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D9.4 Recommendation for the introduction of eLearning tools for science in schools

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Abstract: According to the Description of Work (DoW), the Task T9.7 "will develop the roadmap towards the Inspiring Science Education Federation. According to the consortium approach the proposed process will be integrated in the evolution of the EPS European Science Education Academy, that could provide not only a standardized framework for teachers professional development but also a series of recommendations on how the consortium re-imagine the science education and the role of eLearning tools and resources in developing this vision."

This deliverable presents the alternatives, discussions and decisions in relation to the ISE Federation and sustainability beyond the ISE project lifetime.

Keywords: ISE Federation, Sustainability

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5	2016-08-31	Christian M. Stracke, Esther Tan	OUNL	Final draft for review and approval

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1 The Science Laboratory: A Unique Resource for Science Teaching and Learning

Knowledge of the natural sciences is constructed to explain objects, phenomena, and their interactions in the natural world. With time, scientific ideas or concepts become connected by wider-ranging theories, and especially since the Renaissance, new knowledge and understanding has developed through continual, dynamic interaction between scientific theories, research, and experimental data. This complex interaction sometimes results in the rejection or modification of prior ideas and the development of newer ideas that link concepts together, in turn suggesting new methods, new interpretations of data, and new questions. Often, but not always, the data have come from carefully controlled studies conducted in scientists' laboratories. This kind of interrogation of nature often brings forth information that would not have been evident simply through direct observation of the natural world.

There are interesting similarities and differences between the ways that scientific communities develop new knowledge of the natural world and the ways that learners come to understand their world. Novice learners also construct ideas about the natural world based, in part, on observations of objects, phenomena, and their interactions. With time, these ideas also become linked and tested through the learner's experiences and his or her interactions with the ideas of others. In the process, learners come to retain and develop some concepts and explanations, to reject others, and in turn to wonder about connections to new ideas and implications. Teachers have unique opportunities in science to help students wonder about the exciting natural world, experience and observe interesting objects and phenomena, explore meaningful theoretical ideas, and grow in scientific understanding. The school science laboratory is a unique resource that can enhance students' interest, knowledge of science concepts and procedures, and knowledge of important tools and skills that can develop new understanding. Experiences in the school laboratory can also help students glimpse ideas about the nature of science that are crucial for their understanding of scientific knowledge. These are among the reasons that laboratory activities (practical activities in British Commonwealth parlance) have had a prominent place in the science curriculum since early in the nineteenth century. A classical definition of school science laboratory activities that would have been acceptable in the nineteenth century and most of the twentieth is: learning experiences in which students interact with materials or with secondary sources of data to observe and understand the natural world (for example: aerial photographs to examine lunar and earth geographic features; spectra to examine the nature of stars and atmospheres; sonar images to examine living systems). The development and increasingly widespread use of digital computing technologies in school science near the turn of the twenty-first century provide new tools for gathering, visualizing, and reporting data and findings as well as important and new tools that can support learning. New tools also offer simulation resources for teaching and learning science. Some of these new tools and resources blur the interface between learning in the laboratory and learning with simulations that are representations of nature. In fact, work with simulations has caused some to perceive that school laboratory activities are themselves simulations of some of the things that scientists do (*Lunetta, 1998*). The new electronic tools and resources for teaching and learning associated with the school science laboratory also offer important new opportunities to study learning in science, and they warrant careful scholarly study by researchers in science education as we enter the twenty-first century.

2 INTRODUCING A CULTURE OF SHARING AND RE-USE OF EDUCATIONAL RESOURCES

Digital learning resources were initially conceived as a tool to make distance education efficient, by easing teacher's re-use of self-contained chunks of educational material for course construction. They were subsequently recognised to have the potential to be helpful for education in general, since into learning resources repositories practitioners may find innovative proposals to improve their educational practice (such as materials to carry out problem-based activities), as well as simple technological tools (such as java applets for simulating complex scientific phenomena) whose implementation might be beyond their competence. However the diffusion of digital learning resources has been slowed down as a sequence of the fact that computers, despite having been introduced into schools from the eighties, are not yet deeply integrated into school activity (Stracke, 2016). Moreover, research has highlighted a number of difficulties that still hinder teachers' appreciation and actual use of digital learning resources in school, such as the scarce information on the resources quality and the limited congruence of the metadata standards with the current indications of the learning theories. There is also a problem of context. An educational resource suitable for teaching in UK schools may be unsuitable for supporting the teaching of the National Curriculum in a school in Greece. The following table shows the use of ICT in the prescribed or recommended curriculum in primary (ISCED 1) and secondary school (ISCED 2) science classes in different European countries: "Researching the Internet for data" seems to be rather common approach in many European science classrooms.

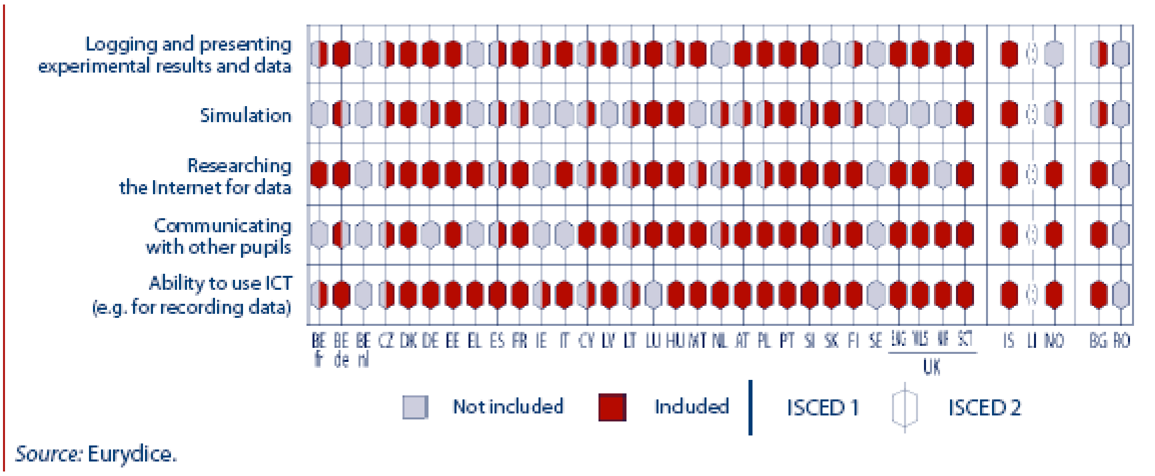

Figure 1: *The use of ICT in curriculum in primary and secondary school science classes*

