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Technologies, resources and inquiry-based science teaching

A literature review

Introduction

Teaching and learning science in a technology-rich environment offers many possibilities: visualisation tools permit to access phenomena which could not be observed without computers, simulation tools allow to test models etc. World-wide communication is possible via Internet, hosts of resources are available on the web. Using technological tools belongs to the scientists' authentic practices; moreover, various software and resources are developed for teaching objectives. However, using ICT to develop IBST is not straightforward. Several gaps exist also for this issue, in particular:

- ✓ between successful experiments and everyday classroom practice. It concerns inquiry-based teaching, but also ICT integration. Despite institutional incitation, a deep gap remains between ambitious aspirations for new technologies in school and actual achievement;
- ✓ between very elaborated tools and teaching device, and the effective learning. Sometimes visualisation can even hinder conceptualisation; students can look for ready-made answers on the Internet, complex tools can introduce specific difficulties etc.
- ✓ between institutional incitation to use technological tools, and the available in-service teacher training programs. The software and resources keep evolving, it requires from the teachers important training efforts, they certainly need adequate support. Developing such support is a challenge, and an important issue for research.

Many research works in science education have studied these issues. We do not intend here to make an extensive presentation of the literature (and certainly could not, because of the number of articles, books, conference proceedings mentioning this topic). We have tried to identify the main directions and questions, the current evolutions and the principal perspectives.

We will first present (part 1) an overall reflection on ICT and IBST, precising the questions raised by this topic, as they appear in the literature. In part 2, we propose a detailed view on a few key papers and projects. The core of the literature review is part 3, were we study issues related with learning (*3.1*), teaching (*3.2*), and teacher training (*3.3*). We conclude with a synthesis of the main perspectives, in particular about design issues.

Part 1
Investigating ICT and IBST

In order to elaborate on the way of bridging the three gaps we mentioned in the introduction (between successful research designs and everyday classroom practice*;* between very elaborated tools and the effective learning*;* between institutional incitation to use technological tools, and the available in-service teacher training programs) this part is devoted to a short reflection grounded on some papers found in the Science Education Literature, and divided in three parts. In the first section (§ 1.1), we focus on the definition of IBST*;* in the second (§ 1.2), on the relationship between IBST and ICT*;* the third part (§ 1.3) is focused on the key issue of authentic practices.

1.1 What is IBST in Science Education Literature?

In the Mind the Gap Project, we retain the following definition*:*

Inquiry-based science teaching may be characterized by activities that pay attention to engaging students in:

(i) authentic and problem based learning activities where there may not be a correct answer

(ii) a certain amount of experimental procedures, experiments and "hands on" activities, including searching for information

(iii) self regulated learning sequences where student autonomy is emphasized

(iv) discursive argumentation and communication with peers ("talking science")

We will keep these four dimensions as a background for all this review (we refer to this definition below as the “Mind the Gap definition”). The articles we examined develop different perspectives on these dimensions. Many of them refer to the definition proposed by Linn *et al.* (2003):

« we define inquiry as engaging students in the intentional process of diagnosing problems, critiquing experiments, distinguishing alternatives, planning investigations, revising views, researching conjectures, searching for information, constructing models, debating with peers, communicating for diverse audiences, and forming coherent arguments ».(p.518)

This definition focuses on a general way of thinking about inquiry, which appeals for a more specific characterization applied to the teaching-learning process.

With this respect, Gengarelly & Abrams (2009) propose a classification of the level on inquiry in a science teaching. This classification is mostly grounded on the respective roles of the teacher and the students. Three dimensions are retained: questions, method, solution. In the following table, a cross indicates what is given by the teacher. The levels are progressively organized, from the smaller amount of inquiry (1, confirmation) to the most important (4, open).

Level of inquiry	Question	Methods	Solution
1. Confirmation	X	X	X
2. Structured	X	X	
3. Guided	X		
4. Open			

Table 1. Levels of inquiry, Gengarelly & Abrams (2009)

The above table enables to elaborate on what means emphasizing “students’ autonomy”, as mentioned in the “Mind the Gap definition”. The authors present a reflection on the differences between inquiry in class and inquiry by researchers, delineating differences in the subjects (more on the edge of what is known for scientists), and differences in the engagement (authentic investment for scientists). The authors define a broad purpose for classroom inquiry: improve the understanding of the scientific concepts; understand the nature of science; cultivate the disposition to find answers to questions; improve attitudes towards science.

This kind of categorization of what can be *inquiry in class* is a useful tool, because it emphasizes both the respective roles played by teachers and students in the inquiry process (there is no teacher in the scientific work !), and the different dimensions of the scientific habits students have to deal with. It seems very important to figure out the relationship between student’s and researcher’s behaviours not only in terms of commonalities but also in terms of (radical) differences, even though the teacher’s goal is to bring students into contact with the scientific way of working, as Van Joolingen *et al.* (2007) argue. These authors demonstrate that the main mean to achieve this goal consists of having the students engaged in scientific inquiry by offering appropriate environments and tasks.

In this perspective, one can raise the “hands-on” issue (second feature of the Mind the Gap Definition). Klahr *et al.* (2007) attempt to clarify this notion. They note that hands-on science “is sometimes used to describe a broad educational philosophy and, at other times, to refer to a specific instructional practice” (p. 184). Klahr *et al.* use the term in the second sense, as “a particular type of activity that could be consistent with a variety of educational philosophies ” (ibid). They suggest a categorisation for hands-on instruction, which is depicted in the following table (p. 185):

Table 1
Space of some potential contrasts in studies of science activities

	Instructional Goal			
	Domain-General Knowledge		Domain-Specific Knowledge	
	Direct Instruction	Discovery Learning	Direct Instruction	Discovery Learning
Hands-on materials				
Physical	A	B	C	D
Virtual	E	F	G	H
Hands-off	I	(J)	K	(L)

See text for explanation of cell lettering scheme.

Figure 1. Categorisation for hands-on instruction, Klahr *et al.* (2007)

These key dimensions of hands-on activities (figure 1) permit to separate important features, and particularly in this study to isolate virtual and physical conditions. Furthermore, the above table enables the researcher to dissociate hand-on activity from discovery learning, for example (as a teacher can implement hand-on activities in her class by practising direct instruction).

The language issue is important in many papers we examined, especially the works studying the potential of networking tools. An IBST approach needs to address the language issue, given that practising a science can be viewed as becoming able to master specific language-games and specific ways of communicating on scientific content. However, the authors do not seem to elaborate further on the language issue, with categorizations or precise definitions as the ones mentioned above for the other dimensions.

1.2 How can ICT foster IBST?

The possible interventions of ICT concern the four dimensions of the Mind the Gap definition.

As mentioned above, networking possibilities are used in several researches to develop argumentation, in connection with the “talking science” issue. We examine such works in § *3.1*, in the section devoted to collaborative learning.

