Representations to go: learning robotics, learning by robotics

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Abstract. We present the first steps of a pioneering didactic approach addressed to primary and secondary school: usually detached in the Educational Robotics literature, the learning *of* robotics and *through* robotics are here rejoined. This approach is rooted in constructivism and invites children to become authors of their own learning tools rather than merely users. Visual representations of didactic content and mobile robots are the items to be constructed by the supervised children. A methodological analogy is set between the construction and manipulation of these two items: they are both subjects of a problem solving procedure whose results are supposed to affect each other. A scenario is proposed to assess our approach and to set the basis of an educational program and tool-artifact. Future works will focus on the validity of this approach and to ultimately verify the impact of technology on children skills improvements with relation to engagement, visually content organization, and aware interaction with technology.

Keywords: educational robotics, learning, constructivism, visual representation, problem-solving, mobile robots

1. From user-centered to authorial-raising approach: the student at the heart of a conscious process of learning

In nowadays society young people grow up as users; technology proliferation at affordable prices makes them talented in detecting slight differences among subsequent versions of the same device and invite them to shape their identity in this or that user-centered brand philosophy. Tool users cohabit with an impressive variety of tools, without really knowing what they are and where they come from. Though perfectly being able to use them. Everything is displayed, but indeed we know, of the entire process, only the final smart result. To what extent this social environment affects learning at school? As Brown & Burton remark, students are great procedure followers (Brown & Burton, 1978). A common problem in verifying students'

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achievements in a certain discipline is the separation between mastering skills and understanding: a student do can execute a procedure without really understanding what he/she is doing. Since the social environments and its pervasive use of technology seem to encourage skills mastering rather than understanding, such a common problem risks growing in dimension and affecting learning (e.g. O'Hara & Payne, 1998; Nimwegen et al., 2008). Many improvements can be acknowledged thanks to the implementation of techniques that enhance an active learning mood in classrooms (Steffe & Gail, 1995). The idea that knowledge is constructed rather than discovered is not a recent one: constructivism and constructionism played a remarkable role in pedagogy since their first statement (e.g. Doyle, 2008; Brooks & Brooks, 1993; Papert 1980; Piaget, 1967) and pointed out that students' learning significantly improves when they are actively involved in building something that is meaningful to themselves. Nevertheless the decreasing interest towards taught contents and the gap between the environment of the school and the social environment outside the school (Parisi, 2001) call for a pragmatic change in didactics which allows to set the student at the centre of a conscious process of learning and find the lost complementarities of the two environments. With this aim, we propose a novel didactic approach conceived to live technology not only as users but rather as "intentional learners" (Bereiter & Scardamalia, 1989) and as co-authors of own learning tools.

2. Learning *of* robotics and *through* robotics: a first proposal

Current experimental studies concerning the use of educational robots in a didactic frame in primary and secondary school show three prevailing research models: (i) robot as assistant or companion, (ii) robot as subject of learning, (iii) learning through robotics as a difference to traditional school protocols (Tejada, Traft, Hutson, et al., 2006; Johnson, 2003). We prompt a new approach to guide young students to the learning *of* robotics and *through* robotics in order to acquire new knowledge by the unfolding of an unconventional nine-phase framed procedure and enhance new problem-solving capabilities. In our didactic model, the two activities (learning of robotics and through robotics) are presented as mutually dependent, in order to raise children's interest towards technology and towards didactic content at the same time. Robot building is thus a mean and an end in itself: too much acquainted to behave as users of final product, children will discover that they can rather be designer, fully authorized to construct and deconstruct on the basis of their curiosity, as well as to explore lessons. Hence, traditional learning programs are animated: lessons become visual representation to navigate, and homework turns into creative solution. Finally technology, which represents the gap between the school and the external environment, is reintegrated within the school in an innovative manner. The proposed approach is merged, rather than juxtaposed, with the current institutional school program. Once acquired, this approach can be customized and reutilized by the teachers with relation to the specific needs of the class. In the following sections we will first briefly introduce the existing projects in the domain of Educational Robotics and the advantages of the use of robots in the classroom for children engagement in didactic activities, then we will question the notions of spatial representation an problem-solving in relation to content learning, and finally we will discuss a first proposal to combine and articulate these two aspects in a didactic scenario aimed at enhancing an active and self motivated learning that should progressively lead children towards an aware use of robotic technology.