2.1 Constraints on the development of reusable learning activities

Recent approaches to eLearning have largely focussed around the reuse of resources to develop economies of scale and thus partially address the low usage of ICT. As Mayes and Fowler (1999) pointed out, one problem in focusing on educational resource reuse is that teachers tend to plan their ICT based activities around 'instructivist' learning models, which focus on single learners accessing content. Thus, it does not help bridge the gap between modern pedagogical theory and implementation. Recent developments in technology allow us to go beyond resource reuse and support implementation of recent pedagogy, in particular social-constructivist learning processes (Stracke, 2015). Interoperable, networked technologies have the potential to support students' collaborative activities, allowing them to source, create, adapt, integrate and store resources in a variety of formats. These new possibilities and affordances of eLearning tools mean that it is becoming easier to use technology to support social-constructivist methods of learning, such as collaborative learning through learning communities. These learning methods focus on the process of learning and on the learning activities students carry out in order to gain knowledge of concepts. There are a number of factors constraining the development of reusable learning activities and learning designs:

First, the current development of tools for the semantic web is increasing the possibilities for personalised learning experiences for students. One way this can be achieved is by sequencing tasks according to the responses of a learner. However there is a tension between this individualised approach and the increasing development and use of collaborative learning activities with groups of students. Collaborative tasks are most commonly found in University contexts (Collis and Striker, 2004) while individualised approaches are frequently used within the context of business and military training.

Second, teachers frequently do not have the skills to develop activities based on a range of educational models. This results in a gap between application of pedagogy and the effective use of tools and resources. Often teachers and learners view technology in terms of how it will help them manage resources rather than supporting learning (Timmis, O'Leary et al., 2004).

Third, associated with the second issue, any inability to engage with educational taxonomies through unfamiliarity with the relevant vocabulary makes it very difficult for teachers to search for generic learning activities from other subject disciplines. Teachers would probably have to browse through activities to understand their potential for supporting effective learning. While browsing could be an effective strategy for a single collection of a small number of activities, it would be difficult for wider searching.

Fourth, eLearning practice is moving towards the reuse of generative resources (i.e. resources developed during learning tasks). This means that the outputs from learning activities should also be considered for reuse. However, most teachers and learners do not have the required e-literacy skills (for example to archive activities) to allow for effective reuse of learning resources and activities.

Finally, any focus on the development of “definitive resources” can lead to the production of inflexible materials that do not cater for individual learning contexts. There is a need for tools that allow the teacher to customise generic components to provide a tailored learning experience (Thomas and Milligan, 2004). However, there are currently few tools available to allow teachers to support learning activity sharing and sequencing (Britain, 2004).

3 Resource-Based Learning: Prospects and Challenges

3.1 Overview of Resource-Based Learning

During recent years, the definition, role and uses of recourses have undergone a metamorphosis. The changes have transformed how we think about resources, the distributed production of and access to digital resources, and how, when, and for what purposes we create and use them. The metamorphosis has been propelled by the exponential growth of information systems such as the internet and the web, and the ubiquitous presence of enabling technologies in classrooms, libraries museums, homes and communities. While increasing the numbers of and access to resources is energizing, realizing the educational potential of these breakthroughs may prove daunting. This is particularly true in formal learning settings (schools and universities) where current practices do not emphasize optimizing available resources or preparing individuals to learn in resource-rich environments. Teaching focuses on established curriculum goals, sequences, resources, and activities.

Subjects like science provide a unique opportunity to exploit Resource-Based Learning (RBL) alternatives, expanding both the materials and the methods used in teaching and learning.

Resource-based learning “involves the reuse of available assets to support varied learning needs” (Beswick, 1990). Several factors make RBL viable: 1) increased access to resources (print, electronic, people) in a variety of contexts not previously available; 2) resources are increasingly flexible in their manipulation and use; and 3) economic realities dictate that resources become more readily available, manipulable, and shareable across a variety of contexts and purposes.

3.2 Components of Resource-Based Learning

RBL features four basic components: enabling contexts, resources, tools, and scaffolds. Taken together these components enable educators to create and implement learning environments of considerable diversity and flexibility.

Table 1: *Components and Characteristics of Resource-Based Learning*

RBL Components	Key Characteristics
Enabling contexts	Imposed: Teacher or external authority determines goal. Induced: Learner or learner and teacher determine the goal.
Resources	People, things or ideas that support the learning process.
Tools	Objects used to help facilitate the learning process. Range from processing to organization to communication tools.
Scaffolds	Support that is faded over time. Includes conceptual, metacognitive, procedural and strategic scaffolds

Table 1 provides an overview of key characteristics. Each of the components will be briefly described in the following paragraphs (for a more detailed description, see: Hill and Hannafin, 2001).

3.2.1 Enabling Contexts

Enabling contexts supply the situation or problem that orients learners to a need or problem, such as recognising or generating problems and framing their learning needs. By creating and enabling contexts, meaningful learning can occur with and through the resources provided or obtained. Enabling contexts can be imposed, induced or generated. Imposed contexts clarify expectations explicitly and guide teacher and student strategies implicitly. Teachers may use determined objectives (e.g. National Curriculum, University Curriculum). Induced contexts introduce a domain where problems or issues are situated, but not specific problems to be addressed. A typical scenario enables multiple problems or issues to be generated or studied based on different assumptions, topical relevance, and the context of use (see **Figure 1**). In generated contexts, specific problem contexts are not provided; rather, the learner establishes and interpretive context based on his or her unique needs and circumstances. The **Figure 1** demonstrates how the Inspiring Science Education system supports both students and teachers during their work by providing a series of tools for the presentation of the images (overlap the images in order the students to perform more accurate calculations) as well as tools that help the students in their calculation (arrows, bars for pointing the selected point on the object under investigation, calculators of distances).