About “hands-on” dimension, ICT naturally offers interesting possibilities: in particular, simulation and visualization tools permit virtual manipulations, which are sometimes easier to organize. It raises nevertheless many questions, about the necessary features of such tools. Learning to observe is a crucial issue in science; a visualization tool can sometimes emphasize to important aspects, which is helpful for the students, but can oversimplify the task.

Students can use ICT tools in their inquiry process to avoid requiring the help of the teacher. Does this mean that ICT can foster autonomy? That it permits authentic practices? According to Van Joolingen *et al.* (2007), “Computers thus allow the creation of computer-based inquiry environments in which learners engage in genuine inquiry tasks and thereby learn the domain together with learning scientific inquiry processes, in an environment that scaffolds them” (p.111). This can certainly be considered as an important goal, for the design and use of ICT. However, this goal does not seem to be reached in all the experiments studied in the literature, and does not seem often encountered in ordinary classrooms either. In particular, an important need for appropriate teacher training, in IBST and in ICT as well is mentioned by many authors.

1.3 About authenticity

Most papers argue that a main goal of IBST consists in providing *authentic learning activities*, and that a way of implementing such activities is focusing on *problem-based* situations. It seems that a strong conceptual issue is to identify what means “authentic” and “problem-based”. Learning activities linked to historical[1] or actual problems (or controversies) are clearly authentic, but in some cases it is difficult to adapt them to appropriate learning designs. We hypothesize that the main criterion stemming from the Science Education Literature rests on the quality of the conceptual-empirical relationship. A learning situation can be viewed as fostering IBST in that it enables students both to fully experience some concrete features and their relations in a specific environment and to link these concrete features and relations to conceptual models which represent and explain them. The ICT approach could be a way to achieve this fundamental relation between abstract and concrete which is fundamental in the scientific practice.

It seems to us that IBST has to be considered with a “goals and means” perspective. In the IBST literature “improve the understanding of the scientific concepts” seems to be the basic goal of the inquiry. Hand-on activities, students’ autonomy, collective argumentation are important dimensions in IBST, but the most important one is the *quality of knowledge* students became able to achieve. In a pragmatist view (Dewey, 1938), the quality of knowledge is not reducible to the mastering of the content, it refers to the way students are

[1] The use of historical problems or controversies in IBST will be discussed in the next WP5 deliverable 5.4 (november 2009)

able to understand knowledge at stake, and to act in order to solve specific problems encountered in science activities. In this perspective, students' attitude while doing science is a fundamental criterion. Students have to be motivated and involved in the learning process. But this involvement and this motivation (as presumably reached in serious games, §*3.1*) are only a part of students' attitude. Students have to be responsible to knowledge; they have to accept to commit themselves in the pursuit of knowledge, in a devolution process (Brousseau, 1997). Inquiry is no longer inquiry if it does not enable inquirers to better understand and practice science.

Part 2
Central projects and synthesis texts

In this section we present a detailed view on some articles that we consider as central in the literature about ICT and IBST. The first of them concerns the WISE project, which holds a specific role in the reflection about the link between ICT and IBST. The second and third articles are synthesis texts about this theme.

WISE design for knowledge integration (Linn *et al.*, 2003)

WISE[2] is an online resource for science teaching, developed at the University of California at Berkeley. WISE stands for Web-based Inquiry Science Environment; the aim of WISE is precisely to foster inquiry in class, offering the support of appropriate web-based resources. It is widely used in science classes, in several countries (WISE resources intervene in a large amount of the papers cited in this review). This is an important feature of the WISE project, in this field where scaling-up often appears as the major challenge for teaching materials issued from research

From a student perspective, WISE proposes inquiry tasks, and diverse sorts of tools and scaffolding to complete these tasks. The inquiry tasks are decomposed in WISE in several steps, composing an "inquiry map". The students must answer intermediate questions; they can take notes, access hints, and sometimes tools for visualisation or simulation.

From a teacher perspective, WISE is a flexible tool, permitting customization. Every teacher with an Internet access can immediately be inscribed on WISE. The inscription provides access to all the WISE projects. Moreover, a teacher inscribed on WISE has her own reserved space, for the projects she selects. She can also add her own content. The teacher can inscribe her students, propose individualized contents and follow with WISE the students work.

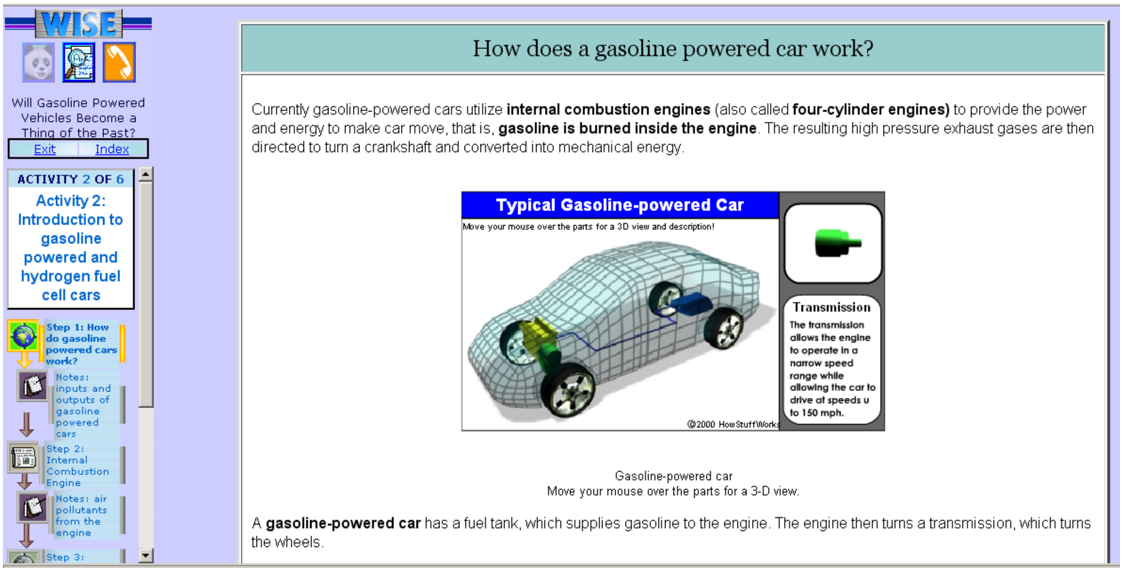

Figure 2 Example of a WISE project: Will Gasoline Powered Vehicles Become a Thing of the Past?

[2] http://wise.berkely.edu

The central principle in WISE is the choice of “knowledge integration”. In a WISE project, students always start by expressing their knowledge and opinions; the path proposed by the environment should build on this knowledge to lead the students to the expert models and concepts.

