Project TERECoP

Work Package 1

A methodology for designing robotics-enhanced constructivist learning for secondary school students (basic principles, learning objectives and strategies)

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[including content from the paper *Javier Arlegui, Rosa Fontal, Alfredo Pina, Michele Moro, Constructivism, language, Logo & Lego*, http://eclass.gunet.gr/modules/group/document.php?userGroupId=1]

1. Theoretical Background: *basic principles*

1.1. Historical development: *from Edison to Robotics*

The first significant technological change that was reflected in education was the invention of typography. But it took several centuries before books were available for every student's individual education. Other attempts in using various teaching aids (generally technology) are connected with the industrial revolution. In education, of course, it is not the steam engine, with which the beginning of technological progress is generally associated. But, for example, the famous inventor Thomas Alva Edison had the idea of replacing the textbooks with motion pictures. Similar ideas appeared with the emergence of phonograph, radio broadcasting, tape players, TV as well as video. These attempts were rather unsuccessful. None of these aids replaced standard textbooks nor changed classical instruction methods. The mass form of one-way information transfer, such as in public broadcasting, prevents individual learning, because it does not reflect individual needs. The sequential presentations such as tapes and videos, etc. do not allow for working with the piece of information actually needed. Therefore these means can only play a role of supplementary specialized material.

Similar attempts were noticed in the 70's and 80's, when first personal computers reached the markets. There were suggestions that computers would soon replace not only textbooks, but also even teachers. These hopes turned out vain again. The computers of that time were trying to manage the instruction process in such a silly way that the interest of students was rapidly vanishing. Instead of the understanding the students were keener on gaining the best results, which was often possible without relevant knowledge.

Today we find ourselves in similar situation, but on a different level and with different consequences. Individual former technical teaching aids as video or tape recorder have been included into integral information and communication technology. Interconnected computers are able to play the role of all the above-mentioned technical aids including textbooks and go further. There is no need to wait for the exact time the desired information is broadcasted or to walk to the library or video store.

The range of possibilities in using the ICT is even much wider. They enable very sophisticated control of the work of the users of educational applications as well as uncontrollable interactions of all the connected people in the social environment of the Internet. They are able also to realize specialized spaces dedicated to the personal knowledge development.

Robotics & Didactics. According to an interview to Paolo Bianchetti and Emanuele Micheli of 'Scuola di Robotica' e to the teacher Linda Giannini (see http://ted.sophia.it/cgi-bin/WebObjects/News.woa/wa/showSnip?uid=sdpPYT5HxmrAqAoF&nli=15520&__snip=46449), Robotics means the concreteness of a technological-scientific area where to study 'why' is an activity strictly integrated with studying 'how'. The specific profile of this new science promotes the creative attitudes of the students and their communication and cooperation abilities. Studying and applying robotics lead students to manifest interested attitudes also towards traditional base disciplines (e.g. maths, physics, etc.). From the analysis of the recent school system history you can notice the contraposition between classroom and laboratory didactics, which not always means exclusion or not reconcilability. Under a pedagogical point of view the same contraposition can be represented by the dichotomy between instructionism, for which the reason of teaching are prevalent, and constructivism, for which the reason of the learning subject are prevalent. The laboratory mode supports a motivated participation of the student to his/her own learning process and creates an active relation with the reality and a collaborative behaviour towards teachers and fellows. These facts tend to promote a deep understanding.

A second motivated reason to consider robotics is the possibility to prepare the suitable conditions for an active, constructive, contextual, problematic, conversational, collaborative, intentional and reflexive learning. This laboratory didactics makes practicable constructivist principles like to put attention to all the conditions, to problematise contents, to utilize operability, to make use of meta-knowledge. Moreover, educational robotics does not mean only to force the students to build and use robots but also to give new opportunities to experiment new methods to reasoning and discovering and exploring the world.

Didactically a central aspect is that students are attracted by robotics thank to the conjugation between thinking and doing: a robot presents a mechanical part which is to be designed and carefully built, and a controlling program.

Seymour Papert was interviewed in March 1997 by the TV educational program 'Mediamente' (see http://www.mediamente.rai.it/home/bibliote/intervis/p/papert.htm). In this interview he wanted to fix some general principles on ICT at school. The most interesting are the following:

- We must create new contexts: for example, I think that children can learn to realize wonderful projects using the computer like building robots or doing computer art for multimedia performances.
- This is not exactly post-Logo: Logo has grown, the computers have become more powerful and, together with the fact that with the computer we can now do more operations interesting for children, Logo has been expanded. It is not a finite system; on the contrary it approaches a philosophy, a way of thinking, a way to delegate the control to the pupil. So the modern forms of Logo present an aspect quite different from the previous formulations. Unfortunately I think that in Italy only its oldest forms are known.
- The teacher should be a sympathetic, suggesting and, above all, learning person.
- If the student becomes an active element, we need some experts in learning: this is the most important ability of a teacher.

Therefore, it is not good to teach to youngest students what they will need during the rest of their life, apart from one thing: how learning something new when they need it. Thus, the simple answer to the question "what a teacher should be" is: the teacher must become the one who learns.

1.2. Instructionism vs Constructivism

According to the professor Seymour Papert's classification the instructive educational methods are those, where the learner is only executing given instructions or he/she follows a set pattern. Instructionism advances from the so-called behavioral concept of psychology, according to which the behavior of humans is mainly determined by mere reaction on perceptions during lifetime. We know that there are specific situations, where instructive methods are essential. But they shouldn't dominate.

You are probably familiar with the way of teaching, where the teacher presents set facts without relevant links and the students are forced to learn these facts by heart. I am afraid that this still happens quite regularly everywhere. It is mainly caused by the fact that the teachers have often to follow strictly a curriculum that prescribes too large amount of matter, which is consequently required at the entrance examinations at higher schools. This situation is, of course, unsatisfactory.

The instructive methods can be easily supported by the ICT. It is not difficult to convert the texts that should be learnt into electronic form make them accessible on the Internet, and then examine the students on what they learnt by computers. It is even easier when we insist on them learning something by heart. Such applications can help especially those teachers that use these instructive methods. The teachers only have to obtain or create the electronic explanatory materials, drill exercises and tests, and then he/she can just keep checking the results. In better case the teacher does some explanations and offers consultations.

