Discussing about IBSE, Constructivism and Robotics in (and out of the) Schools

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Abstract

When we look for “Inquiry Based Science Education” (IBSE) in a search engine we find more than 2.000.000 items. The IBSE we refer to is, at the same time, a Problem Based Learning (PBL) approach enriched with experimental activities (using technological tools) and a constructivist learning method. It is consistent with our overall conception of the science and technology school activity, an activity of problem solving by building and using models through hands-on-experiences that introduce and motivate concepts present in school curricula and that are performed by pupils using technology. Here we concentrate on programmable mini robot and describe activities for a constructivist IBSE introduction to concepts from standard school curricula by programming mini robots. We propose in this paper an innovative vision to use IBSE, PBL, and constructivist strategies to design up-to-date and effective (regular) educational paths involving technological artifacts (like mini-robots) and linking the schools with cultural and scientific institutions (out of the schools) to promote the establishing and the application of new knowledge.

Figure 1. At the Educational centers: Trainers, Trainees and Pupils

Keywords

IBSE, PBL, Programming mini Robots, Constructivism/Constructionism, ICT, Science & Society

Introduction

Since its publication in 2007, Rocard's Report is a mandatory reference for European projects with educational impact (Rocard et al, 2007). Rocard and his co-authors emphasize the Inquiry Based Science Education (IBSE) approach as a guideline to be followed in projects for the future life in our schools from the very first years in order to trigger science attitudes from the very young age. In this paper we discuss relationships among IBSE, Constructivism/Constructionism and the use of technology in schools, particularly referring to authors' experiences in 'robotic-oriented' programming activities they have carried out during last three years with pupils from primary to high schools in Italy and in Spain (figure 1).

If we have a look to this conference call-for-paper, where the idea of constructionism is described, we find the following sentence (about the students): "They also need opportunities to actively explore and experiment with new concepts and materials on their own, to test and extend their understanding by designing and constructing sharable artifacts". In fact for us, Constructionism may be seen as a methodology to produce empirical facts by designing, assembling, planning and drawing, with pencils on paper, paths for the robots, in short concretely working. Observing the fact that current technological tools & devices are attractive to schoolchildren and are used by them normally more easily than by adults, technology shall be employed more often than it is nowadays to produce facts (or data) and in more original ways than it has already been used.

More specifically, here we suggest the use of autonomous mini robots because they are themselves technological devices for producing facts when students assemble different robots, then design different behaviors for their robots, scenarios where they have to move and finally implement programs discussing and comparing robots movements and behaviors with their classmates. Robots and programs are artifacts designed and then assembled or implemented by groups of schoolchildren. When a program is run also the behavior the robot shows during the program execution is an artifact. All these artifacts produce data that are collected by pupils, shared and discussed among them.

Activities based on technology implement an IBSE approach where pupils do not only collect facts from the experience but also produce new facts or can produce other new facts by changing data and/or achievements from these activities: i.e. when they are authors of their experiences. When we work concepts in standard school curricula using an IBSE approach we implement a learner centred education because pupils are the guided designers and authors of experiments where they produce facts, collect them and derive from them a concept relevant for their standard school curriculum.

For each activity the teacher gives pupils a problem to solve having a didactical objective. Each group of pupils decides how to assemble its robot, designs a behavior for that robot and develops its own program to implement the decided behavior that, with the assembled robot, is a solution to the given problem. The teacher follows discussions within each group and among groups of pupils monitoring them toward his/her didactical objective.

An adequate sequence of problems, designed to follow a constructivist strategy, can be used to organize courses. The didactical value of traditional formal teaching/learning may be expanded to include non-formal and even informal activities that can be carried out within the school or out of the school (figure 2). This obliges us to make serious reflections about the roles in the Educational issues of both officially educational institutions and cultural and scientific institutions and the society in general.

In the 2nd chapter we present a theoretical framework where our approach could fit. The 3rd makes some reflections about the interactions between IBSE, PBL and technology. In the 4th we describe some concrete activities where we propose using programmable robots in education according to the constructionist approach. The 5th chapter relates our educational approach with an education based on competences and with a social and professional framework, the European Qualifications Framework. In the last chapter some conclusions.