One of the main originalities in WISE is the associated design process. The WISE inquiry projects are collaboratively designed by teachers, educational researchers, scientists and curriculum designers. This collective design process permits to broadcast the educational research results, about inquiry-based teaching. The work benefits from the researchers’ experience and at the same time from the teachers classroom experience. The WISE projects are tested in class; preliminary versions are revised before they are published on the Web site, in a design-in-use principle (Rabardel & Bourmaud, 2003).

VITEN[3], the online resource designed by the Oslo University partners of the Mind the Gap project, follows principles similar to WISE, and complements these principles by adding in particular visualization tools.

Issues in computer supported inquiry learning in science (Van Joolingen *et al.* 2007)

This text introduces a special issue of JCAL, dedicated to ICT for inquiry science learning. It is indeed focused on learning, although the need for teacher scaffolding is mentioned; the special journal issue, and this text, examine the changes brought by computers for inquiry based science learning. Most of these changes are directed towards enhancement of inquiry permitted by ICT, but difficulties are also quoted by the authors (the articles of this special issue are mentioned in part *3.1*).

For the authors, an inquiry-based teaching must offer students « environments and tasks that allow them to carry out the processes of science: orientation, stating hypotheses, experimentation, creating models and theories, and evaluation » (p.111), in order to bring « students in contact with the scientific way of working ». The similarity with the authentic scientific work is central in these authors' perspective. They consider that the learning processes, in such a teaching, follow the « inquiry cycle », characterizing the researcher activity: « orientation, hypothesis generation, experimentation, conclusion, evaluation » (p.112). This stance shapes the possible interventions of the computer. Its central role is to permit the design of manageable inquiry tasks, and to scaffold students in their inquiry, reducing the complexity of the real research situations.

The authors distinguish four such possible interventions of the computer, and associated digital material: simulation, visualization, collaboration and modelling.

For all these interventions, the aim is to scaffold the learning process (with two kinds of possible effects: better learning, and higher knowledge), and thus to influence the inquiry cycle. This leads to dedicate a specific attention to cognitive tools: templates, concept maps, steps to follow…This also leads to be cautious about the possible additional tasks brought by the computer, and to the balance between compulsory and optional scaffolding. More generally, the authors emphasize the importance of learning conditions. Some of these

[3] http://www.viten.no/

conditions depend on the students. In particular, prior knowledge (content knowledge, or more transversal inquiry knowledge) plays a significant role in students learning processes. Cognitive tools can be used to set up diagnosis and summary of this prior knowledge, in order to propose adapted scaffolding afterwards. Other conditions are external to the students; in particular, the role of the teacher, and more generally the working environment.

We retain here the distinctions between the four possible roles for technology: simulation, visualization, collaboration and modelling. These roles appear as complementary; they can be considered as categories, for a taxonomy of technological resources. They can also be viewed as necessary features, in particular for online resources aiming at a comprehensive scaffolding of inquiry-based science teaching and learning. We also retain the delicate issue of the balance between a completely optional scaffolding and strictly guided learning paths, which also appear as a challenge for resources designers.

Technology-enhanced inquiry tools in science education: an emerging pedagogical framework for classroom practice (Kim *et al.* 2007)

This work is a key paper for our study: it proposes indeed a review of the literature about ICT and IBST. Our choice of questions and articles for the rest of this review is therefore orientated towards completing the work of Kim *et al.*, by investigating further issues they mention as important, and incorporating more recent research.

This text presents also a framework for teaching and learning in technology-enhanced, inquiry-based science classes. The design of this framework leans on a literature review aiming to "examine the findings and implications of research on science inquiry tools on classroom teaching and learning practices" (p. 1010).

The starting point of the authors' study is the recognized difficulty of implementing inquiry-based activities in the science classroom. This difficulty seems to increase significantly when technology is used to support inquiry. However, institutional policies and standards and the multiplicity of tools available nowadays plead for the use of technology to facilitate scientific inquiry.

The authors identify, in their literature review, three assertions advocating the use of technology-enhanced tools to foster student learning: "(1) tools supports mindful investigation of driving questions, (2) tools serve as metacognitive scaffolds for building and revising scientific understanding, and (3) tools support collaborative construction of scientific knowledge." (p.1012-1013). For these three assertions, several research works have given evidence of successful applications of technology in science classroom. But contradictory findings have also been proved. For example, concerning assertion (2), a research study has demonstrated that low-performing students using *Ergomotion* don't benefit from the metacognitive guides and prompts of the software, even though it was designed to help them in their inquiries (Land & Hannafin 1997). Though, the authors emphasize the need of new research works about student learning in order to understand why the use of technology to support inquiry remains a challenge and to design substantial tools from an epistemological and didactical point of view.

For each assertion, additional research seems to be needed in the following directions:

(1) Studying "student problem-solving strategies during technology-enhanced inquiry, cognitive and social learning patterns associated with different characteristics (e.g. prior knowledge, self-regulation, and motivation)" (p.1013).

(2) Exploring the many factors which influence technology-enhanced inquiry implementation in everyday science classroom in order to understand why some students succeed in using tools and metacognitive scaffolds embedded in them "as cognitive aids to attend to their scientific investigations, whereas other students don't". (p. 1014).

(3) Clarifying "how students collaboratively build and revise their understanding with the assistance from diverse type of scaffolding". (p. 1015).

The literature review also focuses on teaching practices; it explores the question of the use of technology-enhanced inquiry tools in science classroom. As we will see in part *3.2* of this report, for a long time, teachers' roles and knowledge were often a blind point of research works. Since, studies have considered the specificity of the teacher's role in inquiry-based classes compared with more traditional classes and the influence of teacher scientific knowledge and professional experience upon the quality and frequency of inquiry-based activities. As for teacher roles, Crawford (2000) identifies that teachers have to play a diversity of roles (motivator, diagnostician, guide, innovator, experimenter, researcher, modeller, mentor, collaborator, and learner) to be a successful teacher, promoting inquiry-based classes' activities.

About teacher knowledge, it has been proven that a weak scientific culture and an absence of experience "seriously limit the quality and frequency of inquiry-based classroom activities". (p. 1016). There is a real need of designing collaborative professional development programs. This point will be exposed in part *3.3* of this report.

Concerning teacher practices, the authors insist on the fact that very few research works about inquiry-based science teaching study "teacher's role in implementing and supporting technology-enhanced tools in the classroom" (p. 1016). They mention that even though teachers may be provided with well-designed inquiry tools, they may use them in a way that differs form designers' intentions. Research is still needed to examine the consequences of integrating technology into inquiry-based science teaching.

From these observations, the authors propose a framework for teaching and learning with inquiry tools, aiming at embracing everyday classroom settings. Their framework "assumes that knowledge is socially constructed, that learning occurs in the process of becoming a member of communities of practice, and that language and tools play central roles in collaborative knowledge building." (p.1018).

They structure their framework into three imbricate levels, as presented below (figure 3): the macro level (the systemic level, reform and standards), the teacher level (teacher community), and the classroom level (technology-supported inquiry class).