2.1. Robots in the classroom both as goal and mean of learning

Robotics is an engaging mean for teacher to put in practice didactic notion (Hsu et al., 2008; Alimisis, 2007; Krose, 2000). Different kinds of educational robotic scenarios in the current literature can be listed: techno-centric, creation and exploration of micro-worlds, public performances to promote insight and advances in cognitive sciences, or computer assisted experimentation and programming (Denis, 2001). Very often the implementation of these scenarios implies a well defined temporal course: phases of training are alternated to phases of challenge (Atmatzidou et al., 2008). For example, a five-phase model has been applied to describe projects development: engagement stage, exploration stage, investigation stage, creation stage, evaluation stage (Frangou et al., 2008). Nevertheless most of them are conceived to teach to children scientific disciplines through concrete experiences with robots, or, in alternative, to let them familiarize with the robot as a programmable artifact: settings are designed to enhance better understanding of the hardware-software relationship (Lund, 2000), as well as to help students transfer their programming knowledge from the robotic environment to more typical programming environments, or to learn scientific concepts (e.g., physic concepts) thanks to the feedback resulting by the manipulation of the robot (cf. Frangou, 2008) and to figure out the functioning of a complex dynamic system (Miglino, Lund, Cardaci, forthcoming). Beyond the current idea that the primary task in education is motivating the students, not merely with rewards, which seems to undermine intrinsic interest (Sklar, Johnson, Lund, 2000), a further and controversial idea is taking place: the idea that the transformation of work into play and play into work (for ex. Serious game) may elicit skill acquisition as well as an intrinsically motivated learning (Kiili, 2007; De Freitas et Jarvis, 2007). Moreover it helps overcoming the problems of a reiterated extrinsically motivated learning (Lepper & Henderlong, 2000). Hence, how to take advantages of this engaging mean to exploit its potential beyond the technical aspect? In our method, we propose then to merge the building and programming of a mobile robot, with the building and navigating of visuo-spatial structures, all packed in an educational scenario. For this purpose, and seeking to engage children in an active process of learning, we propose to use technologies that are specifically conceived for educational activity, such as The LEGO® Education robotics series - which provides brick components, software and progressive curriculum activity packs - and the Khepera III series - based on ten years of expertise in miniature robotics and capable of moving on many different surfaces. The educational scenario, as detailed in section 3, will focus on how to approach a robot both as a companion and a non-finite object, susceptible to be adjusted with relation to spatial features of navigated surfaces. In this frame, robotics is thus introduced at the same time as goal and mean of learning:

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children will be guided to the assembling and programming of mobile robots in order to navigate the lesson under the form of a visual representation.