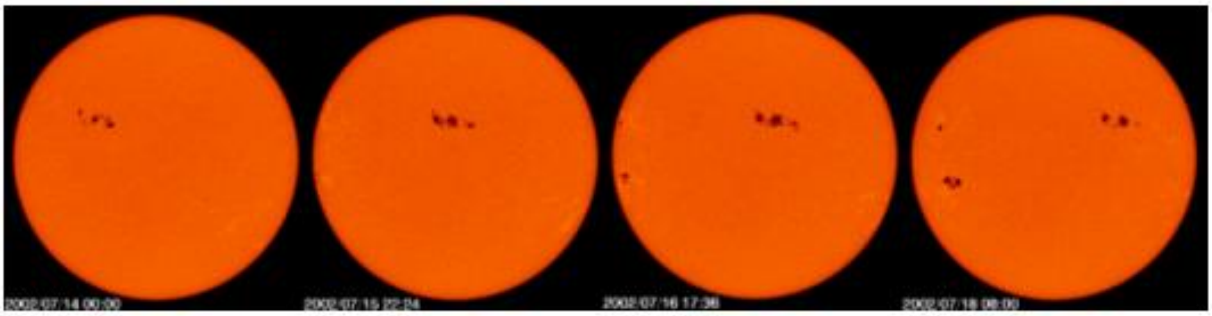

Figure 1: *The Inspiring Science Education system support for both students and teachers*

3.2.2 Resources

Resources are “raw materials” that support learning, such as electronic databases, textbooks, video, images, original source documents, and humans. Resources maybe provided by a more knowledgeable other (e.g. teacher) to assist others in extending or broadening knowledge or understanding. Resources may also be gathered by the learner as questions and/or needs arise. Given varying contexts of use, the utility of a resource may change dramatically from situation to situation. The web for example, enables access to millions of resource documents, but their integrity and usefulness is judged by the individual and in accordance with the context of use. As resources become both increasingly relevant to the learners’ need and accessible, they assume greater utility.

3.2.3 Tools

Tools enable learners to engage and manipulate both resources and ideas. Tool uses vary with the enabling contexts and user intentions; the same tool can support different activities and functions. Eight types of tools are used in RBL: processing, seeking, collection, organisation, integration, generation, manipulation, and communication.

Processing tools help students to manage the cognitive demands associated with RBL. Processing tools, such as self-directed learning systems, for example, enable learners to work with ideas, extending their cognitive abilities and reducing the need to "remember" or engage in unnecessary mental manipulation (see Jonassen and Reeves, 1996, for a discussion of cognitive tools).

Seeking tools (e.g. keyword searches, topical indexes, search engines) help to locate and access resources. Seeking tools can also be specific to a particular context. For example "Sustainable Table" provides an educational portal that offer access to numerous resources, activities and games and promotes the positive shift toward local, small-scale sustainable farming. Sustainable Table was created to educate consumers on food-related issues, and to help build community through food. (http://www.sustainabletable.org/intro/).

Collection tools, ranging from paper-based worksheets to high-end PDAs, aid in amassing resources and data for closer study. Learners might use collection tools as they explore a learning space or after completing a tour. For example the MEATRIX site (http://www.themeatrix.com/interactive/), which includes an animated, 360 degree interactive industrial dairy farm scene, provide an entertaining way to give students an overview of the problems associated with factory farms.

Organisation tools are used to represent and define relationships among ideas, concepts, or "nodes". Like collection tools, organisation tools range from electronic to non-electronic devices. Concept mapping tools (e.g., www.insparation.com) are powerful devices that enable users to demonstrate relationships and links between and amongst ideas.

Integration tools help learners to relate new with existing knowledge, which helps to both organise and integrate ideas. Integration tools might range from a word processing program to a web site. The depth and breadth of what is represented by a single tool or set of tools vary according to the needs and abilities of the user.

Generating tools as simple as a web site or as sophisticated as a modelling tool (e.g. SimEarth), help learners to create "objects" of understanding.

Manipulation tools, which also range in their complexity, are used to explore beliefs and theories-in-action.

Finally communication tools (both synchronous and asynchronous) support efforts to initiate or sustain exchanges among learners, teachers, and experts.

3.2.4 Scaffolding

Scaffolding – support provided to assist learners and subsequently faded (Vygotsky, 1980) – varies with problem(s) encountered and the demands of the enabling context. Four types of scaffolding could be useful in exploring ways for the introduction of RBL in formal learning environments: conceptual, metacognitive, procedural and strategic.

Conceptual scaffolds guide learners in what to consider, identifying knowledge related to a problem or making organisation readily apparent. Worksheets have traditionally been used in formal learning settings to help guide students as they explore a new concept or a topic. Conceptual scaffolding might be extended through communication tools in the form of leading questions or scenarios that set a context for the learners on a web site. Problem based learning makes considerable use of conceptual scaffolding to help guide learners as they explore new areas and build understanding (Knowlton and Sharp, 2003).

Metacognitive scaffolds support the underlying cognitive demands in RBL, helping learners to initiate, compare, and revise their approaches. Scenarios or cases are often used to focus and guide the learners as they explore and attempt to understand. Scenarios or cases can present ideas for learners to consider as well as checkpoint where learners examine their understanding, seeking to uncover what they do and do not know or understand (Kolodner, 1993).

Procedural scaffolding aids the learner while navigating and emphasizes how to utilize a learning environment's features and functions. WebQuests, for example, use procedural scaffold extensively and have been used in a variety of contexts and content areas. According to Bernie Dodge, the primary creator, "WebQuests are designed to use learners' time well, to focus on using information rather than looking for it, and to support learners' thinking at the levels of analysis, synthesis and evaluation". By focusing on "how to", procedural scaffolds free up cognitive resources for other important learning activities (e.g. problem solving, higher-order thinking).

