Black-and-white-box perspectives to distributed control and constructionism in learning with robotics

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Abstract. The paper discusses compromises to transparency in the design of robotics kits for learning so that users can engage in meaningful, interesting and challenging constructivist activity through the control of robots and/or their environment. Aspects of control are analyzed with respect to their potential to generate constructivist learning processes and to address learning domains such as science and mathematics. The paper focuses on a set of robotics exhibits specially designed for a serious game exhibition centre called 'Polymechanon' in Athens.

Keywords. Constructionism, control, distributed control, generation of meanings

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 (for a discussion see 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

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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 for addressing the questions has been that of a special kind of constructivism termed ‘constructionism’ by Papert and his group at the Media Lab (Kafai & Resnick et al., 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 & 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 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 & 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 form 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, 2006b). This white-box metaphor for construction and

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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 were 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 in amongst others. This is seen as part of a complex learning environment also embedding the construction of robots and programs to control them as usual but different in that there is also emphasis on interesting learning activity with robot control.

In this paper, I consider robot control as an integral part of constructionism and describe and discuss a series of interactive exhibits designed for learners to control in interesting game situations and made available at a special informal serious games centre in Athens which we call 'Polymechanon'. I 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.

Control and constructionism

Robotics are 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 it is they are controlling 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 to do something interesting. For instance, the ways in which robots respond to changes in the environment and to which changes they do 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 what can be constructed by typical construction kits has also been overlooked. The means by which we can

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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.

In Polymechanon we thus designed a series of interactive exhibits where visitors would 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 –

- which robot behaviors can the human control,
- what kind of control do they have on these behaviors,
- how do these behaviors affect the game at hand,
- which behaviors are not controllable.

With respect to the robot's environment

- can the human control aspects of the environment and if yes which aspects can they control and which are out of control.
- How do the robots respond to aspects of the environment.
- Do the robots have consistent or changing roles in the game at hand.

A case for control: the 'Polymechanon' site.

At the Educational Technology Lab (http://etl.ppp.uoa.gr), after more than 15 years of design research involving the infusion of pedagogical innovations in schools based on the use of digital technologies, we felt it was time to think outside the box and consider informal education contexts where we would be at liberty to think of innovations without the constraints of the schooling system. Our main interest has been in the design of learning environments based on the use of microworlds (Sarama & Clements, 2002) embodying concepts and representations with which students generate meanings through constructions, experimentations and argumentation amongst themselves and with their teacher (Kynigos, 2007, Kynigos&Latsi, 2006).

Our aim in venturing towards informal educational settings is to consider ways of using technologies that are becoming available and affordable such as robotics, in order to design learning environments within the above framework but not constrained by the schooling context. With respect to learning process we are interested in exploring fusion between action (movement), representation, construction, experimentation and argumentation. With respect to content we are interested in the fields of mathematics, science-kinematics/mechanics/forces and spatial awareness-orientation. In order to create successful informal settings these environments need to be ecologically and culturally tuned to activities of 8-15 year olds. Our design therefore is based on serious gaming and on relatively quick immersion with games and less support from more experienced others than in the school setting.

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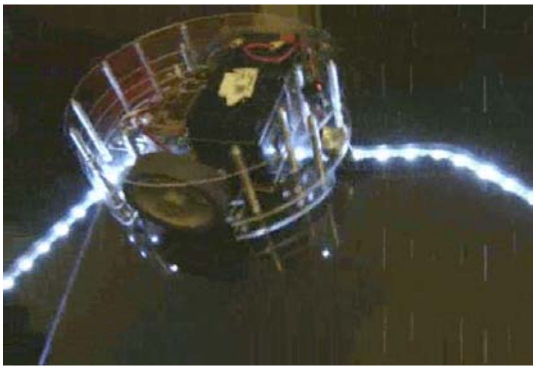
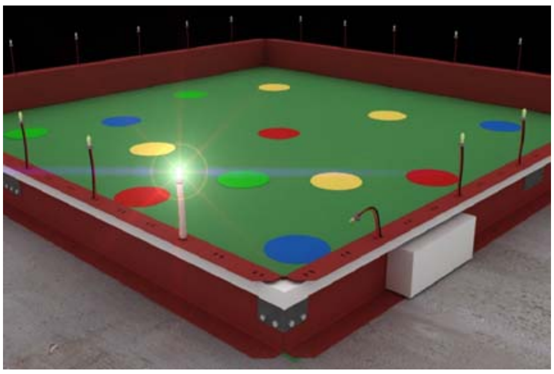


A series of robotics games have been developed and are available at 'Polymechanon', which is a place where visitors can engage in social games which require the use of computational interfaces to control machines and software. In the process of setting the site up, we have collaborated with interaction designers and robotics specialists. A description of the exhibits-games we are developing as a first phase to setup the Polymechanon site follows. The exhibits are thus based on the principle of quick immersion and low support. However, our next aim is to organize courses and seminars where visitors will spend more dedicated time and will have much deeper access to the rules and relations behind the games, will be able to create their own and try them out.

