Guidelines for design of online resources for inquiry-based science teaching

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Guidelines for design of on line resources for IBST

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The description of the work planned within Work Package 5 of the Mind the Gap project mentions:

“**Deliverables 5.1 and 5.2**

Review of a selection of ICT based tools for inquiry based science teaching, followed by the development of guidelines for further development and design of ICT based tools.”

We presented in deliverable 5.1 (Gueudet *et al.* 2009) a literature review entitled “Technologies, resources and Inquiry-based science teaching”.

This deliverable 5.2 is strongly linked with 5.1: we drew on the results of the literature review to build criteria for the analysis of ICT based tools.

We expose in part 1 the overall organisation of these criteria, the way we built them from the results of the literature review, and the reasons for our focus on on line resources.

In part 2, we detail the criteria, distinguishing between on line resources for teachers and for students. We also propose a special focus on collective dimensions.

In part 3, we draw on the criteria and analyses to identify guidelines; we present in part 4 a synthesis of these guidelines.

1. Analysing the potential of an on line resource for IBST, towards criteria.

For the last twenty years, the number of available ICT tools to promote IBST has expanded highly. Teachers have at their disposal a large variety of software, data collector or data analysis tools, simulations tools, modelling tools, web sites etc. However, many research works have shown that integration of ICT to foster inquiry in classroom remains limited, despite strong institutional incitations. Many reasons are mentioned to explain this phenomenon: the difficulty to integrate ICT and inquiry in everyday teachers' practices, the lack of teachers' scientific and technological knowledge, the under equipment of schools with computers, the time needed to integrate ICT in classroom, the lack of teachers' training on ICT and IBST, the gap between expected benefits of using ICT to improve students' scientific knowledge and the effective learning, the too fast evolution and change of technological tools etc. This is a non-exhaustive list and the reasons detailed above come under different categories.

However, in spite of all the underlined difficulties to integrate ICT in classroom, and to foster IBST in particular, a new trend has appeared for the last decade. Since several years, the main evolution concerning ICT to promote IBST leads to the development of on line resources addressed to students or teachers or to both of them. Furthermore, these on line resources seem to be more easily adopted by teachers than other technological resources. Such on line resources are developed by institutions taking part in Mind the Gap: Viten, developed in Norway, and PEGASE, developed in France.

For all these reasons, we decided to focus our research on the definition of criteria to evaluate the IBST potential of technological resources and guidelines to resources designers specifically on on line resources.

Focusing on on line resources intending to promote IBST raises several kinds of questions:

- Are the IBST aspects proposed by an on line resource coherent with definitions given by researchers and institutional standards (Linn *et al.* 2003; Van Jooligen *et al.* 2007; Gengarelly & Abrams 2009; NSTA 2004)?
- The generalized access to and use of on line resources and the generalized possibility to design on line resource raise questions concerning the quality of these on line resources. On which elements teachers can rely to select an on line resource among several ones? What are the major scientific, didactical or technical features designers of on line resources promoting IBST have to take into account?

Definition of IBST

The literature review on technologies, resources and IBST we conducted in the first part of our work within the Mind the Gap Project (Deliverable 5.1, Gueudet *et al.* 2009) and more generally our work within the Mind the Gap project lead us to retain the following definition of inquiry in science classes:

Inquiry in science classes corresponds to a sharing of responsibility towards knowledge between the teacher and the students leaving important parts of responsibility to the students. Inquiry can be considered a specific mode of didactic contract (Brousseau, 1997), where in particular the students' productions are the starting point of the teacher's work.

This definition not only matches most of existent definitions of inquiry, and more particularly the characterization of IBST activities given in the Mind the Gap Project (Gueudet *et al.* 2009, p.4 and p.7), but, allows to overtake a recurrent obstacle observed when analysing inquiry sessions carried out in real classroom conditions: even though an activity seems, a priori, to fit all the criteria to foster inquiry in science classes, the implementation in class of this activity sometimes distorts it and leads to no real inquiry from a student's point of view. So this definition is helpful to identify the IBST potential of activities while keeping in mind the crucial effect of on line resources' feedback or teachers and students' interactions on the achievement of real inquiry activities.

Quality of on line resources

As Gueudet (2009) underlines it, several research studies, covering different disciplinary fields, take an interest on trying to define the quality of ICT resources. Most of the time, this research establishes criteria trying to describe this quality, from the point of view of the disciplinary field they are engaged in.

In the field of ergonomy, analysis of the potential of a resource is called “analysis by inspection” (Tricot *et al.* 2003). This kind of analysis articulates three dimensions: utility (e.g. adequation of the tasks proposed and the learning objectives), usability (e.g. reasonable quantity of text, articulation of different media) and, acceptability (e.g. coherence with the users’ beliefs). This approach has been complemented with more didactical content oriented criteria to take into account the effective classroom use of a technological resource, for example in the Intergeo project (Trgalova *et al.* 2009). Some criteria, concerning the specific content at stake in the resource, the appropriation of the resource and the possible management of the resource by a teacher, have thus been added to the previous ones. Moreover, the development of researches about teaching resources (Gueudet & Trouche, 2009) leads to emphasize the importance of associating users to a continuous design process of resources, in a design-in-use perspective (Rabardel & Bourmaud, 2003).

We articulate these different criteria and points of view on quality of technological resources in our proposition of analysis criteria, taking into account our specific interest for on line resources. For example, focusing on on line resources leads us to introduce the possibility of customization of the resource as an important criteria (Bueno-Ravel & Gueudet, 2007).

But the research studies mentioned above do not focus on technological resources specifically designed to foster inquiry. Thus, we develop our grid of analysis of on line resources with specific criteria related to IBST issues.