Resource-Based Learning Scenario

Imagine a student engaged in a course of astronomy, engaged with the topic of Sun Rotation. A traditional top-down approach would start with learning theory, followed by doing one or two experiments in a lab and concluding with an examination. An alternative approach based on problem-based learning is starting with a research question (e.g., "How fast does the Sun rotate?") and provide the student with the means and support needed to pursue that question. The student has the opportunity to actually experiment with the telescopes and be able to construct a recommendation for the way of calculation of the rotation speed of the Sun. Theoretical knowledge would be directly applicable to this realistic endeavour, and hence it will be easier to integrate this into student's existing knowledge.

While on such a mission, students perform several types of learning actions that can be characterized as productive (experiment, game, share, explain, design, etc.), students encounter multiple resources, they collaborate with varying coalitions of peers, and they use changing constellations of tools and scaffolds (e.g., to design a plan, to state a hypothesis etc.). Fulfilling such a mission requires a combination of knowledge from different domains (e.g., physics, biology, engineering and/or social sciences). Scaffolding will take place by dedicated scaffolds and tools that will assist learners in all aspect of the inquiry and design processes. Scaffolds will include tools for data collection in the lab and in the field (using mobile equipment), means to create intuitive and mathematical models of phenomena, visualizations of data and processes of inquiry and collaboration and templates for the creation of reports and designs.

Finally, strategic scaffold provide ways to analyze, plan and respond, such as identifying and selecting information, evaluating resources, and integrating knowledge and experience. Several models have been particularly useful in selecting and evaluation resources. The I-Search process (Joyce and Tallmann, 1997) strategic scaffolding focuses on integrating knowledge and experience. I-Search enables learners to select a topic of personal interest, then guides through the process of finding and using information and developing a final product.

3.3 Opportunities and challenges with Resource-Based Learning

RBL creates opportunities for the qualitative upgrade of both teaching and learning, heretofore unavailable, optimising the affordances of available and future technologies across a range of diverse settings.

RBL enables access to multitude of perspectives on a given phenomenon. One of the most completing characteristics of RBL is the ability to view a variety of resources from a potentially unlimited number and range of perspectives. This is currently apparent in how textbooks are used in formal learning settings. Textbooks are often written from a particular perspective to promote a specific view of events and processes. Digital resources may also be written from a particular perspective, but ready access and easy cross-referencing enable extended access to more resources and therefore, multiple perspectives.

RBL can be implemented in a variety of contexts. RBL approaches change both the nature and also the role of traditional resources (e.g. books), as well as the contexts in which they are used. RBL frameworks can be applied in multiple contexts, ranging from formal to informal, electronic to physical, specific to distributed locations, and at particular through unlimited time.

RBL facilitates learner-centred approaches. While RBL tends to focus on individual approaches to learning versus teacher or large group approaches to learning, it is not inherently limited to one-to-one interactions. Learners (individually, in small groups, or classes) can access a multitude of electronic, print and physical resources to assist with their learning in an RBL context. While the individual needs maybe addressed, it does not necessarily follow that student work is isolated or without guidance. Learners may receive guidance or direction from an expert peer (e.g., an astronomer) via a communication tool. The key RBL focus is what the individual learner needs to facilitate growth in knowledge and understanding, not simply the group size or ratio; thus learner-centred approaches are not only supported but encouraged through RBL.

RBL cultivates key skills and competencies. The skills and the competencies of the learners in the Knowledge Society are different from those of generations past. With the explosion of knowledge, resources and challenges, learners need more strategic approaches to identify what is important and the depth of knowledge or skill needed in different contexts. Increasingly, learners need to discriminate when "knowing that" versus "understanding why" is appropriate or necessary. Given the prevalence of inaccurate, questionable, and contradictory evidence, assertions and propaganda expands geometrically. It is no longer sufficient for learners to simply master what they encounter; they also need to demonstrate greater critical thinking, problem solving, reflection and self-direction than past generations. The use of open questions e.g. "how fast does the Sun rotate?" for example, stimulate an investigation rather than simple answer-seeking and engages the students in critical examination, reflection, and manipulation of multiple resources, thereby cultivating needed information seeking and evaluation skills.

The potential of RBL is considerable. Whereas conventional teaching approaches address known learning goals using well-organised sequences, resources, and activities, methods for supporting context-specific, user-centred learning have been slower to develop. Increasingly, individuals evaluate a vast number of digital resources located in expanding information repositories. Individuals must recognise and clarify their learning needs, develop strategies to address these needs, locate and access resources, evaluate their veracity and utility, modify approaches based on learning progress, and otherwise manage their teaching or learning. RBL enables teachers and learners to take advantage of the information systems we now have available, expending the resources they use to enhance the teaching and learning process.

4 CONTEMPORARY APPROACHES TO SCIENCE LEARNING

Inspiring Science Education focuses on engaging students in inquiry learning based on remote and virtual labs, tools and databases (online) labs in order to let them learn about science topics, to have them acquire scientific skills, enculture them in science communities, and to let them develop an interest in science careers. In this chapter we describe what is currently known about inquiry learning with simulations and remote and virtual labs, as well as their current implementation paradigms, and then we discuss how Inspiring Science Education initiative brought the current state of knowledge a step further.

4.1 Inquiry learning and TEL environments

Nowadays there is at large consensus that inquiry based approaches to learning science incorporating students' active investigation and experimentation are necessary to motivate students for science (e.g., Osborne & Dilon, 2008; Rocard, et al., 2007) and that, therefore, inquiry should be part of the curriculum also because inquiry skills have a value on their own (e.g., National Research Council, 2000; National Science Foundation, 2000; The National Academies, 2011). Inquiry is the process in which students are engaged in scientifically oriented questions, perform active experimentation, formulate explanations from evidence, evaluate their explanations in light of alternative explanations, and communicate and justify their proposed explanations (National Research Council, 2000). There is also overwhelming scientific evidence that inquiry leads to better acquisition of domain (conceptual) knowledge (de Jong, 2006a). A recent meta-analysis reviewing 138 studies indicated a clear advantage for inquiry-based instructional practices over other forms of instruction in conceptual understanding that students gain from their learning experience (Minner, Levy, & Century, 2010).