The instructive elements can be also incorporated into rather different concept of teaching. Sometimes it is even inevitable, e.g. in teaching of specific matter, such as root definitions and skills (alphabet, irregular verbs, multiplication table, basic foreign language vocabulary, traffic rules, certain manual skills, etc.).

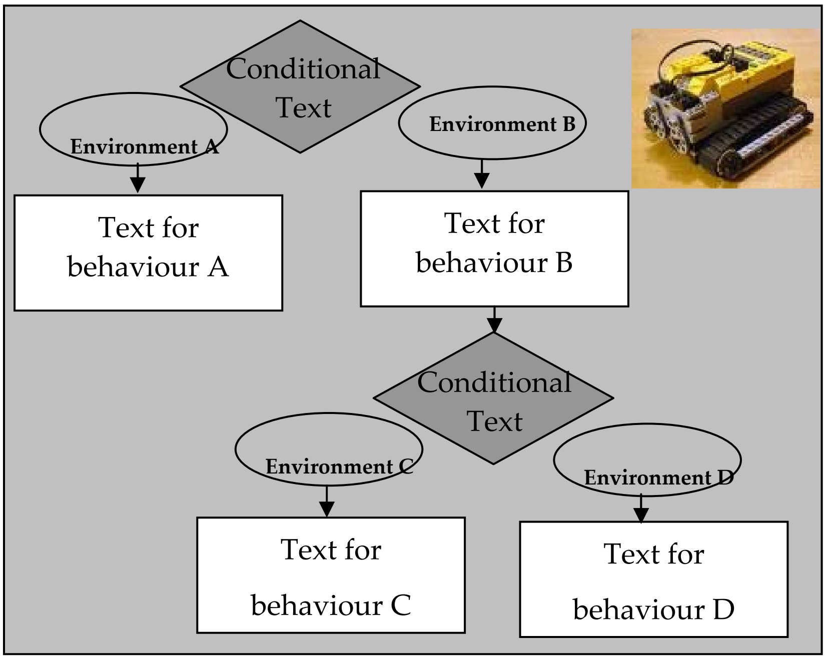
The instructive way of applying technology in education is the easiest. The student is firmly controlled by a computer during such instruction process. The desire to control all the sensual inputs of learners given by the behaviorist didactic theory results in the drive towards creating as short curricular steps as possible. Within these short steps this control can be easily exercised. Typical example of such a concept is the programmed learning, which formerly started without computers and later was used as the core principle of the teaching machines developed during the late 1960's. Every step is determined beforehand and no space for individual initiative is allowed here. The program shows what should be studied, then asks multiple-choice questions, and if this is correctly answered the program goes on to next subject matter. If the answer is incorrect, the program goes back to additional explanation.

We can mostly see on schools too many applications more or less inspired by this instructionistic paradigm until today. It is very easy to recognize them – the control of the activity is taken by the program (in reality by the author of the program), not by the students.

Constructivism is a theory about learning, one where the learner has a "a self-regulated process of resolving inner cognitive conflicts that often become apparent through concrete experience, collaborative discourse and reflection" (Brooks and Brooks 1993). Simply put, when someone doesn't understand something, it bothers them internally. This nagging is resolved when one has the chance to experiment by doing, share the experience with others, and have time to think about the confusion.

Instructive vs. Constructive pedagogical concept:

Instructivism	Constructivism
fixed curriculum and standards	topic oriented curriculum
knowledge based education	task based education
drill and practice	self guided work
divided subject	connected subject
divided lessons	connected lessons
students divided by age	students divided by abilities and interests
the same activities for all	individual work
testing and marking	words based evaluation
teacher as the highest authority	teacher as guide and helper
discipline is the highest quality	interest is the highest quality
teacher as a source of information	many sources of information
closed school	open school
external impacts minimized	risk of undesirable external impacts
programmed methods	project methods



The *constructivism* as an educational - learning process. The expertise in “commanding tasks to robots so that they have certain behaviours (with a goal in mind)” can be the object of constructivist education (on the teacher’s side) and learning (on the student’s side).

For this we have to select and adapt to our objective the most pertinent characteristics of the theories of Piaget and Vygotsky, known as cognitive reconstruction theories assuming a constructivist education-learning.

The adaptation process according to Piaget

The Piaget theory is a theory of the *dynamic construction* of knowledge. Piaget bases this construction on the process of “majorant” (increasing) adaptation, that formulates as the tendency to a balance (equilibrium) every time bigger between the processes of *assimilation* and *accommodation*.

Assimilation: We intend “the process by which the subject interprets the information that comes from media, on the basis of his/her schemes or available conceptual structures

Accommodation: We intend “the process of modification of schemes or conceptual structures by the subject, when trying to assimilate new characteristics of the media”

The assimilation suggests that “we see” all things not as they are, but as we (ourselves) are, according to our available schemes of understanding. Of the reality we incorporate only those (inclusive) elements that correspond to ours previous schemes[1].

If only the assimilation exists, great part of our knowledge would be fantastic and it leads to continuous mistakes.

The accommodation explains the tendency of our schemes of assimilation to adapt them to reality, and to transform themselves into “agreed” (or more *balanced*) schemes. If my schemes are insufficient to assimilate a determined situation, I will probably modify some of my schemes adapting it to interpret additional characteristics of the situation.

But the accommodation supposes not only a modification of the previous schemes based on the assimilated information, but also a new assimilation or reinterpretation of the data or the previous knowledge based on the new constructed schemes. It is what we call “reconstruction” and is the most important effect of the adaptation and the personal constructivist process.

Education - learning like a process of successive reequilibration. When a student has a first contact with a new “knowing work”[2] generally s/he is unbalanced in front of it. S/he applies her/his previous cognitive schemes to it (his/her context) and generally s/he assimilates only part of the aspects of the subject. A double work: a *direct empirical interaction* with the object and *a linguistic interaction* with a teacher (in reference to the object). This will facilitate the student to have a progressive adaptation both to the understanding of the actions of this object and to the understanding of the terms of the language with which we described these actions.