Our literature review on technologies, resources and IBST (Gueudet *et al.* 2009) leads us to integrate the following issues in our grid of criteria:

- *Importance of tasks proposed to students*: offering students appropriate environments and tasks to get them engaged in scientific inquiry (Van Joolingen *et al.* 2007), addressing students with well-defined tasks to motivate, construct and refine knowledge like in the Learning-for-Use (LfU) model (Edelson, 2001).
- *A special focus on language issues*: indeed, “practising a science can be viewed as becoming able to master specific language-games and specific ways of communicating on scientific content” (Gueudet *et al.* 2009). The language used in the on line resource should be adapted to students knowledge and scientific language should be introduced carefully (Brown & Ryoo, 2008; Clark & Simpson, 2008).
- *Importance of 'hands-on' dimension:* 'hands-on' activities are central in an inquiry process and can be proposed virtually (Khlar *et al.* 2007; Zacharia *et al.* 2008).
- *The link with authentic scientific practices*: a goal of IBST is to provide students with authentic learning activities through problem-based situations (Van Joolingen *et al.* 2007; Kim *et al.* 2007).
- *The choice of the media integrated in the on line resources*: on line resources offer the possibility of integrating several technological tools such as simulations tools, modelling tools, videos etc. Many research works underline the importance of presenting knowledge through a large variety of representations to foster students' learning during their inquiry process.
- *Students' prior knowledge and students' scaffolding* (Quintana & al. 2004; Kim *et al.*2007).
- *Needs for teachers' scaffolding*: Many studies emphasize teachers' lacks of technological, scientific and didactical knowledge concerning IBST (Kim *et al.*2007; Zion, 2008; Kubicek, 2005; Trumbull *et al.*2005; Underwood *et al.*2008; Moss, 2003). On line resources can offer scaffolds on such issues.

- *Importance of collective work for students and teachers*: from a student's point of view, studies outline the need for collective activities engaging students in argumentation and real 'talking science' situations (Clark & Sampson, 2007). From a teacher's point of view, studies underline the importance of giving teachers time for collective activities in order to enhance evolution of their practices and their professional development (Kim *et al.* 2007, Dori *et al.* 2002; Zion 2008; Gueudet & Trouche 2008).

In order to take into account criteria coming both from studies related with quality of technological resources in general and from specificities related with IBST oriented on line resources, we organize our criteria around height dimensions, presented below in table 1. Moreover, our grid of criteria aims at being applied to all kinds of IBST oriented on line resources; from on line resources designed for students, to on line resources designed for teachers or even for teacher trainers. This point is very important for us as we think that analysing interactions between students and teachers is one of the keys to understand why an inquiry process supported with on line resources can be successful in real classroom conditions or not.

This grid of criteria was conceived with the aim of producing guidelines, grounded in the analysis of several websites. The guidelines being addressed to resource designers, this grid of criteria can not be considered as a potential tool for teachers, to help them in their choice between different resources.

C1 Potential for IBST, scientific aspects
C2 Potential for IBST, scaffolding aspects
C3 Possible customization, equity issues
C4 Ergonomy, technical features
C5 Choice of media, media articulation
C6 Possible involvement of the users in the resource design
C7 Collective dimensions
C8 Privacy policy and intellectual property

Table 1. *Potential of an on-line resource for IBST, dimensions considered*

All the criteria mentioned in table 1 are relevant to analyse the overall quality and IBST potential of an on line resource. We will discuss below all of them but the “legal aspects” criterion (C8). It is a very important aspect, that each website designer should be aware of; but detailing it is not relevant for our IBST objective.
Moreover, criterion C6 (Possible involvement of the users in the resource design) and C7 (Collective dimensions) being related with collective aspects, we will detail them in a specific section.
The discussion will be organized as follows: we will first adopt a learning point of view to detail these criteria (§ 2.1). Then, we will detail other specific aspects of these criteria, when teachers are the target public (§ 2.2). Section (§ 2.3) will be especially devoted to collective aspects (criteria C6 and C7), both for students and for teachers.
In these three sections, we present sub-criteria, sometimes identified only by their title, and complemented by a short comment if necessary. We illustrate the use of these criteria by the analysis of examples of on line resources. Drawing on the criteria and on the analyses, we identify guidelines in each section.

2. Detailed criteria and identification of guidelines

2.1 On line resources and inquiry-based science learning

We detail below specific aspects of the criteria, when students are the target public of on line resources promoting inquiry in science learning.

C1 Potential for IBST, scientific aspects

Coherence with the official curriculum

Clarity of the objectives, and adequacy of the tasks proposed with the objectives

One important issue to enhance scientific inquiry with students is to design activities leaving important parts of responsibility to the students. To get involved in such activities, students must be proposed comprehensible and challenging problems or questions. Clearly defined objectives and well-designed tasks to reach these objectives are genuinely helpful to foster students' enrolment in proposed tasks. With this sub-criteria, we partly meet the first step of the LfU model (Edelson, 2001). This first step is named “Motivation” and focuses on the importance of designing activities that create a demand for knowledge and elicit students' interests and curiosity. Clarity of the objectives can help to make this first step a success. Of course, clearly defined objectives and well-designed tasks should not be limited to the moment students get involved in the proposed activities. It is crucial to examine if this sub-criterion is fulfilled at each step students are engaged in.

Providing access to a rich scientific content

From the point of view of students, the scientific content here means the subject matter content. An on line resource can present recent results of science research adapted to students' level; but also historical sources. The more important here is that on line resource can present scientific content in diverse ways: written texts, graphs, diagram, images, animations, hypertexts, etc. and naturally, any association of these possibilities. Having access to a large variety of representations of scientific concepts is a key point to construct solid knowledge in science.

Articulation of empirical evidence and concepts

The quality of the conceptual-empirical relationship is central for IBST. 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.