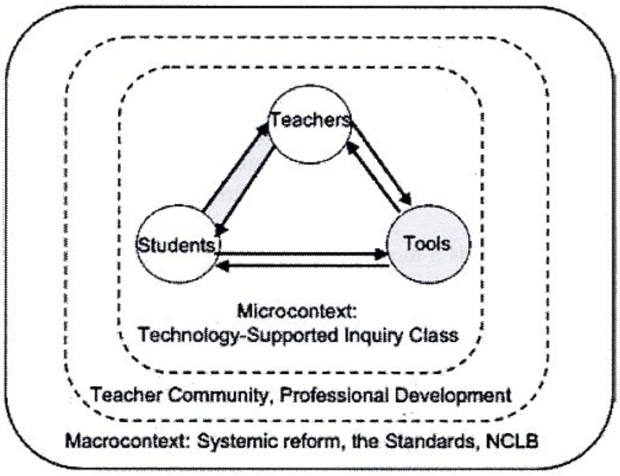

Figure 3. The pedagogical framework (ideal), as proposed by Kim *et al.* (2007)

Macrocontexts promote inquiry-based activities in science classroom. This partially shapes teachers' professional development offer and so, influences the microcontext. It has been proven that sharing scientific and didactical knowledge between teachers is an effective way for changing teachers' practices. Acting on the development of teachers' communities seems to be necessary to support inquiry-based science teaching in classroom. Finally, taking into account student-tool interactions, teacher-student interactions and teacher-tool interaction is central as this microcontext is where students construct their knowledge with inquiry tools, teachers and peers.

We retain this theoretical framework as a productive guide to analyze the role of technology in inquiry-based science teaching, even though, in science education reality, the alignment of the three levels is not so ideal. For example, "the microcontext is influenced not only by teacher community, but also by other factors, such as school culture, parents, and students' values and characteristics." (p.1025).

Part 3
ICT and IBST: learning, teaching, developing professional knowledge

This part is divided into three sub-parts, each of these dedicated to one of the interconnected subjects evoked in the title. How does ICT affect the students, the teachers' practice of inquiry in class? How are they leveraged by teachers, by teacher trainers to enhance IBST?

3.1 ICT, inquiry, and students' learning in science

The effects on students' learning of inquiry-based teaching have been considered by a host of research works. In our review, two specific themes related with this student-centred perspective have emerged as prominent: the collective learning of science; and the learning using virtual environments. We detail below each of these topics.

ICT, inquiry, and collective learning in sciences.

Computer Supported Collaborative Learning (Dillenbourg & Fischer, 2007, Stahl *et al.*, 2006) is now a well developed research domain; within this domain, IBST has been considered by many authors. Naturally, many questions on this topic remain open, as noted by Kim *et al.* (§2, 2007). We fully agree with these remarks; however, they do not seem directly connected with inquiry-based learning. Our focus led us more to consider, in the literature, how technology can enhance collective processes for IBST. We noticed three different directions for this enhancement, which we present below with a role for technology of increasing importance for collective inquiry.

- In a first direction, students collectively work with ICT in inquiry-based sessions. The same ICT tool could be used individually; but the teacher, or the researchers, decided to organize group work. In this case, most of the time the choice of this collective organization aims at fostering argumentation, recognized as an important part of scientific inquiry. Ergazaki *et al.* (2007) use this way modelling software in biology; Kearney (2004) organizes tasks for small groups with a multimedia tool permitting to predict, observe, and explain in physics; Russell *et al.* (2003) observe and analyze similar processes in kinematics etc. In all these cases, the authors observe the collective building of new understandings. In biology, these new understanding seems to be often linked with the creation of structured categories, and the affectation of a given object to one category: a student can propose categories, and objects belonging to these categories to a partner, present or not, they can then discuss the model proposed, supported by ICT simulation (this is for example central in several inquiry-based teaching device organized with BGuILE, a classification tool for biology Reiser *et al.*, 2001). In physics, the emphasis seems to be more on evolving from previous knowledge, grounded in empirical experience, to scientific concepts and models. Confronting their previous knowledge can lead students to conflicts, necessities of debates, which can be scaffolded by simulation or modelling tools. In all these cases, as acknowledged in CSCL, "what matters is the effort required to construct shared knowledge" (Dillenbourg & Fischer, 2007); and ICT tool intervenes as providing arguments.

- In a second category of articles, ICT (mostly Internet in this case) is used as a networking tool, permitting students to communicate. The view on IBST is not very different from the previous case: what matters is argumentation, discussion, in order to build shared knowledge. Anderson (2003) presents a project, about salted lakes and their evolution, comprising a collaborative work associating Israeli and Jordanian students, exchanging via Internet. Often online forums are used for discussion (Zion, 2008, Clark & Sampson, 2008); they permit distant exchanges, between pupils in different places (they also permit communication with scientists, but we do not discuss this issue here). Naturally, the corresponding studies, exploiting the data provided by written exchanges, are focused on argumentation. However, online forums alone do not guarantee the development of real argumentation; moreover not all forums share the same technical features. Clark & Sampson (2008) list functionalities of forums supporting students' argumentation:

- ✓ asynchronous and synchronous collaborative communication interfaces
- ✓ co-creation and sharing of intellectual artifacts
- ✓ enriched access to information

- ✓ collaboration scripting functionalities
- ✓ awareness heightening tools

They note that not all online environments designed to foster dialogic argumentation incorporate all of these features. Moreover, this work as others focusing on forums stresses the importance of monitoring, when such devices are used. Connecting students, even with very sophisticated ICT device, is not enough to foster learning. The teacher (§ *3.2*) is essential to monitor communication: avoid long discussions on purposeless issues, foster exchanges directed towards conceptualization etc. This observation matches the recent evolutions in the CSCL research, oriented towards a new focus on the teacher's interventions (Dillenbourg *et al.* 2009).

- A last kind of articulations between ICT, inquiry, and collective learning concerns ICT tools which require collaboration. This is often the case for handheld devices, when students go with such a device on the field, while others receive at school the data collected, simultaneously or later (Dunleavy *et al.,* 2008, Sanchez, 2008). The development of such portable devices is a major issue in CSCL (Pea & Maldonaldo, 2006, Laru & Järvelä, 2008). Other kinds of ICT are also designed to foster collective processes in inquiry. In VITEN[3], for some topics debates are planned, and scaffolded by the online resource: specific roles are attributed to pupils, who can look for arguments within the resource or via Internet. As mentioned before, the communication between students has to be regulated; in this case, the online resource comprises features for this regulation (Jorde & Mork, 2007). Some ICT tools also permit collective display of students productions. In this case, small groups' work often alternate with whole-class discussion. Hegedus *et al.* (2009) organize such activities in mathematics, in classes networked by SimCalc MathWorlds®. SimCalc MathWorlds® creates an environment where students can work on functions: testing algebraic expressions, representing them etc. These functions can be created on individual calculators, and then displayed for all the class, gathering several propositions, from different students. It permits comparisons and debates. Naturally, for such a sophisticated material, the challenge is on up-scaling its use, reaching ordinary classrooms.