S/he will reach a one first reequilibration, but a new interaction with the object and/or a new problematic question of the teacher regarding the object will lead the student to a new situation of disequilibrium that s/he will have to overcome through the same procedure (of do-with and of speak-on the object) to reach a new state of equilibrium. And so on…

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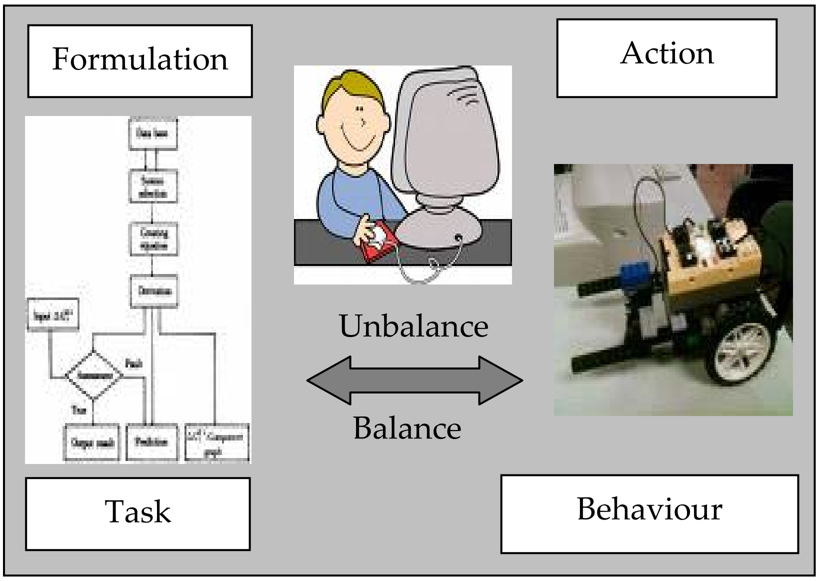
1 see the (constructivist) theory of AUSUBEL about the significant verbal learning

2 this term designates any element, more or less complex, of our environment whose structure and/or function must later be explained by the student

The main task of the teacher is to cause successive “controlled” unbalances (in order to not introduce too many new aspects in the same problematic question) and, to guide (lead) with “demos”[3] towards the reequilibrium of the student (showing “well realized” actions contingent with the object, and linguistic expressions referring to the object and “well formulated”).

The aim of the student is essentially to follow the process in an “active intellectually” manner, making an effort in identifying and incorporating the new inclusive elements in the previous schemes and trying to add meanings to the teacher’s demos[4].

Let us say, eventually, that in front of “knowing works, where the student must be able to talk about verbally to them or on them, the individual constructivism of the student does not fit; one is necessarily “a guided” constructivism of the student: interacting with the object and, concurrently, engaging in a dialog with the teacher.



Levels of complexity of the re-equilibration

Following J.I. Pozo[5], Piaget elaborated, throughout all his work, several models of the equilibrium process. In the last of them he says that the equilibrium between assimilation and accomodation takes place (and breaks) in three levels of increasing complexity:

1 At a first level: *equilibrium with the facts*: the individual schemes must reach the balance with the new objects that s/he assimilates

2 At a second level: *equilibrium with the schemes*: s/he must reach a balance between the old and new individual schemes, that must be assimilated and comply reciprocally.

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[3] We will see better this issue when we consider the Vygotsky theory

[4] to construct with it the elaboration of shared meanings

[5] POZO, J.I., Teorías cognitivas del aprendizaje, Ed. Morata, Madrid, 1989

3 In a third level: *equilibrium with the hierarchic structure of schemes*: s/he must reach a balance between the old and new hierarchies of schemes.

1.3. Constructionism

What is the difference between Piaget's constructivism and Papert's "constructionism"? As Ackerman (2001) suggests "Beyond the mere play on the words, I think the distinction holds, and that integrating both views can enrich our understanding of how people learn and grow. Piaget's constructivism offers a window into what children are interested in, and able to achieve, at different stages of their development.

The theory describes how children's ways of doing and thinking evolve over time, and under which circumstances children are more likely to let go of—or hold onto— their currently held views. Piaget suggests that children have very good reasons not to abandon their worldviews just because someone else may be it an expert, tells them they're wrong. Papert's constructionism, in contrast, focuses more on the art of learning, or 'learning to learn', and on the significance of making things in learning. Papert is interested in how learners engage in a conversation with their own or other people's artefacts, and how these conversations boost self-directed learning, and ultimately facilitate the construction of new knowledge. He stresses the importance of tools, media, and context in human development. Integrating both perspectives illuminates the processes by which individuals come to make sense of their experience, gradually optimising their interactions with the world."

Moreover, Papert also approaches the issue of relevance and emotional attachment with an observation that by adding new objects such as "cybernetic construction kits" for LEGO/Logo, children might "want to learn it because they would use it in building" (Harel and Papert ,1991).

What does it mean *constructionism* in (elementary) robotics? Following Papert's words, " … [constructionism] adds [to constructivism {learning as "building knowledge structures"}] the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe", we must define more and more clearly what this means in the robotic context.

A progressive knowledge means using the past experience in order to synthesize new experiences and a new knowledge. In case of Logo it is realized in two aspects. First, through the recursive procedural paradigm which permits, starting from the language primitives, to create substantially homogeneous building blocks (i.e. they can be used just like new primitives, one command and possible parameters). Second, through the drawing turtle paradigm, which operates on a 2D simple environment: complex figures can be built juxtaposing simpler, already programmed, parts.

When you consider the robotic context, you must distinguish the phase of the physical building of the robot from the phase of programming it (or, saying better, of instructing it). The Lego Robotic system leads to a bottom-up oriented developing of the first phase: starting from the basic brick, which defines the fundamental standard for all the other elements of the Lego kits, you can build more and more complex architectures combining simpler, already realized parts. The reusability of these components is not so obvious and it depends on the detailed process of construction of the robot. For example, a large bumper mechanically connected to one or two touch sensors is a more or less replicable part of a robot able to react to obstacles found during its movement, but very often changing robot requires minor modifications to an accessory like a bumper. These limitations in reusability are apparently made even worst in the NXT system whose kit contains much less traditional pieces in favour of more technical elements (this aspect is referred by the student who is presently working with the kit and it must be more deeply investigated). Actually, kids and adults using Lego Mindstorms experience an increasing ability to build robots: they start from proposals given in the documentation which comes with the kit, in other books and in specialized web sites on the Internet; later the can try to design new architectures by themselves applying general rules they applied during this progressive learning process. But this kind of layered knowledge seems not to be so clearly formalized (and so easily formalizable) as in the Logo environment.