Figure 2. Some external activities:Venice Open day 2008, Discovery 2008, FLL 2008

Pedagogical concepts about IBSE

This chapter defines inquiry-based learning as introduced by Yves Chevallard (Chevallard, 1999). With respect to other definitions Chevallard addresses what IBSE is, i.e. which are its peculiar elements and characteristics, rather than how it can be put into practice during school activities as done for example in Andee Rubin (1993).

Linking facts to laws

In experimental sciences the IBSE methodology can be considered as constructing "praxeological" units, whose meaning is explained by Yves Chevallard as follows: 'A praxeology shows the linking structure between a class of facts of a physical phenomenon and its "technical law" (or a technical model) that "explains" these facts. It also shows the linking between a class of technical laws (from similar phenomena) and its corresponding "technological law" that "explains" them, building in this way a hierarchically structured "theory" about the phenomena' (see figure 3).

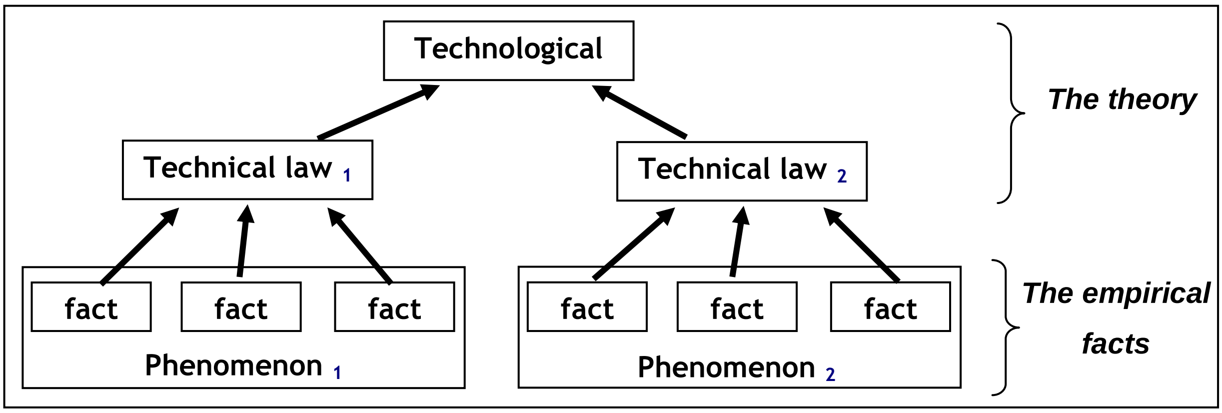

Figure 3. A praxeology structure from the facts to the theory

The "empirical facts" are the factual level (related with "doing") and the structured law in the "theory" is the level of formalization (related with "knowledge"), and this praxeology structure ensures the link between the two. When, in a school class or laboratory, we build a praxeology structure from the facts to the theory (in the bottom – up sense of the diagram in figure 3) we are working in an inquiry based approach.

All this suggests a didactical strategy for the teaching and learning of a science praxeology at school:

1. Formulating an every day problem and reformulating it as a “scientific” (phenomenon) problem
2. Constructing the model:
    a. Collecting experiences about the problem (“interaction” activities by the pupils)
    b. Modelling the experience to build up a technical law (“formulation” and “verification” activities by the pupils)
3. Using the model:
    a. Using the technical law to solve problems
    b. Looking for the limits of the model, extending the initial problem to one more general and applying again the IBSE process to reach a technological law.

We can see that the above IBSE learning way is, at the same time, a problem based learning (PBL) approach and a true constructivist learning method, and it is according with our overall conception of the science and technology school activity as an activity of “problem solving by building and using models”.

IBSE, Constructionism and Technology

As we have said constructionism is based on giving students “opportunities to test and extend their understanding by designing and constructing sharable artifacts” through which they can actively explore and experiment with new concepts and materials on their own. Constructionist IBSE approach in school subjects is based on letting pupils design and construct the empirical facts. Technology can play an important role in these experiences. Software tools have been successfully used to produce facts (or data), for example by simulating real world events. Autonomous mini robots for some aspects allow us to go a step further because they are themselves technological devices for producing facts when students assemble different robots. Then when students design different behaviors for their robots and implement corresponding programs they have another chance of producing facts related to a concept. Both robots and programs are artifacts designed and then assembled or implemented by groups of schoolchildren and allowing experiences shared among pupils.