- *“Hands-on” activities, including virtual manipulations:* most of IBST activities are characterized by the possibility they offer to investigate questions with empirical data through direct or virtual experiments and manipulations. On line resources can be associated with data-collection and data-analysis software, can provide dynamic modelling tool or virtual simulation of scientific phenomena.
- *Searching for information:* students can be led to seek for methodological or scientific informations during their inquiry process. Does the on line resource offer bibliographical sources, links to websites, etc. ?
- *Introduction to scientific language:* Brown and Ryoo (2008) have proven that starting teaching science using a vernacular language before introducing a scientific one improves students' science learning and understanding and use of scientific language. Is the language used in the resource vernacular or scientific? How is the scientific language introduced? What is the articulation between vernacular and scientific language?
- *Epistemic value of the situations proposed:* the “epistemic value” refers here to the potential of the situation proposed for introducing scientific knowledge. Does the situation lead to tackle important scientific concepts? Does it enlighten the meaning and possible use of these concepts?

Relation to authentic scientific practices: One objective of fostering IBST in school is, among others things, to struggle to stop the disaffection of scientific course of study. Do the activities proposed offer to the students the opportunity to approach authentic scientific practices?

C2 Potential for IBST, scaffolding aspects

Scaffolding students' learning has been a matter of concern of most designers of ICT resources promoting IBST. For the last ten years, the design of scaffolding resources has increased. Quintana *et al.* (2004) have made a review of research studies centred on ICT and IBST; focusing their analysis on students' scaffolding. This work has led them to elaborate a scaffolding design framework for software to support IBST. According to them, “The framework can provide a basis for developing a theory of pedagogical support and a mechanism to describe successful scaffolding approaches. It can also guide design, not in a prescriptive manner but by providing designers with heuristics and examples of possible ways to address the challenges learners face.” (Ibid., p.338)

This framework is organized into three elements: sense making, process management, articulation and reflection. We present below a summary of this scaffolding design framework and the guidelines designed to take into account these three elements:

Sense making: Guideline 1: Use representations and language that bridge learners' understanding Guideline 2: Organize tools and artefacts around the semantics of the discipline Guideline 3: Use representations that learners can inspect in different ways to reveal important properties of underlying data Process management: Guideline 4: Provide structure for complex tasks and functionality Guideline 5: Embed expert guidance about scientific practices Guideline 6: Automatically handle non salient routine tasks Articulation and reflection: Guideline 7: Facilitate ongoing articulation and reflection during the investigation.

Table 2. *Summary of Quintana et al. (2004) scaffolding design framework*

We naturally take into account the work of Quintana *et al.* (2004) in our research; we combine it with the work of Kim *et al.* (2007), which introduces in particular the notions of conceptual, strategic, procedural and metacognitive scaffolds. Moreover, we integrate the *argumentation* dimension, important for IBST. We retain thus five sub-criteria:

Conceptual scaffolds: conceptual scaffolds are strongly linked with "sense making" and precisely with guidelines 1 and 3 of Quintana & *et al.* It is also related with *"Hands-on" activities, including virtual manipulations* and *Introduction to scientific language* sub-criteria (C1)

Strategic scaffolds: in order to manage a scientific inquiry, students need to understand the ways scientists approach and solve problems in their disciplinary fields. This sub criterion is also linked with "sense making" and interacts with guideline 2 of Quintana *et al.*

Procedural scaffolds: procedural scaffolds correspond to Quintana *et al.*. second element (process management) and cover guidelines 4 to 6.

Metacognitive scaffolds: students may need scaffolds to get engaged in reflection and assessment of their investigations. Guideline 7 of Quintana *et al.*. takes into account challenges that students face in "articulating and reflecting productively" (ibid., p.369).

Argumentation scaffolds: argumentation scaffolds proposed by an on line resource should be analysed for two main reasons. Firstly, promoting and facilitating discussion among students helps them to justify and evaluate their ideas. This process of debating under construction scientific knowledge between pairs of students tends to develop higher conceptual quality of subject matter, especially when the debating students defend conflicting points of view (Clark & Sampson, 2008). Asynchronous on line forum can be a way to organize such debates. Secondly, activities that pay attention to engaging students in "talking science" are an important part of IBST. How can an on line resource develop such activities for students? This sub-criterion is related with criteria C6 and C7 concerning collective dimensions (§ 2.3)

C3 Customization

A very important feature of on line resources is the possibility of customization they can propose to students. We retain here the following sub criteria:

- *Possibility to select a individualized learning path*, according to one's level (link to students' prior knowledge and scaffolding criteria)
- *Possibility to get personalized feedback* (link with scaffolding criteria and technical criteria)
- *Possibility to customize the resource according to one's disability.*

C4 Ergonomy and technical features

From the student's point of view, we restrain our analysis of ergonomy and technical features of on line resources to the following dimensions:
- Clear indication of the *location of the web page displayed* in the website structure and facility of *access* to the resource.
- *Quantity of information* on a page, ranging from little information to overload of informations
- *Downloading possibilities*: This aspect should not be neglected. Indeed, articulating work on on line resources and on paper and pencil is challenging in ICT sessions. Downloading data collected, summary of students' work, lessons, exercises may be a way to create such an articulation, which is important for students' learning and memorization.

C5 Choice of media

Data collectors or data analysis tools
Simulation tools
Web links
Videos of scientific experiments
On line assessment tools

We can summarize this set of criteria for analysing on line resources from a learning point of view in the following table.

C1 Potential for IBST, scientific aspects	*Coherence with the official curriculum*	
	Clarity of the objectives, and adequacy of the tasks	Enrolment in tasks
	Providing access to a rich scientific content	Diversity of representations
		Research results
	Articulation of empirical evidence and concepts	“Hands-on” activities
		Searching for information
		Introduction to scientific language
		Epistemic value of the proposed situations
	Relation to authentic scientific practices	Opportunity to approach authentic scientific practices
C2 Potential for IBST, scaffolding aspects	*Conceptual scaffolds*	
	Strategic scaffolds	
	Procedural scaffolds	
	Metacognitive scaffolds	
	Argumentation scaffolds	Asynchronous on line forum and “talking science” activities
C3 Customization	*Possibility to select a individualized learning path*	
	Possibility to get personalized feedback	
	Possibility to customize the resource according to one's disability	
C4 Ergonomy	*Location of the webpage*	
	Quantity of information	
	Downloading possibilities	Articulation of the paper and pencil work and of the work on the computer
C5 Choice of media	*Data collectors or data analysis tools*	
	Simulation tools	

	Web links	
	Videos of scientific experiments	
	On line assessment tools	

Table 3. *Detailed criteria for the analysis of an IBST-oriented on line resource for students*

2.2 On line resources for teachers and IBST

We detail below the criteria, when teachers are the target public.

