiences in robotics. In accordance with this idea, the projects proposed in our methodology focus on themes broad enough to give everyone freedom to work on a project according to their interests and are developed around open-ended problems engaging participants not only in "problem solving" but also in "problem finding" (Rusk et al, 2008).

The knowledge and the experiences gained, as well as the lessons learnt during the joint action of the TERECoP partnership lasted three years (2006-2009), are presented in the next chapters of this book, including valuable feedback from the teachers actively involved as trainees in our training courses. The authors' aspiration is to contribute to the progress of the relevant dialogue among the research community in the field and, more importantly, to convince teachers and teachers' trainers about the pedagogical potential of robotics and to provide them with training and learning methodologies, tools, examples, ideas and resources that they will, hopefully, find useful, when introducing robotics in a constructivist way in their school classes.

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