In the field of inquiry-based science teaching research the French Academy of Sciences has initiated the Pollen project in the frame of its international cooperation. Pollen is inspired from the previous and well known “Mains à la pâte” project, also French, and “invented” by the Nobel Prize Georges Charpak. Both projects promote science teaching renovation in primary schools based on the inquiry approach. For this, Pollen aimed at creating a sustainable framework for science education through a child-centred approach. Activities developed within the Pollen project on light, sound, temperature or other topics can be found at www.pollen-europa.net.

We share the same aims of “Mains à la pâte” and Pollen but projected towards a broad use of robotics and other technologically advanced tools. Our contribution concerns investigating the kinds of activities students can develop using technology as the main tool they employ for building their own knowledge. The fact that the learner is able to build his/her own knowledge is one of the inquiry-based science education main issues. In our everyday life we can observe how young people are uninhibited and easy to get involved in activities using technological devices. Our research concerns taking advantage in schools of this confidence in order to make pupils discover concepts from different disciplines during and by means of activities they design, discuss, implement, verify working with a group of classmates and then show and discuss with the rest of their class. Technology has been positively used to present in more attractive ways educational concepts: for example by asking students to build hypertexts (or podcasts or other types of document) describing history events or other subjects. It has an unreachable success in simulating events, in recording and helping the analysis of natural and unnatural events, for making visible and manifest biological, chemical processes. Our investigations concern giving to the pupils opportunities to be authors of activities where technological devices are used; in this way empirical facts are produced and collected in order to derive/work concepts from school standard curricula.

More specifically in this paper the authors analyse different research works they have carried out using programmable mini robots in schools. One of these aspects concerns the programming language offered to schoolchildren. Sometimes a textual Logo-like language is introduced to children in different layers of primitives corresponding to new types of activities the teacher suggests for introducing new concepts from the standard curriculum of her/his pupils. Some times we use iconic languages, but always we see the need of establishing different layers of "complexity" (gain through the creation of procedures or primitives).

Indeed our first and main goal with educational robotics is inquiry based education in primary schools or for even younger pupils (De Michele, 2008). We also observe that teaching programming is a sort of side effect contributing to introduce principles of Computer Science in education according to the 2006 ACM curricula.

A constructivistic IBSE using programmable robots

In Rocard's 2007 Report we read: "By definition, inquiry is the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments (Linn et al., 2004). In mathematics teaching, the education community often refers to Problem-Based Learning (PBL) rather than to Inquiry Based Science Education. In fact, mathematics education may easily use a problem based approach while, in many cases, the use of experiments is more difficult." In activities where pupils program mini robots, experiments on mathematics concepts are also possible as we sketch in this chapter. We also emphasize the constructionistic methodology suggested in approaching robot programming activities in schools.

Using natural and programming languages at different ages/levels

In our activities "not yet writing" children use the BeeBot mini robot by TTS (described at http://www.tts-group.co.uk/Bee-Bot). Children can move the BeeBot (back, forward, left, right) by pushing buttons on its back. Didactical goals to reach are counting, comparing quantities, problem solving and finding one or more strategies to make the BeeBot reach a given goal position. BeeBot is also quite used in schools where teachers are somehow frightened of 'programming through a computer'. We try to overcome this fear by offering the programming language and the Integrated Development Environment specifically conceived for pupils and teachers described in (Demo, 2009). The textual and Logo-like programming language, called NQCBaby, can be used for programming the RCX and NXT Lego bricks. Educational itineraries introduce the programming language by means of different layers as described in (Demo, 2007). Commands of the first language level, called NQCBaby0, correspond to the BeeBot buttons commands that pupils have used before writing, i.e. in k-2, or, in higher school grades, if robot activities begin later. Each next layer is introduced for making possible conceiving and implementing activities having new educational goals with respect to previous activities or for a constructive introduction of some programming commands or concepts. As an example, NQCBaby2 is NQCBaby1 plus commands allowing pupils to make experience of synchronous activities the robot can perform such as playing a song and/or rotating a palette and/or switching off/on a light while moving.