C1 Potential for IBST, scientific aspects

Coherence with the official curriculum

Clarity of the objectives, and adequacy of the tasks proposed with the objectives
One of the main differences between inquiry in class and research by scientists is that inquiry in class is linked with a teaching objective, framed by the curriculum. From the point of view of the teacher, a proposed lesson, or activity, or even idea of possible activity within an on line resource is much easier to use if the teaching objective associated is clearly displayed (which could be said for any kind of pedagogical resource, but is an especially delicate issue with some inquiry-oriented activity. Indeed from a student point of view, the teaching objective of such an activity must not be too obvious; thus the activity's text by itself is not sufficient, a specific text must be directed towards the teacher). Naturally, it is also essential that the task proposed fits this objective.

Providing access to a rich scientific content: research results, historical sources
The scientific content here means both the subject matter content and the didactical content. An on line resource can present recent results of science research; it can offer historical sources; but it can also draw on recent results of science education research, especially results about IBST. An on line resource can present such results in different ways:
- As bibliographical sources, or links to websites;
- As specifically written texts;

and naturally, any association of these two possibilities.

Articulation of empirical evidence and concepts

The sub-criteria here are similar to the criteria for students, we just recall them shortly:

- *Hands-on activities, including virtual manipulations*
- *Searching for information*
- *Introduction to scientific language*
- *Epistemic value of the situations proposed*

Relation to authentic scientific practices

C2 Potential for IBST, scaffolding aspects
The scaffolding aspects, from the teacher's point of view, in an IBST perspective, concern the sharing of responsibility towards knowledge between the teacher and the students, which is at the core of our definition of IBST.
Thus the criteria listed below are all related with the role of the teacher, and roles of the students in class. All the students scaffolding aspects (§ 2.1) are still relevant, from the teacher's point of view; the presence of features of the resource directed towards students' autonomy roughly means≈ that the computer will play a part of the role usually devoted to the teacher. Thus these aspects must naturally be taken into account when analysing a resource from the teacher's point of view. We will nevertheless not detail them here, since they have already be mentioned before. We will focus on scaffolding aspects linked with the proposition, by a given website, of lesson plans, or more generally of possible classroom scenarios for a given science activity. These lesson plans can be more or less precise; some website contain resources labelled as "lesson plans" but restricted in fact to students' sheets.

A priori analysis of the activities proposed, from an IBST point of view

This a priori analysis comprises several aspects, in particular :

- Analysis of the knowledge at stakes
- Information about possible students' procedures
- Information about possible students' difficulties

The presentation of foreseeable students difficulties can help the teacher in the preparation of the lesson

Proposition of classroom organisation

We call here “proposition of classroom organisation”, indications about:

- The way students work, during the different parts of the lesson: individual work, group work, precise role for each student;
- Time management;
- Productions expected from the students, on the computer and on paper. The possibility of access to the students' productions is essential for the teacher; these possibilities are recorded in criteria 3 (customization).

Introduction of the lesson by the teacher

The way the teacher introduces the work is determining to start inquiry in class. The stake must be clearly introduced, in a way fostering the engagement of students in the task.

Helping the students in the inquiry process

The possible help of the teacher, to support students' inquiry, is delicate matter. Too much help from the teacher can ruin the inquiry character of the task. Thus two entries must be considered here:

- Forms of possible helps proposed (see 2.1 about the possible scaffolding of the students);
- Level of help preserving the inquiry features.

Use of the students' productions by the teacher

According to our definition of inquiry, the responsibilities of the students towards the scientific content are closely connected with the use of their productions as starting points of the teacher's work. Supporting this use is thus an important feature of a given resource.

Design of the assessment aspects

How can learning be assessed, after an inquiry-based teaching? This question is very often raised by teachers, and can even prevent some of them to organise inquiry in their classes. Thus observing if the resource proposes assessment or not is important. A resource proposing IBST- oriented lessons can nevertheless propose assessments with no connection with inquiry, this must also be taken into account:

- Proposition of assessment
- Link of the assessment with inquiry aspects

C3 Customization

Customization naturally concerns online resources offering a possibility to inscribe students (which means here identifying them individually with a login and password), and select several parts of the resource, which will be proposed to students with different needs. This is a very important feature of on line pedagogical resources: they can help the teacher to propose different contents to students with different needs. Such online resources also often propose tool to follow the scientific work accomplished by the students. Thus the criteria we retain here are:

- *Possibility to inscribe students*
- *Possibility to select specific parts of the resource* for specific students
- *Possibility to access to a record of students scientific productions* (link with scaffolding criteria, 2 and with technical criteria, 4)
- *Proposition of help for students with specific difficulties* (link with scaffolding criteria, 2)

C4 Ergonomy and technical features

All the classical ergonomy criteria for websites are important, from the teacher's point of view, we will not detail them here. We only focus on three dimensions:

- Clear indication of the *location of the webpage displayed* in the website structure
- *Quantity of information* on a page, ranging from few information to overload of information
- *Downloading possibilities*: An important aspect, because of the possible networking breakdown that can hinder the lesson planned is the possibility to download important parts of the resource.