There is still much work to be done, in research but also in the design of ICT environments with appropriate features to foster inquiry in science classes. This is one of the objectives of the SCY project (Science Created by You, Anjewierden *et al.* 2009).

Virtual environments and inquiry-based learning

Many ICT resources propose virtual environments for science learning. Simulation tools are essential for the study of phenomena which could not be grasped otherwise in class. This can be linked with size reasons, in molecular genetics (Marbach, Rotbain & Stavy 2008; see also the dynamic representations in VITEN), but also in astronomy (McDermott, 1996, Yair 2003). It can also result from time economy reasons: for example, studying the moon phases is possible without simulations, but it requires a great amount of time (Bell & Trundle 2008). Virtual environments offer faster changing variables, and adaptation to dynamic processes. What happens though, when physical material is available as well? Is it still advantageous to use virtual environments, when the real, physical situation is at hands, without any size, time, cost or even ethical problem? A classical definition of IBST (§ 1) includes a “hands-on” dimension. Using virtual environments can lead to raise as Klahr *et al.* (2007) the question: “hands on what?”

In an experimental study on physics, movement and forces, these authors engaged seventh and eighth grade children in an engineering design task in which they created and tested a series of ‘‘mousetrap cars’’. They show that instructional medium—virtual or physical—had no effect on students' ability to learn from their own hands-on attempts to discover the causal factors in the distance travelled by mousetrap cars. Students were able to increase their knowledge and confidence equally well even when they spent significantly less time on the task (which occurs in the virtual set number of cars condition). Students in the virtual condition can run many more cars in a fixed amount of time than can children in the physical condition. Instructional medium—virtual or physical—had no effect on students’ ability to learn from their own hands-on attempts to discover the causal factors in the distance travelled by mousetrap cars. They were able to increase their knowledge and confidence equally well even when they spent significantly less time on the task (which occurs in the virtual environment). Similar results are observed by other authors (Zacharia & al., 2008). It seems in fact that working in virtual environments, in many cases does not represent a loss. It permits in particular to repeat experiences many times if necessary.

A recent evolution in the literature about virtual environments is the raising interest for serious games (see Barab & Dede, 2007, introducing a special issue of JSET dedicated to such environments). Studies in cognitive sciences indicate that such games can have a positive impact on the integration of information and on the structuring of knowledge (Lennon & Coombs, 2006, Purutshoma 2005). Supporters of serious games emphasize their impact on student’s motivation and engagement (Sauve *et al.*, 2009). Students' engagement is certainly central for inquiry; however, engagement enough is not sufficient to guarantee learning. This engagement must be strongly related with the knowledge at stake. What matters is not only students' motivation, but their involvement in the scientific content. About this central issue, the research remains cautious. Dunleavy *et al.* (2009) study an experiment in school of a simulation game, called “Alien contact”. A school is equipped with a set of laptops, and individual GPS for each student. The software simulates an Alien invasion. The students must look for clues in the school yard; on the laptop this yard appears as a field were the Aliens have landed, and the students are represented by points identifying their positions. The students are organized in teams of four pupils, each with an assigned role. They receive information on their GPS, about the way to analyze a clue they found (i.e. measuring an Alien wing), or just puzzles to solve, in order to win the right to receive a new clue. The result of the experiment is balanced: while the expected effect (engagement of the students) is recorded, the authors also signal a range of unexpected difficulties. In particular, the students, very involved in the competition, sometimes skipped interesting information by rushing for the next clue. Serious games call for specific interventions of the teacher to shape and regulate the students' interactions with the game, and to orient these towards the building of knowledge.

Another critical issue is linked with the way knowledge is presented in the game. Sometimes the games designers want to avoid a disheartening complexity, and propose simplified models. For example Spore, a serious game about biological evolution, proposes a very simplified evolution model (Sanchez & Prieur, 2009). The children playing with Spore design their own creatures, and make them evolve. But the available “species features” remain limited; moreover, there is no random aspect in the evolution process, it only depends from the player decision. Some elements (competition between species, meteorite fall) can slow down the evolution, but there is no proper selection etc. Up to now, many serious games have not been initially designed for teaching purposes. Using them at school is certainly engaging for students, connecting the school environment with their private domains of interest; but it raises important epistemic problems. Designing serious games with a real epistemic value remains a challenge.

Equity issues

Working with ICT in science naturally leads to raise the question of equity between boys and girls. It is well know that girls show less interest for science at school than boys; IBST can be seen as “beneficial to promoting girls’ interest and participation in science activities” (Rocard *et al.*, 2007), but is the use of ICT appropriate, or does it constitute an additional obstacle? Girls' lack of interest for ICT is may be worse than for science, according to several authors (Voogt, 1987, Anderson *et al.*, 2008). Does it lead to discard the use of ICT to foster IBST, in the case of girls?

Surprisingly, the authors who consider this issue do not record significant differences, except perhaps on confidence (Klahr *et al.* 2007). Nelson (2007) even observes that girls outperform boys while working with an inquiry guidance system on a platform; these girls were enthusiastic for this kind of work.

This may be linked with another, more general issue. ICT in class generally favours computer-literate students. Students more familiar with computers are more confident, encounter less technical difficulties etc. This can even lead to a *digital divide* (Murdock 2002) between students having access to computers at home and the others. Wecker *et al.* (2007), studying how students learn in an IBST teaching (more precisely a WISE program about light for grade 12) according to their level of computer literacy, state results that can seem surprising, and are opposed to the ideas evoked above. Students who have a high familiarity with computers learn less than others! Searching for the explanations of this strange phenomenon, the authors observed that these students, moving very quickly from one WISE resource to another, do not spend enough time on each resource to really read its content. Their technological ability permits them to go fast; they guess the path to follow, but do not develop a real understanding. This is a general problem linked with web resources: the obstacle of browsing, inducing a superficial relationship with the resource, attached to surface feature independent from the scientific content.

In fact the digital divide, and related gender equity issues are strongly linked with the kind of ICT involved. Girls are reluctant for very technical ICT aspects: programming, using uninviting software. They are keener on working with Internet, and naturally also with the “ubiquitous technologies”: cell phones, digital cameras etc. Since such technologies are now central in many inquiry teaching involving IBST, they can contribute to engage girls in this inquiry.

Naturally, equity difficulties remain, in particular for visually impaired students: the virtual environments are grounded on visualisation. While research addresses for several years the issue of access to online resources for visually impaired people (Brophy & Craven 2002), virtual learning environments in science have not yet solved this problem.