NQCBaby1 =	NQCBaby0 ∪ {forward(n), backward(n), left(n), right(n)}
NQCBaby2 =	NQCBaby1 ∪ {play(..), switch-on(light), switch-off(light), clock-rotate(n), counterclock(n)}

When the touch sensor is introduced we need commands to specify where it is connected and to check it. The language becomes NQCBaby3 containing primitives for moving while paying attention whether an obstacle to the robot movement has been found.

NQCBaby3 =	NQCBaby2 ∪ {port-1 is touch, forward-always, repeat-always, if-touches, end-if}

In our educational itineraries a further step is covered, i.e. a next layer of the language is introduced, to allow pupils designing new kinds of robot behaviors and teachers conceive each activity, even competitions, as having a specific didactical goal synchronized with her/his pupils curriculum.

Past experiences have interested particularly mathematics teachers. In primary schools, activities have been developed concerning direct and inverse proportions, fractions, geometrical shapes. Also discussions on which of the proposed solutions to a given problem was more general have been carried out in a fifth grade. In junior secondary schools algebraic expressions have been introduced and motivated as a way to express the length of the path (or part of it) a robot covers while running a given program (Demo, 2010).

Procedures or block construction: pure constructivism/constructionism

One of the crucial aspects of the constructivist/constructionist approach is the tendency of assuming a new cognitive equilibrium, with positive balance, after a phase of assimilation of new knowledge stimulated by a problem (or a simple question) followed by a phase of accommodation concerning the conceptual structuring of the new information. These processes are often accompanied by the building of abstractions able to generalize from the specific details of the addressed problem. Dealing with programming (in particular robot oriented programming), these abstractions have a linguistic counterparts represented by a parameterised function or method. This requires that the teacher, after the resolution of a specific problem, helps the student to formalize the general aspects of the problem recognizing its parametric entities and transforming functionally the solution; in fact they are creating procedures or primitives that will be re-used to construct new primitives. More details on our experience on this matter can be found in (Arlegui et al, 2009).

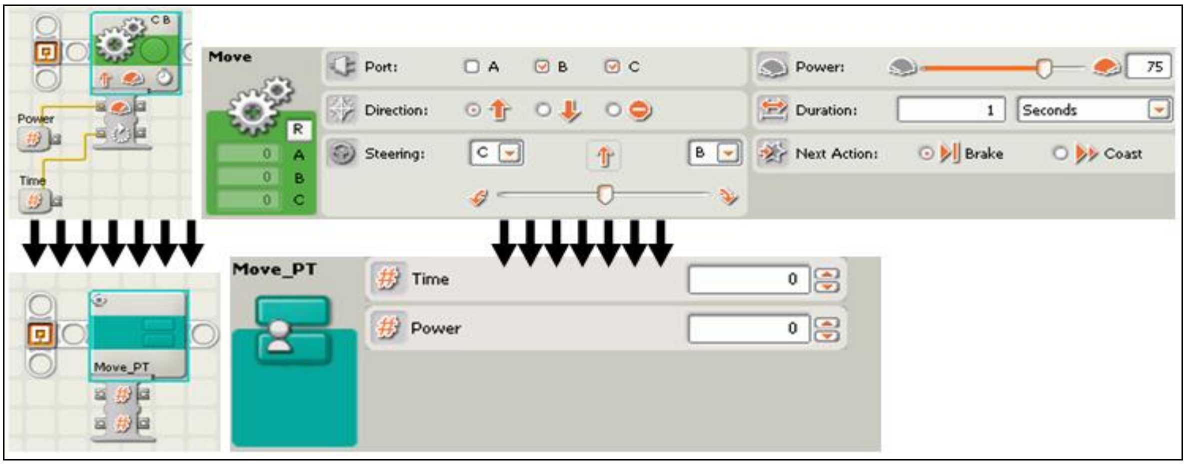

Figure 4. An example where we "simplify" the Move block using a new procedure Move_PT, which is a "rewriting" of the Move block but with only 2 parameters (Power and Time). We are constructing new vocabulary (new blocks) that can be re-used later, for example to define a Move_VT (velocity, t).