C5 Choice of media

Data collectors or data analysis tools
Simulation tools
Web links
Videos of scientific experiments
On line assessment tools
Classroom videos
From the teachers' perspective, an important aspect is the presence of classroom videos, and of appropriate indications about what can be drawn from these videos. The precise content of these videos and of the associated indications is linked with the scaffolding aspects: precisions about the role of the teacher and of the students during the inquiry-based lesson.

We can summarize this set of criteria for analysing on line resources from a teaching point of view in the following table.

C1 Potential for IBST, scientific aspects	*Coherence with the official curriculum*	
	Clarity of the objectives, and adequacy of the tasks	
	Providing access to a rich scientific content	Bibliographical sources
		Specifically written texts
	Articulation of empirical evidence and concepts	"Hands-on" activities
		Searching for information
		Introduction to scientific language
		Epistemic value of the proposed situations
	Relation to authentic scientific practices	
C2 Potential for IBST, scaffolding aspects	*Students' scaffolding*	See detailed criteria in table 3
	A priori analysis of the activity proposed	Analysis of the knowledge at stakes
		Information about possible students procedures
		Information about possible students difficulties
	Introduction of the lesson by the teacher	
	Helping the students in the inquiry process	Form of help: see detailed criteria in table 3
		Level of help preserving inquiry
	Use of the students' productions by the teacher	
	Design of the assessment	Proposition of assessment
		Link with inquiry aspects
C3 Customization	*Possibility to inscribe students*	
	Possibility to select specific parts of the resource for specific students	
	Possibility to access to a record of students scientific productions	
	Proposition of help for students with specific difficulties	
C4 Ergonomy	*Location of the webpage*	
	Quantity of information	
	Downloading possibilities	
C5 Choice of media	*Data collectors or data analysis tools*	
	Simulation tools	
	Web links	
	Videos of scientific experiments	
	On line assessment tools	
	Classroom videos	

Table 4. *Detailed criteria for the analysis of an IBST-oriented on line resource for teachers*

2.3 On line resources and collective aspects

By “collective aspects”, we mean here both students' and teachers' collectives; we will study separately these two aspects.

Collective aspects for students and analysis of on line resources

We consider two different directions in the collective aspects, from the students’ perspective:
- Possible involvement of the users in the resource design (criterion 6);
- Possibilities of collective work for students offered by the resource (criterion 7).

C6 Possible involvement of the users in the resource design

We retain here the possibility offered to students to integrate contents they have elaborated in the resource. For example, they may be interested to submit their inquiry report on line for several reasons: to have an access to this report afterwards, to share it with other students or other users of the resource etc. They may also be willing to integrate in the resource web links they have found interesting or other scientific resources. The Progress Portfolio integrated to The Create-a-World Project (Edelson, 2001) can be a starting point to the involvement of students in the resource design. This Progress Portfolio is an inquiry support environment allowing students recording, annotations and organizations of the different products of their scientific project. The issue of who can have an access to such data has to be examined.

C7 Possibilities of collective work for students offered by the resource

Students can be offered various ways of working collectively: an on line resource can propose possibilities of work for groups of students, or possibilities of work in interaction with teachers or even in interaction with researchers in science (Zion, 2008). Such a collective work has to be organized. Firstly, the technical feature of an on line resource must allow exchange between users of the resource: it can be a platform, a synchronous or asynchronous forum (Zion, 2008; Clark & Sampson, 2008). Secondly, the organization of the collective work has to be scaffolded by the on line resource. For example, if students have to work in groups, the resource can contribute to compose groups of students. Clark & Sampson (2008) have experimented a “personally-seeded discussion software to set up discussion forums that consist of three or five pairs of students who have created different principles to explain the same phenomenon” (ibid., p. 307). The results of their study have shown that putting together students defending conflictual points of view improve students' conceptual quality of the matter. Scaffolding the organization of the collective work also concerns all kinds of methodological elements supporting collective work such as proposition of collective activities guided by open questions to initiate the discussion, proposition of roles for students, a schedule for collective work, etc. Thirdly, an on line resource fostering collective work for students should propose argumentation scaffolds to students (see part 2.1., criterion 2).

C6 Possible involvement of the users in the resource design	*Integration of contents designed by users*
C7 Possibilities of collective work for teachers offered by the resource	*Technical features*
	Composition of groups of students
	Methodological elements
	Argumentation scaffolds (C2)

Table 5. *Criteria 6 and 7, students' collective work*

Collective aspects for teachers and analysis of on line resources

We consider the same directions in the collective aspects, from the teacher's perspective:
- Possible involvement of the users in the resource design (criterion 6);
- Possibilities of collective work for teachers offered by the resource (criterion 7).

Naturally, these criteria apply on different ways for resources designed for teachers, and for resources designed for teacher training, which we also consider in our study.

These collective aspects for teachers are an important characteristic of online resources; they are nevertheless not specific for IBST.

C6 Possible involvement of the users in the resource design
We distinguish here again two dimensions:
- Possibility for the user to formulate opinions on the resource, suggestions that will be taken into account by the designers. These possibilities have technical aspects: existence on the website of a forum, to record the users ideas for example; clear display of a contact e-mail. But they also have organisational aspects: how are treated the ideas on the forum collected? Who takes the decision for changes?
- Integration in the resource of contents elaborated by users, lesson plans in particular.

C7 Possibilities of collective work for teachers offered by the resource
We include here possibilities of work for groups of teachers, but also for teachers and other kinds of agents: first of all, students, but also teachers' trainers, or scientists. Such possibilities include:
- Technical features for collective work. A platform, a wiki, a forum are such features. Networks of calculators provide the teacher with access to students' productions; tools for collective building of concept maps are used in many professional development programs;
- Methodological elements likely to support collective work: these elements can concern the organization, like the proposition of collective activities (discussion on a forum, collective design of a lesson) or a schedule for collective work; they can also be common tools, to scaffold collective discussions about a lesson by providing the trainees with a common vocabulary to describe a lesson.