Considering now the programming phase, things appear even more problematic. If we build a simple robotic version of the Logo turtle, we do not add any special improvement to the learning qualities of the Logo environment. But a robot is generally characterized by some important properties:

- Autonomy: the robot acts without being in continuous connection with a 'master' computer
- Proactivity: in its knowledge it is included the possibility to take more or less autonomous decisions in presence of not completely foreseen stimuli
- Knowledge of its environment: the robot could have a model, more or less precise, of the world in which it is moving and its behaviour could depend on this knowledge

The programming of a robot seems to be much more based on a 'per objectives' approach than representing the application of a layered sequence of applied abstractions like in a general purpose procedural or object oriented language. For example, following the semantic of the Lego Robotic Invention System, if you have a robot with a couple of motors controlling separately wheels or tracks, plus a proximity sensor and a light sensor, you can define separately: a general moving action (for example, starting both motors at the same power), a reaction to the reaching of an obstacle revealed by the proximity sensor, a reaction to the deviation from a drawn path revealed by the light sensor. The actions can be programmed with some simple sequences of very elementary commands and, though a 'my command' option is provided to allow the user to define his/her own macrocommands, this option seems to be very rarely compulsory or at least suggested by the complexity of the required programme.

Thus, the question is: what does it remain of the layered and structured knowledge of Logo when programming a Lego robot? What did Papert have in mind when inspiring the Lego advisory board during the designing phase of their robotic system?

We should remember that the RCX and NXT are actually the descendants of previous experiences: the Lego DACTA division, the Lego Logo and Cricket projects at MIT. There is also another descendant of these old experience, PicoCricket (http://www.picocricket.com/). Some other references:

http://llk.media.mit.edu/projects.php?id=1942

http://mres.www.media.mit.edu/people/mres/

http://uchcom.botik.ru/educ/history/1995/lego/lego.html

http://eurologo.web.elte.hu/lectures/hecht.htm

http://scholar.lib.vt.edu/ejournals/JTE/v9n2/jrvinen.html

http://www.ucls.uchicago.edu/students/projects/1994-95/Lego-Logo/newsletter.html

http://el.media.mit.edu/projects/ybl/

http://www.blakeschool.org/academics/lower/projects/lego/0506gears/page1a.html

By the way, some current projects in the Resnik's laboratory at MIT are of interest:

Learning About Motion (http://llk.media.mit.edu/projects.php?id=212)

Logo blocks (http://llk.media.mit.edu/projects.php?id=141)

Tangible Programming with LEGO Bricks

http://llk.media.mit.edu/projects.php? id=138)

Robotic Art Studio (http://llk.media.mit.edu/projects.php?id=611)

Learning Engineering by Designing Robots

http://llk.media.mit.edu/projects.php?id=345)

Flogo: Robotics Programming for Children

(http://llk.media.mit.edu/projects.php?id=535)

What is LOGO? Who needs it? Some reflections from: S. Papert, "Introduction: What is Logo? And Who Needs It?", in *Logo Philosophy and Implementation*, Montreal, Canada, LCSI, 1999. Available at http://www.microworlds.com/company/philosophy.pdf

- Why then does it need an introduction? . . . The point is the same as the first of two extensions to the principle of learning by doing: *we learn better by doing … but we learn better still if we combine our doing with talking and thinking about what we have done*.
- What makes (them) all Logo projects? An easy answer might seem to be that they all use a programming language called "Logo." They do, but this is not enough to qualify, for when you read the chapters you will see that what is important to the writers is not the programming language as such but a certain spirit of doing things: I (and again I guess all the authors) would see many projects that use Logo as thoroughly counter to the "Logo spirit."
- "Logo is a programming language plus a philosophy of education" and this latter is most often categorized as "constructivism" or "discovery learning."
- I want you to consider the idea that the right answer to "what is Logo" cannot be "An X plus a Y." It is something more holistic and the only kind of entity that has the right kind of integrity is a culture and the only way to get to know a culture is by delving into its multiple corners.
- This acceptance of "negatives" is very characteristic of the Logo spirit: what others might describe as "going wrong" Logoists treat as an opportunity to gain better understanding of what one is trying to do. Logoists reject School's preoccupation with getting right or wrong answers as nothing short of educational malpractice. Of course rejecting "right" vs. "wrong" does not mean that "anything goes."
- The frame of mind behind the Logo culture's attitude to "getting it to happen" is much more than an "educational" or "pedagogic" principle. It is better described as reflecting a "philosophy of life" than a "philosophy of education." But insofar as it can be seen as an aspect of education, it is about something far more specific than constructivism in the usual sense of the word.

- I have adapted the word constructionism to refer to everything that has to do with making things and especially to do with learning by *making*, an idea that includes but goes far beyond the idea of learning by *doing*.
- But the constructionist content area is a different matter. *This is not a decision about pedagogic theory but a decision about what citizens of the future need to know*.
- So this is the choice we must make for ourselves, for our children, for our countries and for our planet: acquire the skills needed to participate with understanding in the construction of what is new OR be resigned to a life of dependency.
- A crucial aspect of the Logo spirit is fostering situations which the teacher has never seen before and so has to join the students as an authentic co-learner. This is the common constructivist practice of setting up situations in which students are expected to make their own discoveries, but where what they “discover” is something that the teacher already knows and either pretends not to know or exercises self-restraint in not sharing with the students. Neither deception nor restraint is necessary when teacher and student are faced with a real problem that arises naturally in the course of a project. The problem challenges both. Both can give their all.
- The best way to become a good carpenter is by participating with a good carpenter in the act of carpentering. By analogy the way to become a good learner is by participating with a good learner in an act of learning. In other words, the student should encounter the teacher-as-learner and share the act of learning.
- Logo, both in the sense of its computer system and of its culture of activities, has been shaped by striving for richness in giving rise to new and unexpected situations that will challenge teachers as much as students.
- In short I like to recognize – only slightly simplifying a complex issue—two wings of digital technology: the technology as an informational medium and the technology as a constructional medium . . . Of course the two wings are equally important; but popular perception is dominated by the informational wing because that is what people see . . .
- However here too there is an imbalance: in large part because of the absence of suitable technologies, the constructional side of learning has lagged in schools, taking a poor second place to the dominant informational side.
- The primary way that digital technology will help is to provide more opportunity for wonderful teachers to work with wonderful students on projects where they will jointly exercise wonderfully powerful ideas.
- The true power of both sides – the constructional and the informational sides — of the digital technology comes out when the two are put together.
- Yes doing is a good way to learn. And it is made better by talking and thinking. But we learn best of all by the special kind of doing that consists of constructing something outside of ourselves. . .
- They [several types of activities including robotic constructions] are subject to the test of reality; if they don’t work they are a challenge to understand why and to overcome the obstacles. They can be shown, shared and discussed with other people. But what causes some of them to be specially valued in the Logo culture is their contact with powerful ideas that enables them to serve as transitional objects for the personal appropriation of the ideas.