The main idea for the robotics exhibits is based on communal control of semi-programmed robots. The point is for visitors to get engaged with an interactive game and to generate meanings and intuitions regarding programming and behaviors of robots. Each exhibit consists of a number of robots (8-10) roaming in an arena with a 4x5 meter area. The robots have been programmed to a certain degree, meaning that they have a pre-programmed behavior (reaction to stimuli, roaming under specific constraints). In the 'grazing' game players control the ways in which the robots respond to systematically changing external stimuli. In the 'traffic jam' game, players control the stimuli, i.e. the lines on which the robots roam. In 'the chase' players control the line paths where robots roam, but also have to handle changing roles amongst the robots themselves. Below is a short description of the three robotics exhibits.

Grazing

Eight robots roam in an arena with a 5X5 meter area. A number of lights are placed around the arena. The lights systematically come on and off for a few seconds in a way which is out of control of the players. There are four teams of three players. Each team can control two specific robots out of the eight. They don't know which ones they are and need to find that out by changing controls and noticing how the robots behave. Each team can



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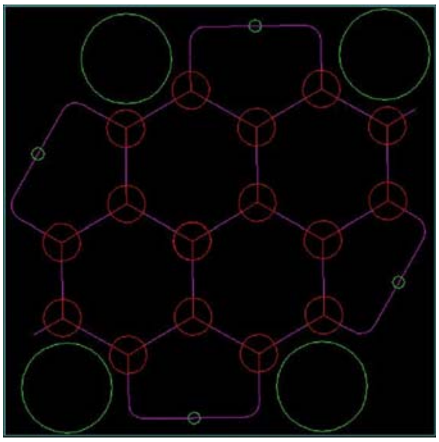
change the type of reaction to light (aversion, attraction) of each of the two robots they control. They can also change the intensity of reaction thus changing the speed with which the robot goes towards or away from the light respectively. By changing these parameters the players try to get their robots to roam over colored areas on the floor and collect points. They need to negotiate and make judgments on how they want each robot to respond to an upcoming change in the lighting and predict such changes. They need to make decisions on which colored areas to go over since each one collects a different number of points and they need to collect a specific number in order to win.

Traffic jam



The players in this game take on the role of traffic controllers, a bit like the well known movie 'The Italian Job'. They have no control on the robots, only on their environment. Five robots roam along a grid of lines in an arena 5x5 meters. Four teams of three payers each play the game. Each team tries to lead all the robots under a designated arch. The players control the line which is to be active as a robot approaches a node. The robot follows the active line. The robots will not collide but keep a small distance between them when close. The players control which lines are active by means of a touch screen, one for each team of three players. They can only control three lines at a time. Out of the three players in a team, one controls the node selection and the other two which line to activate. Each team can make life difficult for others by selecting a node and making the robots go away from the others' arcs. They collaboratively develop strategies for estimation, combinatorics and the mapping of the representations on their screens with the physical robots.

The chase

This is a game resembling the digital game 'pac-man'. Eight robots are placed in an arena which has a grid in the form of colored hexagonal figurations so that there are three colors in each node. Grid lines of different colors end up in each node. The players need to guide the robots by defining the color of the line they want the robot to follow after the next node. This is

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done by means of a specially designed UI on a touch screen. Several robots are in the arena and each one can be driven independently from one of four touch screens. Each player controls one robot. They can define the speed, the direction and the color of the line as described. The robots are predators or pray. The predators have a red light and the prey a green one. They are evenly split at the beginning. The predators want to get close to a robot – pray and touch it. When this happens the robots exchange roles. The one to get points is the pray (and the predator at the moment of contact). The points are scored at constant rate as long as a robot is pray. When the pray robot moves slowly more points are scored in relation to when it moves quickly. When two robots of the same role touch, nothing happens, they continue after a few seconds. The players can see their name and score on a big screen, the game lasts for a set period of time.

Discussion

This set of exhibits was designed so that players would immerse themselves with games which would require them to progressively understand and discriminate what they are controlling. The semantics of the controlling interfaces were designed for them to make links between the mechanical objects and the controlling symbols. Players could control robot response and its intensity, paths for robots to roam over, robot roles. The setting was designed with a black-and-white-box perspective in that players could change parameters and direction of pre-programmed behaviors as well as aspects of the robots' environment. They could thus think about the kinds of sensors and the kinds of programs built in the system. This whole activity is seen as situated in a broader activity of the visitors to the 'Polymechanon' site where white box kits like Pico-crickets and Lego Mindstorms kits would co-exist.

This design for learning environments raises many challenging questions for further research. How can we develop principles and methods for black-and-white-box oriented design of environments for learning with robotics? What kind of interfaces can enable students to begin from interesting games and subsequently de-construct them, inserting their own rules and robot behaviors? We need to re-think the issue of controlling technologies not only as an object to learn but also as a learning process. This poses pedagogical challenges such as the need to understand possible links with other learning domains such as mathematics and science. It also poses technical challenges, such as the need to find ways of making robots cheap, robust

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and in kit form. What new ideas are there for meaningful and practical kits, i.e. robots with a core component and different 'hats', pluggable sensors and motors, generic robot parts. Now that technology is allowing us to have access to more complex and robust robots it is an opportunity to re-consider constructionist learning processes within domains which may make robotics more attractive to communities thinking of a school which may become more relevant with today's society and with learning itself.

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