C6 Possible involvement of the users in the resource design	*Possibility to formulate an opinion*
	Integration of contents designed by users
C7 Possibilities of collective work for teachers offered by the resource	*Technical features*
	Methodological elements

Table 6. *Criteria, teachers' collective work*

3. Guidelines

We presented above criteria for an analysis of on line resources, aiming at assessing the potential of such a resource for the organisation of inquiry in science class. These criteria are not guidelines; they indicate nevertheless possible interesting features, for a given on line resource for IBST. In this section we draw on these criteria and on our literature review (deliverable 5.1, Gueudet *et al.* 2009) to identify guidelines for the further development and the design of IBST oriented on line resources.

Guidelines for the design of on line resources for students

Two features seem to be central for an effective organisation of scientific inquiry using an one line resource:
- The guidance of the student through the resource and the activities proposed. This guidance can be done by the resource, by the teacher; it can also lead to a shared responsibility between the teacher and the resource. To foster IBST, it is important that such guidance preserves important parts of responsibility towards knowledge for students.
- The appropriation of the resource by the students: the contents presented and the language used in the resource should be within reach of students. Possibilities of customization (criterion 3) of resource can be a way to facilitate such an appropriation. If a resource includes specific software (data collectors or simulation tools for example), the appropriation of these software should be considered.

For us, taking into account these two features cannot be done without thinking about the role of the teacher using an on line resource with her students. Criteria and guidelines elaborated in section 2.1 and 2.2 are strongly intertwined.

IBST and scientific aspects
- Giving students important parts of responsibility towards knowledge requires proposing understandable and well-motivated tasks to students to elicit their curiosity and interests and to enrol them in problems to be solved.
- An on line resource should offer multiple types of representations of scientific knowledge. Reflection concerning the dynamic aspect of these representations should be encouraged. It is important to avoid giving

a dynamic representation of a phenomenon to students without giving them the key to interpret such a representation.

- Articulating empirical evidences and concepts is central in IBST. Even an on line resource should give students the opportunities to do “hands-on” activities; virtual manipulations (for example by changing parameter in a dynamic modelling tool) can make these “hand-on” activities efficient.
- The language used should be appropriate to students level. Vernacular language should not be banished but carefully articulated with scientific language. Terms of scientific language should be clearly defined against a precise empirical background and used when necessary.
- Proposed activities should be as much as possible related to authentic scientific practices (thanks to the methodology used or the scientific theme addressed for example).

IBST scaffolding

It is crucial to plan scaffolding at each step of the student's inquiry process. Designers' task is large and complex, as shown by our list of criteria. Five dimensions of scaffolding should be taken into account: conceptual, strategic, procedural, metacognitive and argumentation scaffolds. For the four first dimensions, we take up the guidelines designed by Quintana *et al*. (2004). Concerning the fifth dimension, an on line resource should offer the possibility for students to communicate thanks to asynchronous forums. These forums should group together students exchanging contradictory ideas and sharing assumptions to foster a higher level of epistemic argumentation and students understanding of phenomena (Clark & Sampson, 2008).

But the scaffolding will be all the more efficient as it addresses the specific needs of a student. This is strongly linked with the possibility of customization of an on line resource (criterion 3).

Customization, ergonomy, choice of media

The detailed criteria listed in table 3 for C3,C4 and C5 can be seen as guidelines. An important point is the articulation of the work done on the computer, and the paper and pencil work. Moreover, students should have the possibility to keep a record of their work on on line resources, digital or on paper.

Guidelines for the design of on line resources for students: collective aspects

The following features appear to be central for an on line resource, incorporating students' collective work to promote IBST:

- The tools proposed to students to share resources and exchange.
- The didactical organization proposed by an on line resource to put in place collective activities.
- The argumentation scaffolds (§ 2.1, criterion 2)

Possible involvement of the students in the resource design

The criteria listed in table 5 can be seen as guidelines.

Possibilities of collective work for students offered by the resource

According to us, three points have to be articulated to allow a real collective work fostering inquiry: a clear definition of the tasks students will have to solve during the collective activities (§ 2.1, C1, sub-criterion: *Clarity of the objectives, and adequacy of the tasks*), a didactical organization of the students collective work and, argumentation scaffolds.

The articulation of these three points should be thought in relation with the technical features and the collective methodological elements offered by an on line resource and with teacher's scaffolding to manage collective students' work in her science class.

Guidelines for the design of on line resources for teachers

We develop here as above guidelines drawing on our criteria. We want nevertheless to emphasize first a central aspect: the need for appropriation of the resource by the teacher. This appropriation means:

- First of all, using the resource. In the present context of proliferation of resources, this means accessibility, through a precise indexation, with standard description (LOM, Dublin Core etc.). It also means a appealing presentation, linked with the ergonomy criteria (C4).
- Adapting it in ways that preserve the inquiry aspects. We consider indeed that the important point is not the alignment of the teacher with precise recommendations formulated within the resource. Teachers always adapt one way or the other the resources they use; what matters here is that the adaptation does not hinder inquiry.

Taking into account these two objectives is a delicate matter for designers. For example, an important factor

of use by teachers is the use of the resource by students. Insofar proposing activities directly usable by students might be a good idea. However, research works about curriculum material (Remillard *et al.* 2008) have proven that in such cases some teachers only use the students' part, within a traditional teaching, far away from the inquiry objective.
We present below some guidelines for on line resources designers, taking into account the criteria for IBST and the appropriation dimensions. However, supporting IBST means trying to change the teachers' practices. Elaborating curriculum material, even in the form of on line resources, is not enough to reach this objective. Professional development programs must also be designed to support the appropriation of a given resource.