- But here is a paradox of our educational system: we want children to learn at least some of Euclid but deny them the opportunity to develop the wings of the mind that led geometry to its power. Why would anyone do such a foolish thing? I think that the answer is really quite obvious: The culprit is the influence of technology.
- It was that old technology that pulled geometry down to earth, for it is essentially a technology for drawing static figures on flat surfaces.
- Much of my own current work consists of extending earlier ideas about using turtles to re-empower geometric ideas by breaking the static barrier.
- The Logo programming language is far from all there is to it and in principle we could imagine using a different language, but programming itself is a key element of this culture.
- So is the assumption that children can program at very young ages.
- And the assumption that children can program implies something much larger: in this culture we believe (correction: we know) that children of all ages and from all social backgrounds can do much more than they are believed capable of doing. Just give them the tools and the opportunity.
- Opportunity means more than just “access” to computers. It means an intellectual culture in which individual projects are encouraged and contact with powerful ideas is facilitated.
- Doing that means teachers have a harder job. But we believe that it is a far more interesting and creative job and we have confidence that most teachers will prefer “creative” to “easy.”
- But for teachers to do this job they need the opportunity to learn. This requires time and intellectual support.
- Just as we have confidence that children can do more than people expect from them we have equal confidence in teachers.
- We believe in a constructivist approach to learning.
- But more than that, we have an elaborated constructionist approach not only to learning but to life.
- We believe that there is such a thing as becoming a good learner and therefore that teachers should do a lot of learning in the presence of the children and in collaboration with them.
- We believe in making learning worth while for use now and not only for banking to use later.
- This requires a lot of hard work (we’ve been at it for thirty years) to develop a rich collection of projects in which the interests of the individual child can meet the powerful ideas needed to prepare for a life in the twenty-first century.
- It is based on the belief that the Logo philosophy was not invented at all, but is the expression of the liberation of learning from the artificial constraints of pre-digital knowledge technologies.

Some reflections from: G. Marcianò, S. Siega, , “Papert, Feuerstein, didattica innovativa e formazione dei docenti”, Proceedings of the e-learning Expo 2005, Ferrara, Italy, 2005.

http://robotica.irrepiemonte.it/robotica/biblografia/doc/Papert_Feuerstein_x.pdf

- The [Fauerstein] conviction starts from the assumption that any individual intellectually evolves all along his/her life without any environmental or genetic limitation.
- [The Fauerstein's method] is fundamental for developing the individual learning process, a challenge to fight the social marginalization; for learning to learn, for knowing how to adapt oneself to innovations; for making self-efficiency and self-regard to grow.
- The figure of a mediator plays the role of exciting and supporting individual paths towards a cognitive improvement.
- The mediator creates the conditions so that learners may gradually take direct responsibility of their learning and start to self-evaluate.
- When Fauerstein talks about intelligence he consider a subject that can be taught, guiding the learner to observe and to put questions, stimulating to compare objects and events and to look for links between facts, convincing to use a correct and appropriate vocabulary.
- In the Fauerstein's method there is a continuous exchange of information on different levels (logic, emotive, cultural, affective, etc.) between mediator and mediated. Teachers enrich professionally themselves both under the methodological-educational and relational point of view. This enrichment is not based on notionistic but logic strategies: anybody can have the answer to a problem provided he/she can give a logical demonstration.
- The Mediator acts so that every information becomes knowledge: it means that he/she offer to the learners the possibility to learn and to interpret, to organize and to structure all the information received from the environment and, consequently, this stimulates the possibility to become autonomous in learning and adapting themselves with flexibility to new situations.

The teacher role in Papert approach. The focusing comments by Papert and the real experience of synthesize constructionism and the Fauerstein's method may help to have a clearer idea of how constructionism may be applied to educational robotics. Some general principles may be derived from the sentences aforementioned.

- Educational Robotics is not taught to add new competences to traditional curricula, it is not taught at all. It acts as a problematic challenge both to teachers and students to face practical problems where other competences can be exploited to find effective solutions that are hereafter used as argument of discussions and as source of new problems.
- Guidelines on using educational robotics can refer to specific (programming) languages and robotic architectures (kits) but they should not strictly depend on them. The goal should be how to instil a 'Logo spirit' when constructing, programming and moving robots: experimentations with different languages and robots could result much more methodological validated. Moreover suggestions (and not compulsory recipes) on how conducting discussions and on possible improving the given solutions must be supplied together with basic materials like constructing instructions, programme skeletons etc. This does not mean the programming phase is not important.

- Even in robotics there is no "right/wrong" dilemma: the learning activity proceeds step by step refining the problem specs and improving the more or less acceptable found solutions. It will be very common that the teacher has to afford unpredictable or at least unknown situations during which he/she is co-learner with his/her students. These situations will spontaneously arise during the lab activities because of the nature of robotics itself. And they give new opportunity to teachers and students to try out their skills and eventually their 'believed' limits.
- If we want to emphasize the "constructional side" of digital technology in spite of its "informational side", educational robotics is a perfectly balanced synthesis of "material" (the robot) and "immaterial" (the programme) construction. In this sense, other activities like exchange of experiences and guidelines through the Internet can be allowed without the risk to be prevailing on the mainstream activity.

Self-awareness, self-efficiency, self-regard, self-rewarding, that seem to be so relevant in the Fauerstein's approach, are easily stimulated with experiences of educational robotics. The role of the mediator is important as a co-learner during the developing and problem-solving phases.