3.2 ICT, inquiry, and teaching practices

As Kim *et al.* (2007) indicate, many studies have emphasized the difficulty of facilitating the implementation of inquiry-based activities in science classroom. The current development of technologies is viewed as a way of supporting inquiry-based science teaching in classroom (Kubicek, 2005), because:

- ✓ Teachers seem to be better equipped to act as guide and facilitator, focusing on supporting students during the inquiry process,
- ✓ Teachers have access to a wide variety of resources, through the Web for example,
- ✓ Teachers can help students to enter in a modelling process thanks to simulations tools (Thomas, 2001, Miller, 2001),
- ✓ Internet can facilitate communication between teachers, students and scientists.

Scaling-up successful IBST practices thanks to ICT seems promising, but all the studies considered in this literature review stress the challenge, for teachers, to employ technologies to support students' inquiries. For example, Wallace (2002) explores the experience of one teacher as she uses the Internet (for a radioactivity course with eleven graders) on her own as a tool for changing her practice. Wallace's conclusion is that even if the teacher was motivated and convinced of the benefit of using ICT to support IBST, getting students engaged in classroom activities with Internet was not synonymous with providing them with opportunities to learn science. Indeed, creating such a chemistry course is a complex and challenging work, requiring extensive subject matter knowledge, careful planning, and considerable time.

This part is structured in three themes, discussed more or less in detail in all the articles: (1) constraints to the utilisation of technology in inquiry-based science classes, (2) ICT, IBST and teachers' knowledge, and (3) the importance of resources' design.

Constraints to the utilisation of technology in inquiry-based science classes

Many articles examined in our review present case study: researchers develop an inquiry-based curriculum integrating technology and test it in one or several classrooms. A recurrent question is how provide teachers with flexible and secure resources supporting repeatable and scalable inquiry-based activities with technology in everyday contexts (Underwood *et al.*, 2008, Wu *et al.*, 2009).

Everyday classroom contexts set constraints limiting teachers' will of using technology. For example, integrating new tools in one's practice requires a great amount of time and teachers often blame technology to be time consuming (Underwood *et al.*, 2008, Kim *et al.* 2007, Anderson & Helms, 2001). Moreover, schools' computers and communication infrastructures are still low or sometimes inadequate (Dori *et al.*, 2002). Sometimes, standards visions are contradictory with the school districts expectations (Kim et. al, 2007). Others studies indicate the difficulty of finding well-designed resources and "educative curriculum materials" (Davis & Krajcik, 2005, p.3). Finally, all the studies point out that the lack of knowledge of teachers (pre-service and in-service) explains why using technology to support inquiry in science classroom remains a challenge (this theme will be discussed in the following paragraph).

We note that even though most of the researches concerning teaching practice consider that these constraints restrain the use of technology, very few of them propose a framework organising them, in order to explore and improve the integration of technology in science classroom. Kim *et al.* (2007) framework is structured from a generic to a specific level (see part 2.) and has been specifically built to take into account the role of technology into science classes.

Other frameworks exist within the ICT-related literature; they have mostly been applied in mathematics, but seem relevant for science as well.

Firstly, in the anthropological approach to didactics developed by Chevallard (2002), teachers' choices are analysed within an institutional system of conditions and constraints, ranging from a generic level to a specific level (regarding the subject matter). The teachers' practices are shaped by these constraints, which also influence the structure of the curriculum material and of online resources in particular (Bueno-Ravel & Gueudet, 2009, p. 4).

A second classification is proposed by Ruthven (2007), who organises the constraints according to "the structuring context of the classroom practice", which comprises five key structuring features of the classroom practice with ICT: Working environment, Resource system, Activity format, Curriculum script (a "loosely ordered model of relevant goals and actions which serves to guide the teaching of a topic") and Time economy.

We consider that these frameworks are necessary to analyse teaching practices with technology and to develop new resources for teachers. More researches are needed on this subject if we want to guarantee the viability of the use of technology to support inquiry in science education.

ICT, IBST, and teachers' knowledge.

Different types of knowledge are involved when integrating technology in inquiry-based science classroom and usually, studies point out teachers' lack of knowledge: scientific knowledge (Zion, 2008, Kubicek, 2005, Kim *et al.*, 2007), pedagogical and didactical knowledge (Trumbull *et al.* 2005, Zion 2008, Kubicek, 2005, Kim *et al.*, 2007), and, technological knowledge (Underwood *et al.* 2008, Zion 2008, Moss, 2003, Kim *et al.*, 2007).

We will take two examples to illustrate this theme and show how technology can improve teachers' knowledge.

Underwood *et al.* (2008) study aims at developing a sustainable way of scaling-up e-science projects in classroom. For now, the authors are conscious that setting up such projects in class requires too much technical skills for teachers. According to them, resources' designers should offer most of the technical guidance needed. "Clearly the services and users of tools (…) need to know, or be able to find out about the resources available to an educational e-Science community in order to efficiently manage interactions between these. For example, a service employed by a teacher to find a science expert able to answer a class's questions about space travel in alive conference amongst other things needs to know: who knows about space travel, their availability, the possible time slots for a video conference, the communication channels available at both ends, the time zone at both ends, and the languages spoken by participants." (Underwood *et al.*, 2008, p. 541).

Zion (2008) focuses on the contribution of technology to develop scientific and didactical skills for teachers. He analyses the teachers' forum of the Biomind program which is an open inquiry program for Israeli biology high school students. The results obtained indicate that teachers use this forum to seek for assistance, on the one hand, regarding scientific knowledge and on the other hand about the way to support students' inquiry process (didactical knowledge). By means of this forum, teachers also exchange about the way to interact with students in an open inquiry learning. A quotation of a teacher enlightens this need for scientific and didactical knowledge: "Hardest of all is to facilitate students in finding a subject and phrasing inquiry questions. It demands very extensive expertise and knowledge of biological phenomenon on the teacher's part… and I fear we'll start to recycle subjects within a few years." (p. 362-363).

Through these examples, we want to emphasize that:

- ✓ Well-designed technology tools can help to teachers to update their scientific and didactical knowledge;
- ✓ There is a need for collaborative work between teachers and between teachers, scientists and resources designers, thanks to synchronous and synchronous network technology, to scale up the use of ICT in inquiry science classes (§ *3.3*).

Besides, concerning teachers' didactical knowledge, studies show that teachers, during inquiry activities, need to adopt roles that are not the roles they usually play in traditional lecture or exploratory classes (Kim *et al.*, 2008). Indeed, Crawford (2000) has identified ten roles a teacher has to play to be successful in setting up inquiry in her science classroom: motivator, diagnostician, guide, innovator, experimenter, researcher, modeller, mentor, collaborator, and learner. But most of the researches of this review focus on teachers' central roles which are facilitator and guide, roles considered as crucial to the success of students learning through inquiry (Ng & Gunstone, 2002, Kubicek, 2005). Pre service and in service teachers' training should take this point into account. Furthermore, Zion's (2008) and Kim *et al.* (2008) work indicate that this training should be collaborative. Research is needed to analyse in great details teachers' roles in technology supporting inquiry activities and to develop and analyse teachers' means of collaboration.

