Inquiry-based learning in Science Education. Why e-learning can make a difference

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Inquiry-based learning in Science Education is based on the belief that it is crucial to ensure that students deeply understand what they are learning, and not simply repeat contents and information. To this extent, IBSE is not only a way to teach Science effectively, but more importantly it can be a way to teach how to learn in a broader sense, developing problem solving comprehension and critical thinking skills, using properly prior knowledge and rejecting naïve conceptions. It implies a cooperative endeavour, soliciting communicative skills to share with others observations and research questions, and it requires specific skills to work successfully as a part of a team. However, it is arguably that nowadays IBSE is a widespread teaching and learning practice, mainly because it involves more complex pedagogical skills than those needed for traditional face-to-face classes (e.g. organizing stimuli and experimental settings, managing the observational process and holding group discussion on formulating questions and ideas, guiding students

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in recording and reporting their experiences). But most of all, this happens because its development is multifaceted, highly personalized for each student, and based on a variety of sources and stimuli. In this frame of reference, several hints can be envisaged for designing e-learning solutions specifically devoted to strengthen a wider cultural perspective in Science Education, thanks to personalized and automated solutions for learning which includes: interactivity, multimedia educational materials, social networking, virtual environments for learning.

1 Paradigm shifts in Science teaching

European countries are facing a progressive decreasing in the number of university students enrolled in science-related subjects courses, even though modern societies heavily rely on technology and innovation development. Over the last decade, the share of graduates from science, mathematics and computing has reduced from around 12 % to 9 % at European level (EACEA, 2012, p. 173).

Several reasons can be envisaged for a poor quality Science Education, e.g. shortage of infrastructures in schools or lack of well-trained teachers. Apparently, one of the major faults of educational systems and daily teaching practices is to offer not sufficiently appealing classes for Science Education. Learning from experience is more engaging than learning from a book, but this has not become so far a widespread practice in schools. Thus, the core of the problem lies with teaching and learning processes.

Literature shows a clear distinction between two main teaching paradigms: one based on rote learning, devoted to acquire pre-packaged knowledge, and the other mainly focused on ensuring that students truly understand what they are learning thanks to an inquiry-based approach. It would be strange not to agree with the implicit efficacy of the latter, despite the fact that it is not an entirely new idea - as it will be discussed later on.

Nonetheless, why has this paradigm shift not happened yet? This paper will try to outline the main theoretical assumptions beyond inquiry-based Science Education (IBSE), its specific features in everyday teaching and how it can be enhanced by a systematic and proper use of a variety of e-learning solutions.

2 The nature of inquiry-based pedagogy in Science

In social sciences, arts and humanities, interactive teaching based on common psychological inner experience of students is a usual practice. When it comes to science, it is not rare that the bulk of notions and knowledge are taught like dogmas, with a one-way communication from teacher to students. Even in laboratories or in project working, the need to follow a set of guidelines or to apply predetermined rules does not allow many possibilities of independent thinking.

Rather than a shallow scientific knowledge on theories and their outcome, IBSE gives the possibility to apply scientific methods to solve problems, to perceive relations between general concepts and real-world experience, and lastly to evaluate the relevance of results with a critical thinking approach (Worth, *et al.*, 2009, p. 9). In IBSE pedagogy, motivation to learn does not depend on rewards but it becomes an intrinsic engagement produced by the satisfaction of understanding natural facts and events. And it is widely known that motivation is one of the key factors of learning effectiveness.

Hence the emphasis is to return to science subject-matter, which is not to be found exclusively on textbooks, but in the real-world experience, exactly in the "matter" in itself. The main distinction between inquiry-based approaches and current laboratory practices can be envisaged in the attempt IBL makes to bring concepts alive in the imagination and in the intellect of learners, whereas laboratory traditions are often repetitive attempts to certify the only possible truth, as it has been previously announced in theoretical assumptions. In a traditional laboratory setting, students follow a standard set of actions but only rarely they fully understand the reasons and the nature of the outcome achieved. According to Hawkins, in this setting the teachers are the "knowers" or the "explainers", members of a "social caste" that often offers too soon advice and help to students, whereas only when the learner has worn out his own resources and still fails, he should be aided with new knowledge (Hawkins, 1965-2002, p. 15).

Inquiry-based learning contrasts the transmissive assumption of traditional Science Education, and moves the focus from the teacher to the students, in a learner-centred approach. In this sense, teachers should support active learning and guide students toward self-regulated processes, devoting particular attention to the relevance and meaningfulness of tasks proposed. Relevance of tasks can be a natural consequence of the use of real-world stimuli and it has a positive effect not only in generating a proactive attitude towards learning but also on knowledge retention in the long term.