1.4. Project-based learning

Project-Based Learning is a comprehensive instructional approach to engage learners in sustained, cooperative investigation (Bransford & Stein, 1993). Project-Based Learning is a teaching and learning strategy that engages learners in complex activities. Projects focus on the creation of a product or performance, and generally call upon learners to choose and organize their activities, conduct research, and synthesize information. According to current research (Thomas, Mergendoller, & Michaelson, 1999; Brown & Campione, 1994), projects are complex tasks, based on challenging questions, that serve to organize and drive activities, which taken as a whole amount to a meaningful project. They give learners the opportunity to work relatively autonomously over extended periods of time and culminate in realistic products or presentations as a series of artifacts, personal communication, or consequential tasks that meaningfully address the driving question. PBL environments include authentic content, authentic assessment, teacher facilitation but not direction, explicit educational goals, collaborative learning, and reflection (Han and Bhattacharya, 2001) http://www.coe.uga.edu/epltt/LearningbyDesign.htm.

Project-based learning as a method of teaching and learning is mainly based on contemporary learning theories which argument that knowledge, thinking, doing and the contexts for learning are inextricably tied. We know now that learning is partly a social activity; taking place within the context of culture, community, and real life experiences (BIE, 2003). Knowledge construction has become a key term in describing a more active student role in developing and creating their own knowledge (see for example McCormick & Paechter, 1999). It is central in describing the process of learning within problem-based and project-based learning. It is based on pedagogical ideas from Dewey (1966) and certain constructivist perspectives (Steffe & Gale 1995).

Knowledge construction implies an active and reflective information-seeking process among the students where the teacher is not the primary or sole provider of information. Within these case studies it also implies a social process where the students have to relate to each other in order to complete their tasks. What is lacking in many studies, however, is how the use of information and communication technology influences the process of knowledge construction in different subject areas. One objective of the cases has been to provide better insight on how students work on knowledge management and construction in different activities and learning environments.

Project-based learning (PBL) is a model for classroom activity that shifts away from the classroom practices of short, isolated, teacher-centered lessons and instead emphasizes learning activities that are long-term, interdisciplinary, student-centered, and integrated with real world issues and practices.

PBL helps make learning relevant and useful to students by establishing connections to life outside the classroom, addressing real world concerns, and developing real world skills. PBL supports learners to develop a variety of skills including the ability to work well with others, make thoughtful decisions, take initiative, and solve complex problems.

In the classroom, PBL provides many unique opportunities for teachers to build relationships with students. Teachers may fill the varied roles of coach, facilitator, and co-learner. Finished products, plans, drafts, and prototypes all make excellent "conversation pieces" around which teachers and students can discuss the learning that is taking place.

Components of Project-Based Learning. Key components of Project-Based Learning that should be considered in describing, assessing, and planning for projects, are (Han and Bhattacharya, 2001):

1. Learner-centered environment
2. Collaboration
3. Curricular content
4. Authentic tasks
5. Multiple expression modes
6. Emphasis on time management
7. Innovative assessment

<u>Learner-centered environment</u>*:* PBL should be designed to maximize student decision-making and initiative throughout the course of the project involving learners in topic selection, and throughout the course of the project providing them control over the production, and presentation of artifacts. Additionally, projects should include adequate structure and feedback to help learners make thoughtful decisions and revisions. Learners should document their decisions, revisions, and initiative, with the am to enhance reflections on their learning process and capture valuable material for assessing their work and growth.

<u>Collaboration</u>: PBL aims to the development of communication and collaborative skills, enhancing group decision-making, interdependence, integration of peer and mentor feedback, providing thoughtful feedback to peers, and working with others as learners researchers.

<u>Authentic tasks</u>*:* PBL should connect to the real world stimulating learners to address real world issues that are relevant to their lives or communities.

<u>Multiple presentation modes:</u> It is important to support and prompt learners, in the course of the project, to effectively use various technologies as tools in the planning, development, or presentation of their projects.

<u>Time management</u>*:* Learners should have control of their learning through the course of the project, planning, revising and reflecting on their learning. Given the time frame and

scope of a project, all projects should provide adequate time and materials to support meaningful doing and learning.

Innovative assessment: Assessment should be an ongoing process of documenting learning through the course of the project. PBL requires varied and frequent assessment, including teacher assessment, peer assessment, self-assessment, and reflection. Assessment practices should involve learners through consistent documentation of the process and results of their work enhancing reflection and self-assessment throughout the project.

2. Designing Projects based on Robotics: learning objectives

Constructionism is reflected in PBL by (Han and Bhattacharya, 2001):

- creation of a student-centered learning environment
- emphasis on artifact creation as part of the learning outcome based on authentic and real life experiences with multiple perspectives

Thus, learners are allowed to become active builders of knowledge while confronting misconceptions and internalizing content and associated conceptions.

Especially, **Learning by Design** emerges from the constructionist theory that emphasizes the value of learning through creating, programming, or participating in other forms of designing. The design process creates a rich context for learning. Learning by Design values both the process of learning and its outcomes or products. The essence of Learning by Design is in the construction of meaning. Designers (learners) create objects or artifacts representing a learning outcome that is meaningful to them.

Specific guidelines for effective Learning-by-designing provided by Resnick (http://llk.media.mit.edu) are:

- Design projects that engage kids as active participants, giving them a greater sense of control and responsibility for the learning process.
- Design projects that encourage creative problem-solving.
- Design projects are often interdisciplinary, bringing together ideas from art, technology, math, and sciences.
- Design projects help kids learn to put themselves in the minds of others, since they need to consider how others will use the things they create.
- Design projects provide opportunities for reflection and collaboration.
- Design projects set up a positive-feedback loop of learning: when kids design things, they get new ideas, leading them to design new things, from which they get even more ideas, leading them to design yet more things, and so on.

Learning by Design strongly suggests that tasks should be based on hands-on experience in real-world contexts. The designers/participants should be given the option of multiple contexts so that they can devise multiple strategies when they use the problem-solving process. Because the learning process is open and varied according to the student learning preferences, skills, and knowledge, it is important that there be a balance among guided tasks, challenges, discussions and reflections that follow. Collaborative work allows the learners to obtain feedback from both peers and the instructor, who primarily plays the role of facilitator (Han and Bhattacharya, 2001).

In summary, the essence of Learning by Design lies in the experience of the learner as a designer and creator of an external, shareable artifact. Learners become more accountable for their learning through designing, sharing, piloting, evaluating, modifying their work, and reflecting on the process. The instructor acts as a facilitator and motivator by creating an open-ended learning environment and by challenging and scaffolding the learners in a balanced manner while providing options with rich and varied feedback. Through this experience, learners construct meaning and internalize the learning process (Han and Bhattacharya, 2001).