Contemporary, Technology Enhanced Learning (TEL), approaches to science learning provide students with ample opportunities for inquiry. TEL environments that offer simulations, games, data sets, and/or remote and virtual laboratories are significant in this respect. In these environments technological affordances are directly used for pedagogical purposes in that inquiry calls for non-linear, manipulable, and runnable content which technology is able to offer. Evidence is accumulating that TEL inquiry environments provide students with genuinely effective learning opportunities and large scale studies show that, on different outcome measures, TEL-based inquiry outperforms more direct approaches to instruction (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Deslauriers & Wieman, 2011; Eysink et al., 2009; Marusid & Slisko, 2012; Scalise et al., 2011; Smetana & Bell, in press). These promising results, however, only hold when the inquiry process is structured and scaffolded. Scaffolds thus play a pivotal role in inquiry learning. Scaffolds come in many kinds. Examples are tools to create hypothesis, data analysis tools, and tools to save and monitor experiments.

Currently a growing number of TEL inquiry environments have emerged that provide students with inquiry facilities together with integrated supportive structure and scaffolds. Examples of such learning environments are: Smithtown (Shute & Glaser, 1990); Belvedere (Suthers, Weiner, Connelly, & Paolucci, 1995); BGuILE (Reiser et al., 2001); BioWorld (Lajoie, Lavigne, Guerrera, & Munsie, 2001); Inquiry Island (White et al., 2002); GenScope (Hickey, Kindfield, Horwitz, & Christie, 2003; Hickey & Zuiker, 2003); SimQuest-based environments (de Jong et al., 1998); Co-Lab (van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005); WISE (Linn, Davis, & Bell, 2004); STOCHASMOS (Kyza, Constantinou, & Spanoudis, 2011); and SCY (de Jong et al., 2010). All these environments are based on simulations and/or remote labs.

Inspiring Science Education Demonstrators and user generated scenarios follow the approach of inquiry learning as exemplified in the projects mentioned above and in doing this we focus on (combining) remote and virtual labs and integrate them with supportive eLearning tools and scaffolds. In the next sections we zoom in on the virtues of remote and virtual laboratories and its combination and will then discuss the role of scaffolds.

4.2 Remote and virtual laboratories for inquiry learning

Do we need real, physical, laboratories for learning? The first question we should state is if online labs can replace real, physical, laboratories. Real laboratories are used in education for a multitude of reasons. Hofstein and Lunetta (2004), for example, described the values of real laboratory experiments for science education and mention understanding of scientific concepts and interest and motivation as main reasons for using laboratories. Balamuralithara and Woods (2009) list thirteen objectives for the use of physical laboratories which include awareness of safety procedures, and learning how to use humans' senses for observations. Also Feisel and Rosa (2005) present a list of objectives in real laboratories that include learning from failures and learning to work in teams. As an advantage for physical laboratories, some authors (e.g., Flick, 1993) emphasize a role for "physicality" for acquiring conceptual knowledge since it would trigger additional brain activities and also would enhance student motivation. However, studies that explicitly focused on the use of physical manipulatives (e.g., Chambers, Carbonaro, & Murray, 2008) do not find these advantages and also in comparison with virtual manipulatives the assumed advantages of physicality could not be found (e.g., Corter, Esche, Chassapis, Ma, & Nickerson, 2011; van Klink, Wilhelm, & Lazonder, submitted; Yuan, Lee, & Wang, 2010; Zacharia & Olympiou, 2011). Direct comparisons of the effects of physical and virtual laboratories on the acquisition of conceptual knowledge of the domain show that both approaches can be equally effective for learning but that in a number of cases virtual environments led to better results. Studies that found real and virtual laboratory experiments of equal effectiveness for acquiring conceptual knowledge are Wiesner and Lan (2004, chemical engineering), Klahr, Triona, and Williams (2007, physics (designing a car)), Winn, et al. (2006, oceanography), Zacharia and Constantinou (2008, phyiscs (heat and temperature)), Zacharia and Olympiou (2011, physic (heat and temperature)), and Corter, et al. (2011, mechanical engineering). Triona and Klahr (2003, physics (springs)), who focused on the acquisition of inquiry skills, also found that simulated and real experiments were equally effective. Other work shows an advantage of virtual labs over real laboratories: Chang, Chen, Lin, and Sung (2008, optics) compared students who worked with a physical optics laboratory with students learning with simulations, Huppert, Lomask, and Lazarowitz Huppert (2002, microbiology), Finkelstein, et al. (2005, electrical circuits), and Bell and Trundle (2008, moon phases). Overall, we can conclude that the literature supports the idea that remote and virtual (online) labs can replace direct (or face-to-face) access to real physical laboratories.

4.3 The distinctive virtues of remote and virtual labs

The fact that physicality is not relevant for learning makes that remote laboratories can be used instead of real physical labs. *Remotely-operated educational labs* (“remote labs”) provide students with the opportunity to collect data from a real physical laboratory setup, including real equipment, from remote locations. As an alternative there are *virtual labs* that *simulate* the real equipment. Remote and virtual labs both have specific advantages for learning.