IBST and scientific aspects
- An on line resource should contribute to teacher learning, in particular by offering contents likely to update teacher subject matter knowledge and didactical knowledge.
A list of bibliographical sources is not enough; proposing special texts, complemented by bibliographical sources (complete articles to download if possible), is necessary.
- The “living” aspect is an important feature of an on line resource. In the case of a resource directed towards IBST, a possible dynamic aspect linked with scientific inquiry is to add links to recent sources as those mentioned above: articles about current controversies, about recent findings in science or science education research.
- The articulation of empirical evidence and concepts is central in science teaching and learning, and in IBST in particular. An on line resource for supporting IBST must propose access to both aspects; it must also connect both in specific ways, and ensure that the teacher is aware of the important difference between these two aspects, from the students point of view.
- About language: for each term used, it is necessary to clearly present if it is used in its common sense or with its scientific meaning, to specify the similarities and differences between both, and to clarify the different ways to articulate common sense and scientific meaning
- About scientific thinking and practices: if some aspects of the work proposed are characteristic from a scientific work, they must be emphasized as such, so that the teacher draws the attention of the students on these aspects in class.

IBST scaffolding
For scaffolding the organisation of inquiry in class, from the teacher's perspective, it seems important to propose methodological tools. The objective is indeed more to help the teacher to build her own lesson, and not to propose a “model lesson” for reproduction in class.
A few detailed examples of “best IBST practice” can be proposed, including lesson plans, along with videos. These examples should include careful analyses of important IBST aspects :

- Sharing responsibilities between teacher and students;
- Use by the teacher of the students productions.

It is very important to propose a limited number of detailed examples, to support their careful reading.
Including classroom videos is very helpful, in particular to clarify the sharing of responsibilities between the teacher and the students.
Important aspects of the teacher role, that should be emphasized by the resource include:

- Presenting the task;
- Starting and managing a debate, exposing the knowledge to record after the debate (institutionalisation);
- Enlightening the characteristic features of the scientific practices.

These aspects can be emphasized by the use of videos, with specific comments for such moments. Their importance can also be indicated by methodological tools for the teachers. For example, a grid of description of the lesson prepared, with specific IBST categories, leads the teacher to be aware of these categories. This could be proposed in a book; but in an online resource, the categories proposed in a grid can easily evolve, in particular to integrate users suggestions (see § 2.3 below).

Customization, ergonomy, choice of media
For these dimensions, the detailed criteria listed in table 3 can be seen as guidelines. An especially important point, with an IBST perspective, is to provide access for the teacher to a detailed record of the students' productions (not only in terms of success or failure, but displaying the students' procedures).

Guidelines for the design of on line resources for teachers: collective aspects

The *possible involvement of the users in the resource* design is clearly both a criteria and a recommendation. With on line resources, integrating necessary modifications is very simple; this is perhaps one of their main

features, compared to other ICT resources. The literature about quality for on line resources mention "design loops": a continuous process of improvement of the resource, drawing on the user's experience (Trgalova *et al.* 2009).
Incorporating contents designed by the teachers must be made with care: it requires here again a collective work, involving several kinds of experts, to assess the IBST-potential of the content proposed. It is nevertheless important, for appropriation issues: contents designed by teachers themselves are often more easily accepted by teachers than contents elaborated by experts.
About the *possibilities of collective work*, the guidelines differ for a resource directed towards teachers, with no training objectives, and for a resource deliberately aiming at teacher training. Most of the on line resources nowadays incorporate forums, chats etc.: possibilities to establish social networks, around the resource. It is an interesting feature; the organization of the discussion within a forum can also be thought with an IBST objective, for example by raising questions which will orient the discussion towards IBST etc.
For a resource directed towards teacher training, the same kind of forums can be used, with a stronger guidance by the trainers, about the content of the discussions. Another important aspect is to provide teachers with methodological tools to communicate and to work together. Some communities develop spontaneously; but for a teacher training device, elements for "cultivating communities" (Wenger 1998) must be proposed. Without such elements, the communities are less likely to develop. But too much guidance represents a hindrance as well. Thus for example, instead of proposing a detailed situation, completely analysed, the resource can propose ideas of situations ("seeds", in the meaning introduced by Fischer & Ostwald 2005). Elements like models of description of lessons are also useful.

4. Synthesis

The aim of the following synthesis is to provide a short overview of our guidelines, especially for a reader who does want to enter in the detail of the text. It comprises three parts. In the first part, we consider the IBST scientific aspects from the students and teacher viewpoints; in the second part, we consider the IBST scaffolding and customization aspects in the same way; in the third part, we envision the collective aspects, both from the students and teacher viewpoints. This organization is also chosen to emphasize the connections between "students" and "teachers" guidelines. We separated both for the sake of clarity, however, they are strongly connected. Several resources address both teachers and students, and any "student resource" can also be considered as a "teacher resource".
This synthesis has been made by enacting our definition of IBST, which emphasizes the need for sharing responsibilities towards knowledge between the teacher and the students, and rests on a first-hand relationship to knowledge, both for the teacher and the student.

4.1 IBST and scientific aspects

As we wrote above, from the students viewpoint, two features seem to be central for an effective organization of scientific inquiry using an on line resource:

- The nature of the guidance of the student through the resource. This guidance can be done by the resource, by the teacher or by a shared responsibility between the teacher and the resource. To foster IBST, it is important that such guidance preserves important parts of responsibility towards knowledge for students.
- The appropriation of the resource by the students: the contents presented and the language used in the resource should be within reach of students.

We identify the following series of guidelines from the students viewpoint, with respect to scientific aspects of IBST:

- Giving students important parts of responsibility towards knowledge requires proposing understandable and well-motivated tasks to students. These tasks require a real understanding of knowledge into play to be effective;
- An on line resource should offer multiple types of representations of scientific knowledge, dynamic representations in particular;
- Articulating empirical evidences and concepts is central in IBST. Even an on line resource should give students the opportunities to do "hands-on" activities, thanks to virtual manipulations;
- The language used should be appropriate to students level. Vernacular language should not be banished but carefully articulated with scientific language. Terms of scientific language should be clearly defined, related with a precise empirical background and used when necessary;
- Proposed activities should be as much as possible related to authentic scientific practices. These practices have to be presented in a comprehensive way.