The design of resources: a crucial issue

In the literature review, most of the studies analyse resources (technological tools or more generally curriculum material) that have been designed by researchers (Trumbull *et al.*, 2005, Reid-Grifin & Carter, 2008, Underwood *et al.*, 2008, Moss, 2003). But according to Kim *et al.*, several authors have proven that "enactments for inquiry are more successful when teachers actively participate in the designing inquiry-oriented curricula, implementing innovations, and reflecting collaboratively on their beliefs and practices" (p.1015).

This result is not surprising. Indeed, when a teacher decides to use technology in her science classroom to set up inquiry activities, she needs first to select a resource and then, to design a scenario (Trouche, 2004, Bueno-Ravel & Gueudet, 2007) of her course. Very few researches propose frameworks for the design of a course integrating technology to support students' inquiry process.

Reid-Griffin and Carter (2008) have developed a course scaffolding model in order to design a course introducing and facilitating students' use of data analysis system to answered student-selected research question. This model comprises three phases, aiming at allowing "students to engage in social exchange and exploration (and expansion) of ideas as they go through personal maturation and cognitive growth." (p.335): Phase I: introductory activities, teacher directed, Phase II: transition activities, teacher/student directed, and, Phase III, Inquiry, investigation, student directed. The progression through these three phases is valuable in so far as it takes into account students' instrumental genesis (Rabardel, 1995).

Edelson (2001) proposes the Learning-for-Use (LfU) model, "a design framework that was developed to support the design of learning activities that achieve both content and process learning." (p. 356). This model is tested to design the Create-a-Word Project, in which students engage in open-ended Earth science investigations using technology (a geographic visualization and data analysis environment for learners: WorldWatcher). It is also organised in three steps: Motivate, Construct and, Refine.

But these two frameworks are research models. We think that it can be useful to teachers to be provided with guidelines helping them to design by themselves their scenario. Research addressing the theme is needed. Moreover, such guidelines could also be helpful to educational technological tools designers as they have to take into account didactical constraint to design these tools.

Other topical questions concerning resources' design should be discussed by research: (1) many technologies have been developed to support inquiry in school. How "new" technologies can be efficiently articulated to "old" resources (experiences, paper resources etc.)? (2) How to design technological resources integrating guiding and scaffolding for teachers, providing them with teaching resources and training opportunities? (3) As research has proven that participation in long-term collaborative projects foster changes about teachers' practices concerning the use of technology to support inquiry in science classroom (Dori *et al.*, 2002), how taking into account collaborative aspects and long-term professional development in the design of the resources?

3.3 Inquiry in science teaching, ICT and teacher training

Inquiry in science teaching, ICT and teacher training can articulate in several manners. Inquiry and ICT can be used with the aim to train science teachers: in this case inquiry and ICT appear as training tools. But integrating ICT for IBST can also be the aim of a given training, or ICT can be used as a tool in a training dedicated to develop teachers craft knowledge in IBST etc. Since training science teachers to implement IBST in their classes is a major issue, we will focus here on research works considering this issue, and using ICT as a training tool.

This choice does not, in fact, prevent us to embrace the literature about the other categories mentioned above. Indeed most of the training devices studied are grounded on inquiry principles themselves; and in the training devices aiming at ICT integration, ICT always also intervenes as a tool. We consider here both pre-service and in-service teacher training.

Which kinds of ICT tools for science teachers training?

Similarly to what we noticed for students, various kinds of technologies are used in teacher training programs, with an increasing amount of online resources. Within the Mind the Gap project, the PEGASE[4] web site, jointly elaborated by teachers and researchers, proposes resources both for teaching and for teacher training in physics. Lessons are proposed for the teachers, with details on their organization in class; analysis of the aims, of the knowledge involved, but also examples of students' behaviours. Alongside these resources, in strong connection detailed didactical and epistemological analyses are proposed, in a part of the website devoted to teacher training. This association of resources for teaching and training is not frequent; most articles we will evoke here focus on teacher training, and do not address teaching issues.

Angeli (2005) develops a specific model of teacher training, aiming at the development of teachers' ability for*:*

- ✓ selecting appropriate science topics to be taught with technology
- ✓ using appropriate technology-supported representations
- ✓ using technology to support teaching strategies
- ✓ integrating computers with inquiry-based pedagogy.

Two different kinds of technologies are used in the corresponding method course, with two groups of teachers: multimedia authoring software, and modelling software. Evaluating the training impact, and comparing the "multimedia" and the "modelling" groups, the author shows that the second ("modelling") outperformed the first ("multimedia") for the three last aims cited above, and in particular for the inquiry dimension. In fact the multimedia group was more oriented to show pictures, they missed the multimedia possibilities and used it to support traditional teaching. This danger attached to the use of multimedia can be connected with the difficulties noticed with students (§ *3.1*, Wecker *et al.*, 2007): the teacher shows, the students surf the Internet, both activities seem to remain superficial: they have a low epistemic value (§ 1), and can not be considered as inquiry-based.

This naturally does not mean that multimedia must be avoided, but that the teachers and teacher trainers must be aware of these difficulties, and develop adequate uses of multimedia to avoid the identified problems. For example, *multimedia case studies* seems an efficient form of teacher training (Benzce *et al.* 2001, 2009; McGraw *et al.* 2007). Multimedia case methods can represent teaching and learning situations in schools; they are certainly not real school situations, but they permit to study such situations within a training course at university. With an appropriate implementation, they can lead student-teachers to reflect on their action as teachers, with enough time to take their decisions, and possible support by the trainers. Finally, the trainers gain this way opportunity to make the students initial conceptions about science teaching evolve towards more inquiry.

In this last example, student-teachers work together on the multimedia cases. This collective aspect is central in all the literature about teacher training, inquiry in science teaching and

[4] http://xen-web.inrp.fr/pegase-en/index.php

ICT. Several ICT tools are used to permit, or foster, collective teachers (in-service or pre-service) work.

ICT and collaborative dimensions in teacher training

Collaborative work, collaborative design of lessons in particular, is recognized as an efficient means for training pre- or in-service teachers. For example, Fugelstadt (2007) organizes and studies *communities of inquiry*, composed by secondary school mathematics teachers, in order to foster ICT integration. Communities of inquiry are communities of practice (Wenger 1998), where the participants, within the community, critically test ideas, develop new ideas and meanings. Fugelstadt presents the example of spreadsheet use in class. The community of teachers builds a lesson, implements it, revises it... In this case a group of teachers, in a same school, works together in order to integrate a given software, being physically present at the same place. This is not the most frequent intervention of ICT for collective teacher training: in the literature, ICT often appears as offering networking possibilities for teachers, and permitting to develop distant or blended.