The first advantage of remote labs is that they do not mimic the real lab but students actually operate on real equipment. Remote labs thus give a more realistic view on scientific practice, including practical aspects such as occupied equipment etc. It, therefore, also give students a more realistic view on real lab work. Another advantage of remote labs is that measurement errors are present by nature, whereas in virtual environments measurement errors are often ignored. Competency in a domain includes knowledge that measurement errors (of different kinds) exist and how to deal with them (Toth, Morrow, & Ludvico, 2009). The reading of instruments in a virtual environment, for example, (with even a possibility to zoom in) is by nature easier than reading real instruments. Maisch, Ney, van Joolingen, and de Jong (2009) showed that knowledge about measurement errors that is acquired outside a laboratory context doesn't easily transfer to the students' actions in a physical laboratory which suggests that real laboratory experiences may be important. Learning, however, is not all about cognitive challenges and outcomes; also enthusiasm and engagement play a role. Compared to research on cognitive outcomes results on motivational aspects of online and real labs is scarce but there are indications that real and remote labs lead to higher student motivation than simulated labs. Corter and colleagues (Corter, et al., 2011; Corter et al., 2007), for example, who compared a real, remote and simulated lab on the same (mechanical engineering) topic found no differences in learning outcomes but found that student appreciated the remote and real labs more because of their realism. Kong, Yeung, and Wu (2009) also report that both teachers and students show high involvement in remote laboratories.

Concerning the ease of experimentation the advantages go in the direction of virtual labs. In virtual laboratories students can experiment without any costs and can more easily and repeatedly experiment so that ideas can be quickly tested and evaluated. Another advantage for virtual laboratories is that reality can be adapted to serve the learning process. Reality can both be simplified by taking out details (and thus lowering fidelity) or be "augmented" by adding specific features to reality (such as adding vectors to moving objects). Lowering fidelity means that the requirements on students are less severe which may add learning (Alessi, 1988). Augmenting reality means that concepts that are not visible for students in the physical laboratory now become visible (such as the flow of electric current, see e.g., Jaakkola, Nurmi, & Lehtinen, 2010).

In conclusion, remote and virtual labs both have their specific virtues to bring to the learning situation; each of them also focusing on partly overlapping but also different learning goals (Ma & Nickerson, 2006). Our next exploration is how to potentially combine remote and virtual labs.

4.4 The best of both worlds: Remote labs in combination with virtual experimentation facilities

Since remote labs are offered over electronically, remote labs already offer some of the advantages of virtual labs in the sense that remote labs can be extended by augmentations and cognitive scaffolds, thus gaining some of the evident advantages of virtual labs (see the next section). However, also in remote labs, experimentation is as time consuming as in real labs and, therefore, recent research started to develop and investigate combinations and sequences of the two. There are different possibilities here: blending (Olympiou & Zacharia, 2012; van Joolingen, et al., 2005) and alternating both modes for the same (Jaakkola & Nurmi, 2008) or different contents (e.g., Zacharia, Olympiou, & Papaevripidou, 2008). Blending means that characteristics of virtual labs, such as augmentations, are added to remote labs (Yueh & Sheen, 2009). Most of the work, however has been on placing both versions in order and most of those studies showed that a virtual lab preceding a real (or in our case) remote lab is advantageous for learning. Example studies are Zacharia and Anderson (2003) mechanics, optics, and heat and temperature; Akpan and Andre (2000) on the dissection of a frog, Martínez-Jiménez, Pones-Pedrajas, Climent-Bellido, and Polo (2003), Zacharia (2007) on electrical circuits, Zacharia, et al. (2008) on heat and temperature, Jaakkola and Nurmi (2008) and Jaakkola, Nurmi, and Veermans (2011) on electrical circuits, and Dalgarno, Bishop, Adlong, and Bedgood Jr (2009) on a chemistry laboratory. From a more cognitive point of view there are indications that the combination works because students have to compare different types of representations. Jaakkola, et al. (2010) report a study in which they videotaped students who constructed electrical circuits only in a simulated environments with students who first made this virtual construction and then made the same circuit in reality. These video data made clear that students in the combined condition profited from the fact that they had to compare two representations that sometimes differed and had to go into abstract reasoning to explain these differences. A similar finding was reported by Goldstone and Son (2005) who found that offering both abstract and concrete representations in a simulation helped the student understand the principle behind the simulation. In this study it appeared that students who moved from a concrete to an idealized simulation outperformed other students on immediate and transfer test. In Inspiring Science Education we demonstrate different ways to combine remote and virtual experimentation facilities. In any case, both remote and virtual labs need scaffolds to function effectively.

4.5 The role of scaffolds in inquiry learning with online labs

Scaffolding refers to support (dedicated software tools) that helps students with tasks or parts of a task that they cannot complete on their own. Scaffolds aim at the different learning processes that constitute inquiry learning. For example, they can help students to create hypotheses (van Joolingen & de Jong, 1991), design experiments (Lin & Lehman, 1999), make predictions (Lewis, Stern, & Linn, 1993), formulate interpretations of the data (Edelson, Gordin, & Pea, 1999), reflect upon the learning process (Davis, 2000), plan and structure their work (van Joolingen, et al., 2005), and monitor what has been done (Hulshof, Wilhelm, Beishuizen, & van Rijn, 2005). We can also scaffold the complete process by having student work with an inquiry cycle (Manlove, Lazonder, & de Jong, 2007). Different types of structuring and scaffolds and their effects on knowledge acquisition have been overviewed in several studies (Bell, Urhahne, Schanze, & Ploetzner, 2010; Chang, et al., 2008; de Jong, 2006b, 2010a, 2010b; de Jong & van Joolingen, 1998; Fund, 2007; Linn, et al., 2004; Quintana et al., 2004; Sandoval & Bell, 2004; Zhang, Chen, Sun, & Reid, 2004). In any case meta-analyses (Alfieri, et al., 2011) show that inquiry learning is only productive when the inquiry process is structured and scaffolded.