Meaningfulness has also a relevant place in the theory of cognition. It is widely accepted that relevant learning is built upon prior knowledge, and that is *meaningful* when it is subsumed into previous cognitive structures of the learner (Ausubel, 2000). Even if Ausubel's frame of reference is strictly associated with expository verbal learning, juxtapositions are possible with constructivism (Mayer, 2004), in the sense that learners construct their ideas and concepts on existing knowledge (Bruner, 1960).

Another related antecedent within the perspective of the theory of cognition is Bruner's discovery learning. The discovery learning allows pupils to transform information, formulate hypotheses, making meaning from experiences, produce knowledge that is transferable to other circumstances (Bruner, 1996). An in-depth examination of these cognitive theories would probably shift the focus of the present article, so it will not be included here.

Although there are scepticisms about the effectiveness of pure discovery learning based on social constructivism, and even if, according to Mayer, there is sufficient research evidence to demonstrate that teacher's guidance in problem solving activities is more beneficial than pure discovery approaches, two aspects worth mentioning are:

1. The annulment of differences between basic and advanced knowledge of traditional subjects organization in favour of an instruction centred on understanding structure and principles of a body of knowledge.
2. The interpretation of information and experiences based on analogies and differences, i.e. categorization. Categorization process leads perception, conceptualization, learning and decision-making and it allows reach a symbolic level in the organization of knowledge.

Inquiry-based pedagogy fosters hypothetical and critical thinking. The hypotheses generated by learners in order to understand the natural world around them are provisional as all proper scientific hypotheses are: "No matter how many times the results of experiments agree with some theory, you can never be sure that the next time the result will not contradict the theory" (Hawking, 1988, p. 10). The viewpoint can be in some way reversed with respect of traditional knowledge, where transmission of pre-defined assumptions leads so often to rote learning.

A specific element of complexity is given, within Science Education, from the *conceptual changes* that are needed to understand specific topics (Vosniadou *et al.*, 2001). Differently from the empiricist approaches, conceptual changes are a radical reorganization of existing knowledge and not a progressive enrichment of a fixed paradigm. This reorganization implies often the rejection of intuitive causal reasoning, confirmed instead from everyday experience, and it produces a restructured representation of the world. To this regard, it is worth remembering that naïve conceptions are persistent even after a consistent period of education and most non-experts adults do not actually understand even common scientific concepts, i.e. pressure, temperature, mass, weight and so on.

Last important element introduced by IBL is the opportunity to "going meta" – as in Bruner's motto. Metaconceptual awareness is what allows students to remove false beliefs that limit their learning, and to get that coherence in explanatory framework that is typical of experts' categorizations (diSessa, 1993). Nowadays metacognitive approaches are predominant in the educational debate and they contemplate only a feeble recall to contents of learning, presenting their activities as a genuine *passe-partout* that magically opens the doors of knowledge. Nonetheless, probably the most interesting aspect in "going meta" is the negotiation of word meanings that descend from the observation. During classroom talking about scientific experiences, teachers play a fundamental role in bridging two otherwise separate linguistic worlds. The common language used by learners needs to be re-adapted in a more complex encyclopaedia of words, deeply rooted in the bulk of notions that constitute science lexicon.

At the same time, the teacher cannot simply impose the new language as in a traditional lecture, but he has to clarify continuously the link between words and observed events that constitute the learning experience. The art of distinguish between words that mean different things is not a useless burden, not the pedantry that confounds, but the unavoidable premises for symbolic abstraction and reasoning about the nature of concepts. In this way, the original Bruner's idea on "going meta" can be respected, pursuing not worship of well-known scientists and textbooks, but interpretation and critical thinking in science-related competences development (Bruner, 1996, p. 62).

3 Nuts and bolts for inquiry teaching

The opportunity given by the experimental setting of IBSE has a timeless charm for educators, because of its hint of implicit innovation. Too often "experiment" is equal to "try something new", whereas it is in fact a high level cognitive activity that involves hypotheses generation and intentional manipulation of independent variables to produce an effect. But translating theory into practice is something that education has always struggled to do, probably because a neglected theory, transformed in a simplistic way into practice, produces coarse mistakes and inevitable polemics.

Basically, for its own nature, it is extremely difficult to reduce inquiry-based teaching to a single universal recipe. There are anyway several research projects and dissemination initiatives, both in Europe and in US, which produced guidelines and best practices collections useful to describe in broad terms how a good IBSE can take place in classroom[1].