Electronic forums are used to develop pre-service teachers' reflective dialogues (Ebenezer *et al.* 2003, Kuster & Lameul 2008). They can provide appropriate conditions for the development of communities of teachers, or even of communities of teachers and students (Zion 2008), permitting the teacher to support inquiry, and at the same time to reflect about the implementation of inquiry in class. Networking is generally used to foster a reflexive attitude. It has to be associated with specific training scenarios; one of the contributions of the literature studied in this section is to propose such scenarios. An original possibility is described and studied by Tsai *et al.* (2002), who use a networked peer assessment system with pre-service teachers. The corresponding training is directed towards the development of inquiry-oriented activities. The students build such activities; the peer assessment system appears as efficient for the improvement of the inquiry aspects. It seems easier for the students to revise their initial propositions when the suggestions and critics are formulated by peers. Proposing an original mode of assessment seems limited to pre-service teachers training. However, several professional development programs for in-service teachers use collective reflexive thinking as a means for changing teachers' practices. In Germany, this is a central aspect of the SINUS transfer program (Prenzel & Duit, 2000), and of the Intel© Lehren program (Philipps 2007). This last program aims at fostering the integration of ICT in class, trough collective design of lessons. In France, the same program is called Pairform@nce. It proposes blended teacher training, and uses a distant platform (Gueudet & Trouche 2008b). Although Pairform@nce aims to build in-service teachers inquiry communities; it is not always directed towards IBST, the central aim being the integration of ICT tools. However, some of the Pairform@nce training paths in experimental sciences and in mathematics are clearly inquiry-oriented. For example, the "virtual globes path" proposes to use virtual globes in class for an inquiry-based teaching of earth sciences (Genevois & Jouneau-Sion, 2008, Sanchez, 2009). Teams of in-service teachers, supported by a trainer, design a classroom session integrating virtual globes. The appropriation of the technical possibilities offered by virtual globes is associated with a reflection about their integration in class. At the beginning of the training, trainees tend to offer a strong guidance to the students. They evolve towards more open activities: for example, a use of virtual globes associated with outdoor activities. The field activities are prepared in class, using the virtual globe and a specific software (like Trackmaker©); on the field, the actual path is recorded with a GPS, and automatically transferred in the virtual globe by Trackmaker©, then it can be exploited for analysis in class.

Collaborative training can involve a variety of agents, apart from the trainees. The networking possibilities permit to build hybrid communities. We already evoked above communities of teachers and students (Zion, 2008). In Crippen *et al.* (2004), in-service secondary science teachers work with academics. In this program, the improvement of content knowledge is central, and achieved through a collective work of teachers and academics. Several ICT tools are used, with a mobile laboratory. The central tools are curriculum carts, used as cognitive tools, to make thinking explicit. Another very original mode of collaboration is proposed by Gengarelly and Abrams (2009), who associate science teachers and science graduate students in pairs for a long-term work, over one academic year. This research, centred on IBST but not on ICT, indicates nevertheless an interesting mode of collaboration, which could be fostered by networking tools. It also describes the case of a teacher, convinced to implement inquiry because she introduced a new material in class. In fact the lesson she proposed corresponded to the lowest level of inquiry distinguished by the authors ("confirmation"); this was evidenced and reported by the graduate fellow. This indicates again the complexity of the link between ICT and IBST, the need for a didactical reflection about the integration of ICT, and for appropriate training for teachers (Waight & Abd-El-Khalick, 2007).

Conclusion

Investigating technology-related issues is always evolving with technology. Nowadays, the main evolutions are linked with connectivity, generalized access to online resources, and even generalized possibility to design online resources.

This raises difficult questions, about the quality of these resources; this topic is studied within Mind the Gap, a part of our work is dedicated to guidelines, and criteria for analysing the IBST quality of an online resource (deliverable 5.2). The literature review presented above has grounded the choice of quality criteria, which are proposed as initial criteria, which will evolve along their application to different resources, their experimentation by resources users etc. We will not detail here these criteria; we only want to emphasize a few important aspects.

A resource proposing scientific content can always be used in class on several manners, of unequal efficiency. In particular, students can work with digital resources without writing a single word on a paper. Language has a specific importance in IBST; within language, written language plays a specific role, for the organization of ideas, the preparation of a structured argumentation etc. Thus scenarios for class use should be proposed alongside resources, and these scenarios should include written work, articulated with the work on the computer.

Another central aspect concerns the evolution of the design modes, together with the evolution of the technological possibilities. Designing high-quality resources is an important issue; but ensuring that these resources will be used in class is important as well. The resources elaborated by teachers often miss the epistemological and didactical quality of the resources elaborated by educational researchers; but some of these are widely used in class. It seems thus crucial to associate teachers and researchers in the design process; more generally, to associate users to a continuous design, in a design-in-use perspective (Rabardel & Bourmaud, 2003).

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Appendix: literature review methodology

The articulation of ICT and IBST has been studied by many researchers in science education. We did not intend to propose an exhaustive review of this rich field. Our aim was more to identify the major issues addressed by research, the most recent evolutions, the challenging questions...We developed for this aim the following methodology, inspired from (Lagrange *et al.* 2001).

We started by collecting a wide range of sources. As a starting point, our set of sources comprised:

- ✓ Handbooks: the Cambridge handbook of the learning sciences (2006), and the handbook for research on science education (2007).
- ✓ Journals about educational research (general): Cognition and Instruction, The Journal of the learning sciences.
- ✓ Journals about ICT in education: Computers and Education, Journal of Computer Assisted Learning.
- ✓ Journals about science education (including ICT in science education): International Journal of Science and Mathematics Education, Journal of Research in Science Teaching, Journal of Science Education and Technology, Science Education, Science & Education.

We restricted our research over a ten year period (1998-2008).

In a second stage of our collecting work, we added various kinds of sources (books, other journals, conference proceedings, professional associations' websites etc.) found as important references in the first set of articles.

We worked simultaneously on the analysis and categorization of the collected papers. For each of the papers, we constituted a lecture note, with the following categories:

Reference of the article
Authors
Interest for ICT and IBST issues (level, between 0 – none- and 4 -essential-)
Disciplinary fields
Questions studied
Results produced
Definition of IBST
Type of ICT
Research methods
Theoretical framework
Other interesting bibliographical sources

Figure 4. Lecture note model

Using the completed lecture notes, we categorized the papers, with the question studied as the first important characteristic. Grouping the papers this way evidenced the issues considered as important by the researchers, the evolutions etc. The type of ICT is also an important criterion, strongly connected with the question(s) studied: specific questions arise with modelling tools, with virtual reality environments, with online forums etc. The structure of our review was built accordingly. On the opposite, the disciplinary field did not appear as a necessary distinction.

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