For example, in the iconic NXT-G language this corresponds to define a *MyBlock* sub-command, whereas in the textual NXC language this means to define a traditional function with formal parameters. A typical problem of this class is move the robot on a straight line for a given time at a given Power (of the motors). Figure 4 shows how to construct a "new block" able to be re-used.

Finding "real problems" to solve when following at the same time regular curricula

At the secondary junior level students have more awareness of the real world and its challenges. Some real problems and situations offer several cues for proposing, with suitable simplifications, effective robotic-enhanced experiences. For example the control of a supervised metro line can be reduced to a very simple motion planning problem, i.e. a robot moving on a straight line and forced to stop on positions with a fixed distance between one another. After having solved this problem, starting from a basic knowledge of the involved motion parameters (speed, time and distance), the problem can be generalized with not uniformly spaced metro stations.

At the secondary senior level educational robotics can explicit all its potential provided the robotic platform can ensure a sufficient precision, both mechanical and for the controlling program. In spite of its apparent, relative simplicity, Mindstorms NXT provide a good motion control and a complete series of commands able to get enough reliable data from the environment through its sensors. Some briefly explained examples will convince the reader of the wideness of possibilities.

When studying the pivoting of a robot with two wheels and one motor per wheel, when you move in one direction only one of the two motors, i.e. the pivoting is around the still wheel, the student must infer the angle performed by the robot from the rotational angle of the moved wheel. This requires the application of simple relations based on measuring angles in radians, a concept that can be more easily understood when applied to such a practical problem.

If you mount the sonar sensor on a motor, you can rotate the sensor to evaluate distance and angles on a plane. In figure 5 this layout is used to indirectly calculate the distance separating two objects: the distances *d1* and *d2* are measured by the sonar whereas the angle α is given by the encoder integrated in the servo-motor differentiating the angular positions where the distances are evaluated. Now applying the cosine theorem the student can obtain the unknown distance d ($d^2 = d1^2 + d2^2 - 2 \cdot d1 \cdot d2 \cdot \cos \alpha$).

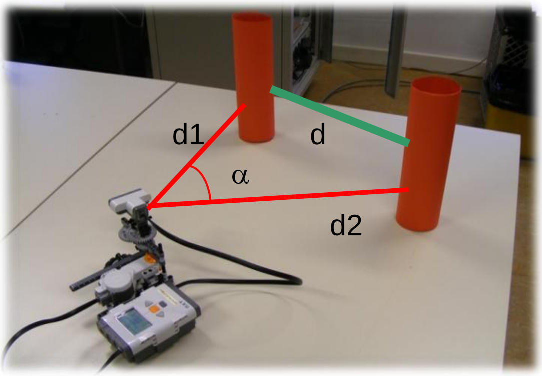

Figure 5. An application of the cosine theorem

The self-positioning problem is a well known problem in autonomous robotics. It can effectively be simplified with the following layout: the robot is initially put in an unknown position in front of, and not so far from, two objects; these latter two are in known 2-D cartesian positions. Measured the two distance d1 and d2 from each object and the robot using the sonar sensor, the student can argue that the position of the robot is for sure in one of the two intersection of the two circles centered in each object position and having respectively d1 and d2 as their radius (a simple heuristic helps to recognize which one of the two is correct). The intersections can be calculated applying a not trivial system of two second order equations.

If you make the robot emit a fixed frequency periodic sound and pass in front of a microphone connected to a PC for analysing the perceived sound, you can experiment the effects of the Doppler phenomenon. The difference of frequencies when the robot is approaching the microphone and when it is going away from it results limited to some Hertz, therefore the analysis must be performed with suitable tools on the PC but it can give a sufficiently precise estimation of the robot speed (in formula, $f_{perceived} = f_{emitted} \cdot v_{soundInAir} / (v_{soundInAir} - v_{robot})$).