As starting point, teachers needs to be trained to a more complex set of skills. As Duschl *et al.* (2006) point out: "*To support student sense-making in instruction, teachers need to know how students think, have strategies for eliciting their thinking as it develops, and use their own knowledge flexibly in order to interpret and respond strategically to student thinking. Teacher professional development can serve as a context for helping them understand students' ideas about the subject matter to inform their thinking*". As it will be detailed, IBSE opens up an infinite series of learning opportunities that require specific skills to be managed.

[1] Among many others, it can be useful to cite here the following EU-funded projects: FIBONACCI project, PRIMAS (Promoting Inquiry in Mathematics and Science education across Europe), S-TEAM (Science-Teacher Education Advanced Methods), PATHWAY (to Inquiry Based Science Teaching).

Even though science investigation does not follow a linear development, it can be described in a series of steps:

- focused observation on direct experience and/or secondary analysis of available data;
- problem definition, planning and designing activities to solve it;
- insights for retrieve essential aspects;
- hypotheses and explanatory models generation;
- hypotheses testing, contrasting data to a model and overcoming possible drawbacks;
- expressing and communicating final conclusions.

This framework for scientific inquiry can be differently organized in classroom activities that take two or more different days, because it would be difficult to develop with students all the stages in one day (Worth, *et al.*, 2009, p. 10). Additionally, designing and carrying out science investigations has a cyclical development, since after first tentative conclusions new questions and doubts can be raised.

Probably the most relevant difference with traditional teaching methods lies in the students' choice of topics and problems to be tackled during classes. In IBSE, questions and concepts are not isolated topics that follow a predetermined and obscure sequence, but descend directly from learners' needs and from the surrounding context in which the school is located, as it is easier to start from daily-based experience. In this sense, topic relevance is strongly connected to the "big ideas" in science that can help understanding of events and phenomena of relevance in students' lives (Léna, 2012; Harlen, 2010). This because the main purpose of Science Education should be to enable every individual to take informed decisions and consequent actions that can influence society and environment.

Besides, IBL is based on cross-disciplinary investigations carried out with multiple resources, more than disaggregated and fragmented lectures on singular topics. In this way also the idea of tackling science subjects one at time is partially overcome by an intertwined series of integrated experiences. Considered from the perspective of the teacher, this can create drawbacks, given the wider knowledge and competences background needed to manage effectively a potentially indefinite chain of learning questions on the various topics.

Another feature of IBL is the collaborative approach to learning which is implicit in its development. From individual learning, IBL moves toward collaborative learning, or a cooperative endeavour to reach the goal/s. Science is hardly ever a solitary activity, and joint work is needed to sharing ideas, debating, drafting suppositions and designing possible actions. Working in team requires the teacher to adopt specific solutions to manage it effectively: small groups with definite tasks and goals, clear indication of roles and few basic rules to participate, accurate moderation of the dialogues in order to allow also reluctant students to participate to the discussion.

Last key aspect is formative assessment, as the chief strategy for a successful implementation of inquiry-based learning in science, particularly as a way for stimulate students' reactions during activities. Other than the obvious non-judgemental feedback, formative assessment is crucial because it can lead to a shared and clarified view of the assessing criteria. These criteria are not only useful to teacher for evaluating students' progresses, but also to students for evaluating their inquiry process and fostering decision-making. Designing proper formative assessment for IBL is not straightforward, and two of its essential elements, i.e. (1) keeping record of observational data and (2) provide detailed and on time feedback, are extremely time-consuming.

Still it is in summative assessment that probably IBSE finds one of the main constraints to its diffusion. Use traditional standardized tests to evaluate students' achievement at the end of an IBL instructional path would be restrictive or, at least, "mismatched". Some authors envisaged in the narrow focus of high stake testing on factual knowledge as one of the reasons for "teaching to the test" practices that leads to traditional teaching practices in Science Education (Harlen, 2010). But this can be a simplistic point of view, that does not take into account all the possible assessment purposes. Summative assessment, as defined by Airasian (1994), should certify student's exit achievement, and it can be correctly implemented at the end of the learning path, when it would be difficult to influence or modify learning. Moreover, design and implement valid and reliable assessment is too often an underestimated issue, that needs a specific professionalism, team working and reiterate field trial validations to be carried out properly. First of all, variance between outcomes of different groups of students poses a problem for teachers on setting the evaluation criteria on a common scale. Secondly, in order to properly evaluate the contribution of the individuals into group work, specific strategies need to be carefully planned in advance. Lastly, if correctly implemented, IBSE produces every time a different teaching situation, making hard to capitalize past experiences as in traditional lectures.