2.2. Visual representation for content learning

The connection between spatial skills and content learning (in the form of problem solving) has long been established in the literature: children with strong ability in visualize content as a structure perform better in final tests (e.g. mathematical problems) if compared with children having a weaker ability in this sense (Blatto-Vallee, Kelly, Gaustad, 2007; Hegarty, Kozhevnikov, 1999). Visual representations are cognitive tools which allow for inferences as well for discoveries (Tversky, 2008). They generally include: (a) a represented world, (b) a representing world, (c) a set of rules that map elements of the two worlds, and (d) a process which manipulates the information in the representing world (Markman, 1999), with components (a)-(b) concerning the question *what* to encode in a representation and components (c)-(d) concerning the question *how* to encode (the latter is treated in next session (2.3). With regards to those four components, in our approach: (a) the represented world is the learning content of an everyday school lesson; (b) the representing world is either a network, a tree or a matrix accordingly to the type of lesson to be translated into a problem and on the type of needed information; (c) rules to map elements of the represented world to the representing world includes conventional legends – basic units types, link (among units) types, etc (see Novick & Hurley, 2001) – along with explanation of their pertinence – cells for matrix, nodes for trees, sets for networks (basic units) and bars as separators, line as connectors, arrows as indicators of asymmetric relationships, etc. (link types) (see Tversky, 2008); (d) navigation of represented world – i.e., creating path of reasoning from a basic unit to another by robot guidance on the correspondent links. In what regard this is different from traditional scenarios in primary and secondary school? What do these visual representations and their navigation add to already-implemented visuo-spatial methods based on generic diagrams, pencils and verbalization?

Our basic assumption is that if an optimal display of learning content through externalized representations - such as matrix, trees and networks - could facilitate students' understanding of learning content itself, still it does not necessarily favor its manipulation and memorization. Long-standing studies tell us that, generally, not only we are able to translate notions in spatial structures, but the "internal imaginistic reasoning" relies on resemblance, spatial proximity and spatial transformation (Kosslyn, 1994). More in detail different studies report children's spontaneous use of space in diagrams and other formats of representation (see for ex.: Tversky, Kugelmass, and Winter, 1991), so that this spontaneous use may be educated and conveyed into goal-directed use. We believe that such human general ability and children-like tendency could serve learning process through a non canonic use externalized representations. Hence, this approach seeks to heuristically define a protocol which could cover the three activities (understanding, manipulation, memorization of learning content) through the enhancement of a mechanism of analysis (which are the components and the relations to be represented?) and synthesis (how to both arrange the representation and to program the robot in order to

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reduce navigational and thus reasoning costs?). This situation can be seen as a problem-solving task, since the children do not have direct procedure to apply but s/he has to discovery it or to be trained in order to learn it (e.g., Newell & Simon, 1972; Richard, 2004). Let's do an example: subjects of study such as history often pose the issue of how to understand past events which are not susceptible to be direct observed nor reproduced in laboratories. Different methods can be exploited: chronologies, analysis of cause-effect relations, primary sources commentaries etc (Vidotto, 2005). In present school programs, children are often guided through sequential steps: being able to differ present from past, to place events, to recognize reasons and results, to pass from an everyday vocabulary to a specific one, to evaluate different interpretation of past events, and to critically approach the study of the latters.[1] Still the issue of how to promote an active process of learning with children consciously mastering and understanding stays. Establishment of civil communities in prehistoric period, for instance, is not only a matter of dates from Paleolithic to Neolithic, nor only a matter of climatic factors or tool development, but rather their integration. Such an integration is facilitated by the use of the more appropriate representations, with the supervised student selecting the most suitable modality according to the topic to be learned (Beecham, Reeve, and Wilson, 2009; Novick, Hurley, Francis 1999): if matrix could easily frame quantitative information (e.g. which and how many primitive settlements for periods and geographic areas), trees could do the same with hierarchical information (e.g. evolution from Homo Habilis to Homo Sapiens Sapiens) and network with logical information (e.g. relation between tool development, migration and evolution). Once the kind of needed information is defined on the basis of the task at hand and displayed through an externalized representation, it is time to structure the chosen representation in order to navigate it.