Some elements describing the current situation in some of the partners' countries. Robotics is not included in the official curriculum of Greek school education. Some occasional implications are mentioned in literature mainly for research reasons. There have also been a few examples of use of Robotic activities with Lego Mindstorms in private schools as extra curriculum activities (Ekpaidefthiria Douka http://www.doukas.gr/tp/tp112.htm, Phychiko College www.haef.gr). Some evening private schools (frontistiria) also use these technologies to teach computer skills to young students (e.g. Interactive Learning http://www.interactive.gr).

Nevertheless, educational Robotics seem to be very popular in higher education and especially in Engineering and Computer Science departments, as part of the curriculum or as a subject for extended coursework e.g. at the National Technical University of Athens, National Technical University of Patras, University of Macedonia, University of Crete. Moreover, several research projects in this field have been developed focusing on the use of educational Robotics in primary and secondary education. Frangou and Kynigos (2000) used Lego Robotics with secondary students (13-15 years old) in order to investigate educational aspects of these technologies. They found that through Robotics students can acquire hands on experience on variety of science concepts, develop problem solving skills and progress in constructing physical and computer models. The project "Technical school students design and develop robotic gear-based constructions for the transmission of motion" developed by the School of Pedagogical and Technological Education in Patras investigated how programmable robotic constructions can be effectively used in Technical and Vocational Schools (student age 16-20). In that project students were invited to design, develop and program a robotic construction using the Technological Inventions LEGO Mindstorms Package. The project provided very promising indications that students learn important mathematical and scientific concepts through their own design and programming activities (Alimisis et al., 2005, Karatrantou et al., 2005). Another project that investigated the potential of educational Robotics in teaching programming in secondary education stressed the importance of the interaction between the construction and the algorithm of the software in understanding basic programming structures (Kagkani et al, 2005). Finally, two more research projects focused on primary education. They stressed the cooperative character (Dimitriou & Xatzikraniotis 2003) and the experimental aspect (Karatrantou et al 2006) of robotic activities.

Though Robotics is not officially included in the **Italian** primary and secondary educational system, the interest on educational robotics is rapidly increasing. Apart from the contributions of isolated experiences and advanced laboratories in technical secondary schools and universities, some relevant recent projects, involving both school teachers and experts, are giving impulse to the subject. Among others: Uso didattico della Robotica (educational use of robotics) at IRRE Piemonte (http://robotica.irrepiemonte.it/robotica/index.htm); Costruiamo un Robot (let us build a robot) (http://www5.indire.it:8080/set/microrobotica/default.htm); La bottega dei robot (the robot shop), The National Science and Technology Museum of Milan (http://www.museoscienza.org/est/museo/robot_0.asp); Robot@Scuola, a school network involved in educational robotics (http://www.scuoladirobotica.it/retemiur/); EduRobot, The Institute for Educational Technology of Italian National Research Council (http://www.itd.cnr.it/Progetti_Rispo1.php?PROGETTO=93); AmicoRobot, a school network in Milan (http://www.amicorobot.net/). Most of these projects are related to the Lego Mindstorms robotic architecture.

The **Spanish** situation is similar to the previous ones, and the use of robotics in primary and secondary education is very limited and not official at all. In general there are a lot of activities in the field of Robotics in Spain mainly in research or industry (http://www.cea-ifac.es/wwwgrupos/robotica/index.html , http://www.robocity2030.org/) and there are also a few robot competitions organized (http://complubot.educa.madrid.org/, http://www.roboteca.org). In some of these competitions the participants are secondary level students. It is also a fact that the different educational institutions (national and regional) are aware of introducing and using computer science & techhnology at schools (http://www.xtec.es/ in Catalonia, http://www.educa.madrid.org in Madrid, http://www.pnte.cfnavarra.es/ in Navarra or http://www.cnice.mecd.es/ as the national reference in Educational Computer Science & technology). Nevertheless it is quite difficult to find deep and complete experiences in Robotics & Education. Some of the relevant experiences are the use of LOGO (the approach is similar to ours) at school (http://roble.cnice.mecd.es/~apantoja), some teachers' initiatives like the project RESS (secondary level experience with LEGO done in 2003: http://www.cnice.mec.es/pamc/pamc_2003/2003_proyecto_ress/) or personal ones like the web page and materials from the "freelancer" Koldo Olaskoaga (http://www.euskalnet.net/kolaskoaga/es/, http://robotikas.blogspot.com/). We found two experiences close to our project; one in Educational Robotics done in Primary school level by Alfredo Rodrigálvarez Rebollo (Director of the public college "San Francisco de Cifuentes", Guadalajara, Spain http://www.educa.jccm.es/educa-jccm/cm/revistaIdea) with an important effort in integrating these activities within the curricula; the other one carried out by the University of Alicante group called TEDDI, which works (among other research areas) in finding didactic applications of robotics at different levels in school (http://www.teddi.ua.es/).

3. Strategies for designing Robotics-enhanced constructivist learning environments

The methodology for designing computer-based robotics-enhanced constructivist learning applied both in the teacher courses and in students' teaching and learning, integrates the main principles of constructivism, constructionism and problem-based learning.

The main aim is propose a framework for designing robotics-enhanced learning activities that promote:

- meaningful learning (based on students' own team work with teaching materials).
- authentic learning (using learning resources of real-life, occupational situations, or simulations of the every day phenomena).
- social learning (technology supports the process of joint knowledge development. The available e-learning environments can support collaboration between fellow students, who can be at different schools, at home or abroad).

- active-reflective learning (students work on experiments or problem-solving, using available resources selectively according to their own interests, search and learning strategies).
- problem-based learning (a method that challenges students to "learn to learn"; student groups are seeking solutions to real world problems, which are based on a technology-based framework used to engage students' curiosity and initiate motivation, leading so to critical and analytical thinking).