4.6 Collaboration in lab work

In addition to being an excellent context for learning activities, lab work also forms a unique setting to develop soft skills such as autonomy and collaboration (Corter, et al., 2011; Feisel & Rosa, 2005). In modern labs work is always done in teams and the ability to work with others is a requirement for skilful lab work (Dunbar, 1999). One of the intended outcomes of learning with Inspiring Science Education online labs is that students acquire those skills. Looking at this issue from the other side, collaboration also helps to raise students' conceptual knowledge and inquiry skills in an inquiry learning situation. There is a growing awareness that knowledge construction processes are influenced by the social setting in which they take place. Collaboration is widely used and recognized as a way to enhance student learning (Lou, 2004; Lou, Abrami, & d'Apollonia, 2001). The positive effects of collaboration can be explained by the fact that engagement in a collaborative learning task provides students with the opportunity to talk about their own understandings and ideas. Inquiry learning tasks allow students to express and explore their own strategies and conceptions. During inquiry learning, students must make many decisions (e.g., which hypothesis to test, what variables to change), in a collaborative inquiry learning setting, students are invited to share these plans and ideas with their partner(s). This means that when students work collaboratively, they need to externalize their ideas; they must provide arguments and explanations so that their partner is able to understand and evaluate their ideas and plans (Teasley, 1997). Externalizing thoughts and ideas is believed to increase students' awareness of flaws and inconsistencies in their own reasoning or theories and to stimulate students to revisit their initial ideas. A study by Okada and Simon (1997) compared the inquiry learning behaviour of individual students and dyads in a molecular biology learning environment. They found that dyads considered more alternative hypotheses and carried out more useful experiments than individuals. The generation of an alternative hypothesis was often triggered by a question or a remark from the learning partner. In a recent study Kolloffel, de Jong, and Eysink (2011) confirmed the effectiveness of collaboration in inquiry learning settings. Specific scaffolds might assist the collaboration process. For example, Gijlers and de Jong (2009) introduced a tool that visualized students' conflicting ideas and prompted students to think about conflicting ideas. In Inspiring Science Education, in order to minimize the change in classroom scenarios, while maximizing the advantages of lab activities, the collaborative learning part is considered as a face-to-face activity limited to classmates. However, Emerging Learning Objects (traces) produced by students in the course of their inquiry learning activities would optionality be shared with others in the Inspiring Science Education Portal (see, de Jong, et al., 2010). Inspiring Science Education Demonstrators scenarios provide guidelines on how to structure and scaffold collaborative inquiry with online labs and supportive tools in the classroom.

4.7 Conclusions from the overview of the literature

The general conclusions from this literature overview are:

- Inquiry based approaches are more effective for acquiring conceptual domain knowledge than traditional more directive forms of instruction,

- For learning domain knowledge, real, physical laboratories are not necessary and can better be replaced by remote or virtual (online) laboratories,

- Remote laboratories and virtual laboratories to a large extend have overlapping characteristics and advantages, but also a few specific virtues, such as ease of experimentation for virtual labs and motivations in remote labs. Recent studies have shown that combining remote and virtual labs might render most effective form of inquiry learning.

- Inquiry learning in remote labs will only be effective if the inquiry process is structured and/or scaffolded.

- Collaboration between peer students is an important learning asset that can be realized in working with online labs, but this collaboration is not necessarily carried out online as well.

In the framework of the Inspiring Science Education large scale experimentation we focused on providing students with experimentation facilities through (combinations of) remote and virtual laboratories, eLearning tools and data sets. We also believe that next to being advantageous for acquiring cognitive knowledge and skills, these types of environments are also very suited to raise students' interest in science. To map this development an integrated approach was used by introducing the assessment of the problem solving competence in the educational activities.

4.8 Existing online labs and the barriers that prevent their uptake

Nowadays, access to remote or virtual laboratory facilities is provided in blended learning or distance learning frameworks for schools, universities of science and technology, as well as universities of applied sciences (Auer & Gravier, 2009; Gustavsson et al., 2009; Kong, et al., 2009; Tan & Gillet, 2005). These remote labs are offered by large scientific organisations such as ESA or CERN, by more pedagogically oriented organisations such as NUCLIO, or by universities, such the Faulkes Telescope Project and IASA, as individual providers (like SIVECO, SetApps, and Learnin3D) or as members of online lab consortia. The labs offered differ widely in domain, intention, interface, and learner support.

The diversity of the accessible online labs is, of course, a great advantage, as teachers may exploit them in their lessons to cover many topics. This diversity, however, also partly form the foundation for a number of barriers that prevent teachers from adopting remote labs as learning resources. These barriers are:

- Existing online labs usually have no structuring and scaffolding for the inquiry process (Cooper & Ferreira, 2009),

- Existing online labs differ in interface and usage possibilities which makes them less usable in the classroom,

- Another potential barrier to use online labs is that they are not geared towards a specific age group and therefore often do not fit. As stated before, Inspiring Science Education takes a quite wide age range on board (10-18 years old) and does intend to offer different interfaces for a given lab depending on the targeted user group.

- Existing online labs are not organized along domains (rather on topics) which makes that teachers cannot integrate more online labs over a longer period,

- For existing online labs it is often unclear where they fit into STEM curricula,

- Most STEM teachers are not aware of online lab technologies and hence do not grasp their benefits,

- Teachers are not sufficiently trained in using online labs: they rarely implement activities in class unless they feel confident with the process and can troubleshoot problems,

- There is no support for teachers from the online lab owners,

- There is no community of teachers who use online labs,

- There is no tools or support to easily customise, localized or repurpose online labs for alternative scenarios or different contexts,

- ICT infrastructure in schools may not be sufficient for use of online labs, e.g., difficulty to book computer laboratory time, low bandwidth Internet access.

Existing online labs often required browser plug-ins that may not be up to date and can only be updated by system administrators in schools. These barriers force teachers, if they use online labs, to only exploit them on an incidental base. In the framework of the development of the Inspiring Science Education Federation we have focused on removing those barriers (in sequence of the bullets above): by offering structure and scaffolding for experimentation with online labs, by providing students with a standardized interface, by making online labs adaptable to context (age, discipline, language), by organizing online labs following “big ideas”, by indicating where online labs (and the associated activities) fit into a curriculum, by setting up extensive awareness building activities, by providing teachers with dedicated support facilities, connecting schools and lab-owners, by creating and strengthening online teacher communities, and by organizing dedicated support infrastructures and events.