4 Re-conceptualizing e-learning for IBSE

According to what has been illustrated so far, even if it is not a recent orientation in pedagogy, inquiry-based learning represents still a challenge. It has been demonstrated that there are consistent memory advantages deriving from insightful problem solving, and that insight solutions found by the students, the so-called "aha! experiences", are better remembered on the long term (Danek *et al.*, 2012). But it is hard to achieve "aha! experiences" for 30 students in a classroom at the same time, whereas is more likely to end up trivializing an otherwise complex knowledge structure. In addition to this, reaching a discovery level does not automatically means a full conceptualization and awareness at the symbolic level.

Existing technological solutions can offer several immediate advantages for an effective implementation of IBSE. What follows is a quick overview of the key elements to consider in designing e-learning for inquiry-based pedagogy.

It is possible to build up a large repository of examples and related multimedia documents useful to support classroom activities. There are many available OERs (Open Educational Resources) related to IBSE but they are isolated and they can vary considerably in their main features. A meta-search engine on IBSE materials could constitute a precious starting base for teachers. There are plenty of videos available on scientific experiments and "big ideas" in science[2], and even if their intent is probably more informative than instructional, they can constitute a prompt for more in-depth activities during lectures.

E-learning and blended learning solutions offer a variety of possibilities for social networking on different supports and in this way can help teachers to keep a systematic track-record of students' interactions during collaborative learning. Within the recent project ATCS – Assessment & Teaching of the 21st Century Skills[3] promoted by the University of Melbourne, Cisco©, Intel© and Microsoft©, has also been made the proposal of combining summative and formative assessment thanks to the possibilities offered with available technologies of collecting, storing and analyzing a huge quantity of data. This should help overcoming at least some of the criticisms previously mentioned, given that the goal is to assess the learning progressions in the individual pathways, merging data from classroom assessment and large-scale testing.

Furthermore, e-learning can provide simulation of laboratory experiences. IBL is the pedagogical approach mostly characterized by hands-on activities and processes, and there is a long-running debate about the value of simulated experiences. However, it is worth mentioning that automation introduced a change in the nature of laboratory work. Currently, there is a differentiation between hands-on laboratories, simulated laboratories and remote laboratories, which are similar to the control of robots used in manufacturing and that are also widespread in innovative research fields (Ma & Nickerson, 2006).

The advancement of technologies and the costs related to laboratories has produced an increased interest in these solutions, but the focus should remain

[2] On Youtube©, other than MIT, UCBerkeley, Nottingham University and other well-known universities channels, it is worth mentioning initiatives such as Minutephysics, Veritasium, the Brain Scoop, Crash Course, Smarter Every day that offer a series of short videos on experiments in physics, biology and chemistry.

[3] URL: www.atc21s.org (accessed on 19/02/2013).

instead on the educational objectives and the target competences associated to each setting. The virtual and remote laboratories can reinforce conceptual understanding and prepare – at relatively low cost and without problems for personal safety – to further experiences in real laboratories.

All these elements can contribute in fostering the diffusion of IBSE at different levels of schooling. But what can really make a difference are the most recent opportunities offered by personalized learning. Personalization can be not only profiling the learner on his descriptive characteristics and learning styles, offering different paths to different individuals, but also and more importantly tailoring study materials on learner's prior knowledge structure, in terms of vocabulary and achieved levels of competences. The adaptivity in learning message could represent the axis on which rests the success of an e-learning system for IBSE. The kind of adaptvity proposed here refers to the category of micro-level intervention, realized at a cognitive-lexical level (Agrusti, 2010).

Conclusions

If it is true that by definition discovery learning does not have to follow textbook nor its predetermined path, it is also true that almost every step of inquiry-based processes needs an accurate use of terminology, chiefly because it is carried out in group. An agreement should be reached, not necessarily at the beginning but surely at some point during learning, on a unambiguous lexicon necessary to describe observations, to generate hypotheses, to plan experiment and finally to communicate results. Any type of mediated education, whether it is e-learning or an hybrid solution, can present specific issues of words comprehension, and the personalization should be focused exactly on those.

Common sense suggests that science has little or nothing to do with language interpretation and words – whereas is exactly with words that is possible to make sense of a laboratory experience and generalize the results obtained into a wider framework of knowledge. A rote learning and a passive use of words is what traditional teaching methods in science can frequently produce. Grasping the idea that is behind words, along with Bruner (1996), allows instead to achieve a deep understanding of natural events and to translate the meaning into a scientific approach for interpreting reality. This is what inquiry-based science education, supported with the proper e-learning solutions, can offer to learners.

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