Designing a robot to do even a simple task can place extensive demands on students' creativity and problem-solving ability (Druin & Hendler, 2000). Building and programming autonomous robots is an ideal context in which to situate a project-based learning experience where learners work collaboratively to understand the problem, propose viable solutions and construct their artefacts. It is quite important a guiding question or problem to set the stage and the project context to allow for a multitude of design paths. Then, students should collaborate over an extended period of time during a problem solving activity. The result of this collaboration is the construction of an artifact that will be presented to a wider classroom audience. The production of an artifact, that is readily sharable with a larger community of learners, encourages students to make their ideas explicit, whilst allows them to experience science concepts in a meaningful, personalized context (Penner, 2001).

Project-Based Learning encourages learners to engage in complex and ill-defined contexts. From the beginning, learners identify their topics and problems, then seek possible solutions. By participating in both independent work and collaboration, learners improve their problem solving skills thereby developing their critical thinking skills. However, one of the problems that learners face in such learning environments is what strategies to employ, how to start and proceed with the problem they have to face. To this end, different approaches have been suggested (Han & Bhattacharya, 2001; Houghton Mifflin, 2007).

Generally, three phases are suggested in conducting Project-Based Learning: planning, creating and implementing, and the processing (Han & Bhattacharya, 2001):

- in the *"planning" phase*, the learner chooses the project, locates the required resources, and organizes the collaborative work. Through these activities, the learner identifies and represents a topic, gathers relevant information and generates a potential solution.
- the *"creating" phase* is, or implementing the project. This phase includes activities such as development and documentation, coordination and blend of member contributions, and presentation to class members. In this stage learners are expected to build a product that can be shared with others.
- the activities for the *"processing"* the project *phase*, include reflection and follow-up on the projects. In this stage, the learners share their artifacts, obtain feedback, and reflect on the learning process and the project.

Moreover, specific features that need to be considered in organising the above phases are the following:

1. A "driving question or problem" that is anchored in a real-world problem and ideally uses multiple content areas, should serve to organize and drive activities
2. Opportunities for students to make active investigations that enable them to learn concepts, apply information, and represent their knowledge in a variety of ways

3. Collaboration among students, teachers, and others in the community so that knowledge can be shared and distributed between the members of the "learning community"
4. The use of technology as cognitive tools in learning environments that support students in the representation of their ideas: cognitive tools such as robotic kits, computer-based environment guiding the robots, graphing and presentation applications, web-based resources.

Especially for organizing learners' activity in robotics-enhanced projects we propose a framework consisting of the following stages (see Table 1):

- **Engagement stage**: students are provided with an open-ended problem and get involved in defining the project. This stage requires the identification and representation of a scientific problem. Students work as a class putting their ideas into a question format. As they are doing so, they are identifying and representing a problem and different issues involved (*e.g. brainstorming at class level*).
- **Exploration stage**: students get familiar with LegoLogo, controlling devices and software, make hypothesis and test their validity in real conditions, provide initial ideas. Students are divided in groups in order to answer to simple questions and study specific cases in order to get familiar with the controlling devices and software (*e.g. work in groups with worksheets – structured activity*).
- **Investigation stage**: students search for resources and investigate alternative solutions. Students reconsider the problem and the different issues raised during the engagement stage based on their experience gained through the exploration stage. At this stage students in collaboration with the teacher formulate the driving questions/problems which link with the learning goals of the project. The student groups undertake to solve the particular problems, investigate alternative solutions and argument on their final proposals concerning the artifact and the software the developed (*e.g. work in groups with worksheets, keep diary – open activity)*.
- **Creation stage**: students share and combine their artefacts, synthesize 'solutions' to the project, reflect on their initial ideas. Students present their work in class and then each group work on the synthesis of a final 'product' including the artifact and the software (*e.g. work in groups with worksheets, keep diary – result in a product)*. This work may lead to similar solutions but also to innovative proposals.
- **Evaluation stage**: students share their ideas, products at class level, argument on their final proposals and evaluate them. Alternative solutions are presented at class level and evaluated based on the driving questions/criteria posed in previous stages of the project (stages of engagement, investigation). At this stage students should critically judge their work, express their opinions, compare their works, and reach a common proposal to the project (*e.g. make presentations, discuss, peer evaluation)*. Students should also reflect on and evaluate their collaboration.

The above stages are not serial but in many cases highly iterative, e.g. the creation stage may include investigation or the investigation stage may include creation. The main aim of the different stages and the supportive material provided in each one (such as worksheets, resources) is to engage learners in meaningful design experiences. To this end, we should design for designers – that is, to design things that will enable learners to design things (Resnick & Silverman, 2005). Thus, what is important in designing a project and the appropriate worksheets at each stage of the framework is to promote students to imagine, realize, critique, reflect, iterate (Maeda, 2000), and according to

Resnick & Silverman (2005), to encourage students to design and redesign their artifacts, to mess with the materials, to try out multiple alternatives, to shift directions in the middle of the process, to take things apart and create new versions.

Stage	Description	Resources	Result	Proposed Tasks
Engagement stage	Students may be provided with an open-ended problem and get involved in defining the project and main issues involved	An open-ended problem Raw material: sites, newspapers, videos, magazines, stories, cases	Project description Open issues	Study of raw material such as newspapers, magazines, videos, stories, cases Discuss Express opinions/ideas Pose questions Negotiate Brainstorming
Exploration stage	Students get familiar with controlling devices and software, make hypothesis and test their validity in real conditions	Representative examples, general guidelines, educational material, software	Artifacts with specific functionality Diary	Study samples of representative constructions/programs Observe Gather information Experimenting Searching Collaborate / Negotiate / Argumentation
Investigation stage	Students formulate the driving questions / problems, investigate alternative solutions	General guidelines that organize students' investigation / diary. Educational material	Driving questions / problems Artifacts addressing the driving questions Diary	Reflect on previously defined open issues Make hypothesis that they can test Planning Collect evidence

				Interpret Evaluate Keep diary Collaborate / Negotiate / Argumentation
Creation stage	Students share and combine their artifacts, synthesize ‘solutions’ to the initial problem	Guidelines that organize students’ diary	Group products / solutions to the initial problem Diary	Evaluate previous work Share ideas Synthesize a product Keep diary Collaborate / Negotiate / Argumentation
Evaluation stage	Students share ideas & products at class level, evaluate final group proposals, synthesize the final product	Guidelines for peer evaluation and synthesis of a final product	Common accepted product	Present their products Discussion Peer evaluation

Table 1. Stages of students’ activity including the stage title, the tasks that students are expected to perform, resources provided to students, results, examples of students work and educational techniques adopted.

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