From a teacher viewpoint, the appropriation of the resource is a central feature. For this reason, accessibility and ergonomy are central features, not related with IBST scientific aspects. But an important dimension is also the incorporation in the resources of elements contributing to preserve IBST, whatever the adaptations are; several of the guidelines listed above, and below, address this issue.

We identify the following series of guidelines from the teachers viewpoint, with respect to scientific aspects of IBST:

- An on line resource should contribute to teacher learning, in particular by offering contents likely to update teacher subject matter knowledge and didactical knowledge. With this respect, proposing specific texts, complemented by bibliographical sources (complete articles to download if possible), is necessary;
- The “living” aspect is an important feature of an on line resource. In the case of a resource directed towards IBST, a possible dynamic aspect is to add links to recent sources: articles about current controversies, about recent findings in science or science education research;
- As the articulation of empirical evidence and concepts is central in science teaching and learning, an on line resource for supporting IBST must connect both aspects in specific ways, and ensure that the teacher is aware of the important difference between these two aspects, from the students point of view;
- About language: for each term used, it is necessary to clearly present if it is used in its common sense or with its scientific meaning, to specify the similarities and differences between both, and to clarify the different ways to articulate common sense and scientific meaning;
- About scientific thinking and practices: if some aspects of the work proposed are characteristic from a scientific work, they must be emphasized as such. The teacher has to draw students’ attention on these aspects in class.

It is important to take into account a kind of familiarity between the two types of guidelines (teacher *vs* student). Through the resource, both must be linked with science in action. Thus the resources designers need to produce a transposition process in order to make the scientific content and process understandable. This transposition work is perhaps more important for students than for teachers, but it is necessary in both cases. It requires a specific work on representations and language.

4.2 IBST scaffolding and customization

From the students viewpoint, we argued that it is crucial to plan scaffolding at each step of the student's inquiry process. We identified five dimensions of scaffolding that should be taken into account: conceptual, strategic, procedural, metacognitive and argumentation scaffolds (Quintana *et al.* 2004; Clark & Sampson, 2008). Concerning argumentation, we emphasized the fact that on line resource should offer to students the possibility to communicate thanks to asynchronous forums, exchanging contradictory ideas and sharing assumptions to foster a higher level of epistemic argumentation and understanding of phenomena. But the scaffolding will be all the more efficient as it addresses the specific needs of a student. This is strongly linked with the possibility of customization of an on line resource.

In this perspective, the articulation of the work done on the computer, and the paper and pencil one is a very important issue. Students should have the possibility to keep a record of their work on on line resources.

From the teacher's perspective according to the organization of scaffolding, it seems critical to propose methodological tools, in order to help the teacher to build her own lesson grounded in a strong conceptual understanding of the activities proposed in the resource. With this respect, a limited number of detailed examples of “best IBST practice” can be proposed, including lesson plans, along with videos. These examples should include careful analyses of important IBST aspects:

- Sharing responsibilities between teacher and students;
- Use by the teacher of the students productions.

Including classroom videos is very helpful, in particular to clarify the sharing of responsibilities between the teacher and the students. In these videos, important aspects of the teacher’s role, which should be emphasized by the resource, include:

- Presenting the task;
- Starting and managing a debate, exposing the knowledge to record after the debate (institutionalization);
- Enlightening the characteristic features of the scientific practices.

These aspects can be emphasized in a grid of description of the prepared lesson, with specific IBST categories, which can easily evolve, in particular to integrate users’ suggestions.
In the perspective of customization mentioned below, an especially important point, from an IBST

perspective, is to provide access for the teacher to a detailed record of the students' productions (not only in terms of success or failure, but displaying the students' procedures).

We observe once again here that guidelines for students and guideline for teachers are strongly connected. In particular, keeping a record of the students' productions, and proposing articulations between computer and paper-and-pencil aspects are important features for both kinds of on line resources.

It is worth noticing that the sharing of responsibilities towards knowledge and the use by the teacher of the students productions, that we identified as essential features of IBST, rest on a deep scientific knowledge, both about the subject matter and the educational sciences. There is a very strong relationship between the quality of scientific aspects embedded in the resource and enacted in teachers' action, and the quality of scaffoldings teachers are enable to foster.

4.3 IBST collective aspects

As we argued above, the following features appear to be central for an effective students' collective work promoting inquiry using an on line resource:

- The tools proposed to students to share resources and to communicate;
- The didactical organization proposed by an on line resource to set up collective activities;
- The argumentation scaffolds.

According to us, three points have to be articulated to allow a real collective work fostering inquiry, involving students in the resource work and design: a clear definition of tasks students will have to solve during the collective activities; a didactical organization of the students collective work, and argumentation scaffolds.
The articulation of this three points should be designed in relation with the technical features and the collective methodological elements offered by an on line resource. This is strongly related with the teacher's scaffolding to manage collective students' work in her science class.

From the teacher's point of view, the involvement of the user in the resource design is critical, for a continuous process of improvement of the resource, drawing on the user's experience.
Incorporating contents designed by the teachers must be made with care: it requires here again a collective work, involving several kinds of experts, to assess the IBST-potential of the content proposed.
About the possibilities of collective work, most of the on line resources nowadays incorporate possibilities to establish social networks, at least by incorporating a forum. But cultivating communities of teachers requires more. It is thus very important to organize teacher development programs associated with the resource and organizing teachers' collective work.

From a general viewpoint about collective aspects of resources for IBST, we notice that a key point lies in the fact that the collective work, whether for students or for teachers, requires some form of evidence based practice which ensures that this work will allow a deeper, richer and more subtle understanding of scientific concepts. In this perspective, relations between experts and teachers must both avoid the ignorance of the experts by the teachers and the government of teachers by the experts.

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