PBL/IBSE, constructivism, competences, European framework

In this chapter we would like to relate the concepts of constructionism and IBSE with an aspect that has recently assumed more and more a strategic meaning in the actualization of curricula, namely the so-called 'competences'. This term has been used in the literature with a wide spectrum of meanings depending on the context. From all these different definitions it may be argued that the competence is an integration of knowledge, practical ability, meta-cognitive and methodological capabilities, personal and social capacities. More recently the term has been related to a unique view of the human potential when stressed by real problems. In this view the emphasis is given to the effective mobilization of the person in front of problems: therefore, a traditional set of “discipline-oriented competences” is now enriched by set of “generic competences” giving the measure of a 'know how to act' that involves the whole personal sphere of knowledge and skills.

In a competences-centred teaching/learning the transmission of knowledge is substituted by offering students opportunities to solve problems together with the assumption of duties and independent initiatives. This implies to design inter-disciplinary work units where different competences (both specific and generic) are worked. The main change is the way of how organizing the entire teaching sphere. Teachers also need to mature in the awareness that their discipline promote the construction of competences.

The competence does not exist until it is practiced in a meaningful context. Even if you can get a better application of knowledge in a real context, and from this point of view, the combined school-work initiatives provide conditions particularly effective; nevertheless laboratorial activities at school can boost the students’ autonomy in order to cope with complex situations.

This view is also consistent with the more recent guidelines issued by the Council and European Parliament. The conclusions to the work of the Lisbon European Parliament in 2000 show 3 main objectives: the definition of key competences, the raising of educational levels and the enlargement of lifelong education, the recognition of non formal and informal learning in the formal ones. The recommendation (Recommendation 2004) points out the necessity to recognize both formal and informal learning because they both contribute to build a strong competence. In (Recommendation 2006) the eight key competences (Communication in the mother tongue, Communication in foreign languages, Mathematical competence and basic competences in science and technology, Digital competence, Learning to learn, Social and civic competences, Sense of initiative and entrepreneurship, Cultural awareness and expression) are officially declared as key aspects of the European citizenship.

Even the successive European Qualifications Framework (EQF) (EQF, 2008) emphasizes the need to promote the validation of non formal and informal learning, especially for students who manifest difficulties applying traditional evaluation criteria. It is remarkable that in this recommendation, along with definitions of knowledge and skill, the competence is seen as a proven ability to use knowledge and practical skills in operational situations, but also personal, social and methodological abilities, and with the application of personal responsibility and autonomy. As you can see this is a definition that includes a significant ethical value: in fact responsibility and autonomy give substance to an active citizenship and to social inclusion.

Teaching-Learning processes designed for acquiring competences have a very close relationship with the constructivist/constructionist approach. Indeed laboratorial activities, autonomy, accountability, creation of artifacts, inductive and collaborative learning, are perfectly in accordance with the competence-oriented view as ‘how to act knowing’. The implementation of such approach through IBSE explorations in coherent sequence of problems to be solved put learning activities strictly in connection with the real world and its complexity and variability, though usually in simulated environments.

When robotics is concerned, we should add the conclusion that it promotes and stimulates any fundamental competence thanks to aspects like multidisciplinary, attractiveness, building of ‘intelligent’ artifacts, interesting links to literature and cinema, etc.. Once again, the emphasis shifts to a thoughtful design of teaching units, within which the construction of the robot and its programming are only instrumental aspects necessary to achieve educational purposes related to the competences the teacher wants to stimulate.

Conclusions

Figure 6 summarizes all the ideas expressed in this paper and specifically shows that, in spite of the augmented role of students in all the active phases of the PBL/IBSE, the teacher maintains a crucial, central position as facilitator and mediator.

We believe that IBSE, PBL, constructivism/Constructionism and technological artifacts can be used to promote a scientific way of thinking among the students/pupils with new, relevant potentialities. This can be done by teachers within the schools and out of the schools (formal and informal learning). They need for that a double support.

First of all we have to set up an adequate teacher training plan (as it is being done in the case of robotics activities) within the schools (in our case trainers from the university are teaching trainees, the teachers at the school, in order to help them to integrate the design of robotic-enhanced experiences in their institutional curriculum and to teach this to the pupils).