2.3. The navigation trough learning content in a problem solving fashion

At the core of our approach lies the idea that, in order to activate students learning, topics content should be formulated in a problem-solving fashion. The well packaged paragraphs, chapters, and indices may be translated in open situations with an initial state, a final state, a procedure to be elaborated to match the two states. In few words, they have to be translated into a problem representation. Of course the representation itself does not tell children how to solve the problem. Here we come to the *how*. During a problem solving process it is possible to distinguish between representations and solution procedures: to understand the underlying structure of the problem, solvers construct a problem representation, which can be either internal, external, or both; then this representation is used to manipulate the inner content towards a possible solution (Novick and Bassok, 2005). Thus, a relevant remark is that representations and solution procedures, though tightly related, are built separately, and they have distinct contribution to the success of the problem solving process (Novick & Bassock, ibidem). As proposed by Greeno (1978) three types of problems are distinguished:

- Transformation problems -: the initial state and the - goal state are clearly defined. The participant has to find the sequence of operations that will enable her/him to move from

[1] See for example: http://www.primaryresources.co.uk/

one state to another. A typical example is the Hanoi Tower problem: the initial state and the -goal state are clearly expressed in the instructions.

- Problems of structure induction: the participant has to find out the pattern of relations among several elements of the problem. In the “Master Mind” game for example, the player has to find what several lists of colors have in common, using feedback from the opponent.
- Arrangement problems: consist in arranging elements in order to obtain a configuration that satisfies certain criteria. The initial state of the problem is clearly defined, the criteria needing to be satisfied are known, but the target-state is unknown.

As an example, let's consider the difference between our chapter of a prehistoric history and a mathematical problem that would both, according to our approach, be translated into a problem solving procedure. In the first case, initial state and final state are likely to be known (e.g. first human establishments take place, and new forms of civilization are developed through migration, until urbanization is achieved). In the second case, the initial state is known (Simon wants to count the number of apples in a container by rows and columns instead of enumerating them) but the final state has not be defined yet. Moreover, while an active learning of history implies students ask themselves whether things could have gone in another way, or, what might have happened had the causal event not occurred – i.e., *counterfactual* reasoning (Rafetseder, Crsiti-Vargas, and Pernes, 2010) – a problem solving process in mathematic would rather elicit analytic skills trough *factual* reasoning. Therefore, different learning contents require different visually problem representations -and bespoke correspondent procedures - that, as mentioned above, can be selected by the children. Nevertheless, in order to guide children to an optimal choice and to reduce the degrees of freedom in the ongoing lesson, some representation will be considered more reliable than others. As Novick and Hurley remark, not all the representations allows for explorations: among the diverse properties listed by the authors (cfr Novick & Hurley 2001) the so-called “traversing” property is more typical in networks. Moreover, navigational rules such as: “do not pass twice along the same path” or “enclose loops” can be set as starting rules which constraint robot programming and which guide path of reasoning as well.

3. Sketch for a classroom scenario

A review of the existing projects in the domain of Educational Robotics (section 2.1) shows that presently there is no conceived or implemented scenario teaching both about robotics and through robotics at the same time, which is rather the kind of effective two-folded program we pursue, seeking the way to positioning robots between objects and educational tools (Ionita & Ionita, 2007). Five kinds of problems have been often underlined in the mentioned scenarios (i) duration of training session should be better calibrated in order to ensure effective teaching (Atmatzidou, Markelis, Demetriadis, 2008); (ii) steps taken throughout lessons are often perceived as too big; (iii); (iii) reporting skills were improved less than other skills, probably due to the lack of intermediate and conclusive steps such as keeping journals and writing lab reports (Sklar et al., 2003); (iv) children complain about the limited number of robots, moreover they propose to disassemble the robot to get parts for their own robot (Sklar et al., 2000); finally, (v) relations between robotic-based activities and other disciplines are not evident to both children and teacher (Lith, 2007). Nonetheless, we believe that the positive effects of the binomial "visual representation – robot manipulation" may open the way towards an overcoming of the last of the five cited problems, which is the possibility to bridge robotic-based activities to other learning activity through a common meaningful construction. In the following points, a sketch for the proposed classroom scenario:

1. *Assessment phase*: tests class skills-level (technology attitudes, visual representation mastering, curricular notions in involved disciplines) and identify needs (cf. regulation process, Leclercq, 1995)
2. *Familiarization phase*: introduces children to the world of Educational Robotics through questions (e.g. "*How a robot could be useful at school?*" or "*Which kind of activity you would share with a robot*?", etc.) and video on the wide range of robotic application, from automatization to entertainment and social utility. The idea of robot as a tool for lesson exploration is presented along with some graphic examples.
3. *Building phase*: children are guided to construct their own robot (Lego Education, Lego MindStorm and Khepera accordingly the age) by following step-by-step instructions. Building components are presented alone and in their mutual function.
4. *Bridge phase*: a daily lesson of a given discipline is transformed into a problem to be solved through the exploration of a visual representation. Proper visual representations are chosen with relation to given discipline and prior formation.
5. *Alphabetization phase*: basic programming notions (variables, parameters, input-output commands, blocks, sequential and conditional structures, etc.) are offered with the help of examples of simple motional behaviors of the robot through a minimal but ergonomically designed computer interface adapted to children.
6. *Explorative phase*: children are invited programming their robot in group to make it moving on the visual representation of the problem, in order to find a solution path.
7. *Working phase*: by the explorative phase, children assess the validity of their visual representation as well as of their code, supervised by the teacher. In case of ineffective representation and mistaken code, a restructuration is proposed.
8. *Goal phase*: a repetition of the explorative phase, once the errors have been pointed out and corrected. Children are invited to verbalize their strategy while they guide the robot along the solution path.
9. *Report phase*: a self-evaluative account of the experience is requested, in order to register procedures, classify strategies, compile a case-history of occurred errors, and note commentaries and proposals with the help of the teacher.

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By an accurate alternation of analytic and synthetic phase, this scenario, cyclically reproduced, aims at developing children diagnostic as well as creative abilities in collaborative tasks. A *methodological analogy* is set between: on the one hand, the construction of a visual representation and its manipulation for the structural organization of learning content; on the other hand the construction of a mobile robot and its manipulation for navigating the elaborated visual representation. The methodological value of this analogy is that, without being explicited, it triggers in the child a procedural mechanism of authentic involvement and conscious monitoring of his activities. The didactic strength of this analogy is that, beyond the broadly spread "learning by doing" and "learning by playing", it allows for flexible application to specific learning content with the aim of rejoin the detached abilities of mastering and understanding. The experimental interest of this analogy is that, an osmotic co-effect is primed on children skills in visually content organization and learning retention on one side, and on interaction with technology on the other side. Finally the actual functioning of this analogy within the proposed scenario opens to insights for future educational settings.

4. Conclusions and first steps toward the successful integration of robotics innovation in school classes

So far we have discussed a didactic two-folded approach to be implemented in the form of supervised team work for primary and secondary school. Such an approach situates itself in a renewed constructivist line and follows the traces of previous proposal in the domain of technology and education. Problem solving and meta-cognition have longer been targeted as higher-order objectives in education (e,g, Bransford & Sherwood, 1986) reachable through innovative protocols and interaction with technology. We believe that not any sort of technology is likely to fulfill such objectives and that, moreover, a special regard should be paid to the fact that most of the technology proposed at school is already biased by its use outside the school, a fact that may weaken or alter the educational potential of these devices. These and several other reasons lead us to propose the introduction of robotics in curricular activities, and to present robots as customized tools of active learning. Such an approach, in future works, will be tested during a longitudinal study, to experimentally validate it. Scientific outcomes will be further discussed, and applicative outcomes are meant to support the design of a pioneering techno-pedagogical tool. The specific educational tool-artifact should allow children to program robots through guided activities, and to modify the resultant behavior. In this way, the appealing aspect of a computer-robot game will cohabit with the possibility to discover important and fuzzy aspects of the real environment (Miglino et al, forthcoming) and children will be introduced to the logic of problem-solving. Analysis and creativity skills are equally implied by this kind of logic, which additionally claim the child at the centre of an active responsible process that does not progress without his or her commitment and that integrate new knowledge in prior one (Chandana, Hafner, Bongard, 2000).

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