Then once the teachers are confident with the tools they can use and with the methodology they can apply, it is the moment to link the school activities with real problems from the real world. At this point the society, through institutions like Public (Science related) Museums or other Public Institutions that promote creativity and innovation among young students, can “give” to the school real problems with real data to be solved, and at the same time the school can “transform” these problems in order to produce the necessary didactical approach (the didactic transposition). These two “bi-directional” steps could enrich both roles; the school gains “real problems from out of the school” to be used with a Constructivist Project Based Learning strategy using IBSE methodologies; and the Public institutions like Museums or others gain a more didactic way of showing/describing/sharing their “contents”.

We think that this is the way we can educate our future (XXI century) citizens, linking schools (at any level) and society, in harmony with the European Qualifications Framework.

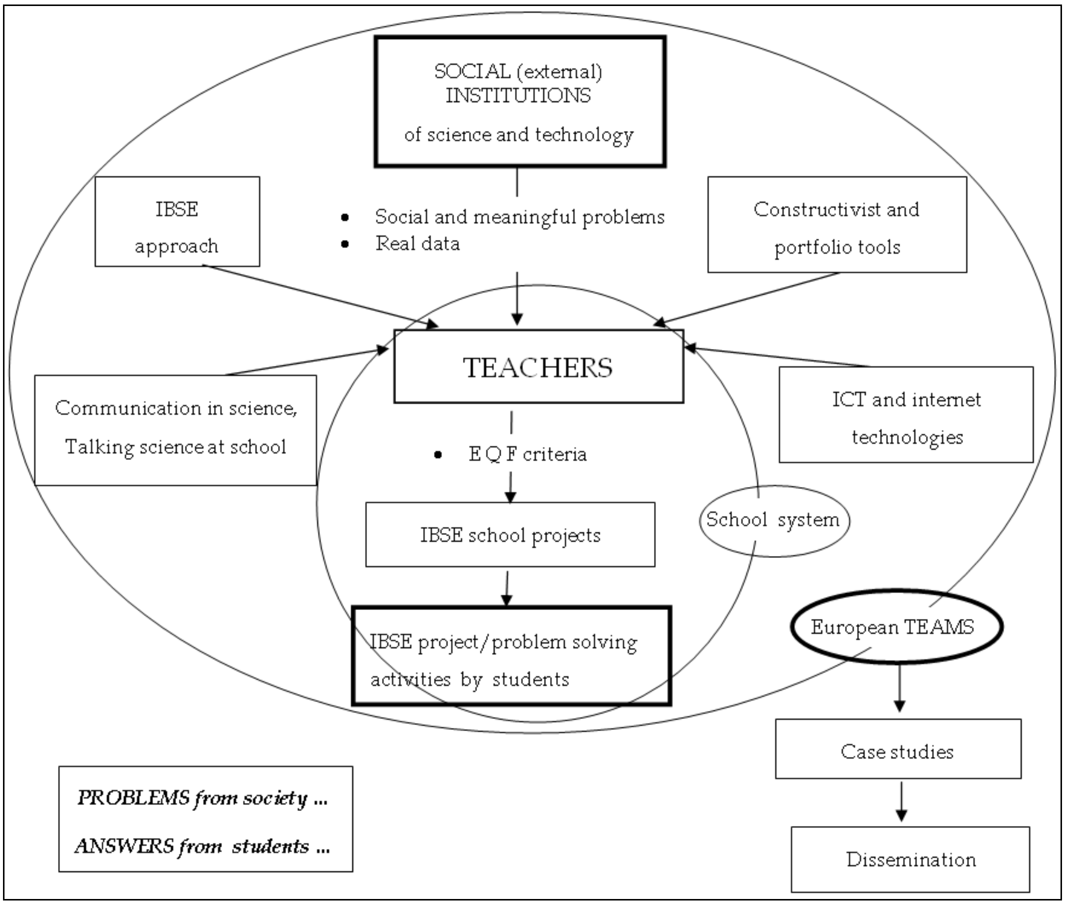

Figure 6. Linking Educational institutions and Social Cultural & Scientific institutions for Educational purposes to provide, share and disseminate "real problems" to be solved using a constructivist IBSE by our Teachers & Students

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