5 PEDAGOGICAL INNOVATIONS IN INSPIRING SCIENCE EDUCATION

The main goal of the Inspiring Science Education initiative was to bring existing online labs (as single labs or exiting federations of labs) accessible and usable by students and teachers on a large scale. Pedagogical innovations in Inspiring Science Education affect both students and teachers and are developed with the single objective to bring online labs within the realm of the classroom. For students, the first main innovation that Inspiring Science Education achieved was to bring all online labs under a similar structure and extend them with online tools and educational materials. As indicated above structure and scaffolds are key to successful inquiry learning and most online labs lack these facilities. Still, Inspiring Science Education Demonstrators can be personalized by teachers when they compose the learning scenario from the Inspiring Science Education Inventory. A second pedagogical innovation for students concerns the combination of remote and virtual labs. Trying to find the right, and most effective, balance between remote, and thus still real, laboratory-based inquiries and their simulated counterparts is a challenge that the Inspiring Science Education approach tackled. Students were also able to collaborate with other students by sharing emerging learning objects. For teachers, Inspiring Science Education pedagogical innovations focus on the areas of pedagogical plug-and-play and teacher communities.

5.1 Structuring, scaffolding, and personalising the inquiry process

To structure and scaffold the inquiry process, Inspiring Science Education approach designed an inquiry cycle and a set of scaffolds (tools) that are basically domain and age independent but that can be adapted to fit a certain age or a certain domain. Whereas most available inquiry cycles are domain and age independent, scaffolds and tools often have a domain specific, and sometimes age related, character. The challenge in the framework of the large scale experimentation was to develop an inquiry cycle that provides students with a single recognizable inquiry structure that still can be personalized to domain and age, and potentially other student related characteristics. As example, for less experienced students an inquiry cycle should include a phase in which theoretical variables and experimental parameters are related; for more experienced students this phase could be redundant. The Inspiring Science Education portal will allow teachers to compose learning spaces dedicated to their students from a set of options that are offered. Another pedagogical challenge was to define mechanisms to personalize the proposed Demonstrators during the inquiry process. Experiences from earlier projects (e.g., ODS and SCY) on learning analytics and educational recommender systems were brought in but these needed to be moulded to fit into the Inspiring Science Education scenarios. Related to the above listed challenges is that in Inspiring Science Education it was necessary to find principles to decide which support should be given to the students online and which support should be given by the teacher. There are two reasons to involve the teacher: one is that in some cases teachers are better equipped to give some kinds of support and the other is that to get real involvement in the classroom the teacher should play an active role. Inspiring Science Education initiative created an innovative instructional design for classroom inquiry instructions using the proposed Demonstrators and in this respect extended on work on blended learning (see e.g., Bonk & Graham, 2006).

5.2 Pedagogical Plug and Play: Focusing on Big Ideas of Science

The concern that was expressed in the previous section to equip people with the ideas they need for dealing effectively with science-based questions and decisions in their daily lives positions the discussion firmly in the field of science education. Yet it leaves open the questions of whether the big ideas conveyed through studying the natural world in school should be the same as those created through the activity of scientists. In the Inspiring Science Education approach it is obvious that they should be the same. Otherwise a disastrous gap could open up between 'school science' and 'real science'. But what about the advances made by scientists working at the frontiers of knowledge in almost every domain of science – for instance using the Large Hadron Collider (LHC) to explore conditions at the time of the 'Big Bang' or decoding the genomes of organisms – which depend on complex knowledge surely far beyond school students? These investigations may well lead to new ideas about the origin of the Universe and what determines the differences among organisms. The Inspiring Science Education scenarios demonstrated that although the route to creating and testing new ideas may involve some extremely complex technologies to collect relevant data, the underlying ideas are not necessarily too complex for school students. As often happens, once identified, ideas can seem very obvious. Even phenomena studied in the LHC and genomics are understandable at some level by someone who has understood that 'all material is made of very small particles' and that 'the cells of all organisms contain genetic material which helps determine their characteristics'. The Inspiring Science Education consortium proposed an organization scheme for the development of the federation that helped teachers to introduce to their classrooms educational activities that reflect the big ideas of science, expressed in ways appropriate to learners at various stages in cognitive development. In this context all labs, tools and scenarios were classified following a list of big ideas of science. Defining a relevant set of big ideas and positioning the online labs on this set was one of the major pedagogical innovations in Inspiring Science Education. Furthermore, in Inspiring Science Education we have designed the Demonstrators in such a way that they are modular enough to be easily included, that they are adaptable so that they can be adjusted to a certain extend to the curriculum, and that they are tagged with appropriate metadata so that teachers can find the activities that fit their needs. These actions were based on curriculum analysis that was carried out during project. The project has designed one overarching approach to ensure that the proposed Demonstrators will find their way into curricula of different countries. This has helped teacher to place an online lab at the correct place in the curriculum.

5.3 Combining virtual, remote experiments and online tools

The clear trend in the literature, as described above, is that benefits can be gained from combining physical, in our case remote, and virtual laboratories. In Inspiring Science Education, the complementarity between real scientific equipment and instruments (remote laboratories), their model-based simulated, emulated or animated versions (virtual experiments), as well as the associated acquired or generated scientific data sets was explored. The components of this "trinity" are the essence of the Inspiring Science Education online tools and are exploited concurrently or sequentially in inquiry-based learning activities. As example, augmented reality interfaces to online labs combined live video of the real equipment with virtual view animated with acquired data. It could be that both the more reflective attitude needed in remote labs and the more quick experimentation facilities in virtual labs are complementary, it could be that students who have to change between different representations learn from the abstractions they have to make, and it could be that the augmentations and the fact that experiments can be accelerated and slowed down in virtual labs offer should be combined with the realism and higher motivation gained from realistic interfaces. One of the challenges in Inspiring Science Education was to find out what kind of combinations of virtual and remote labs are most beneficial for learning. One issue that was specifically explored here was that students can understand that science is about models (for conceptualization and prevision), and that models have to be validated by comparing the real world with its current (virtual) conceptualization. In a number of selected cases we created combinations of remote and virtual labs and perform in-depth studies into the cognitive processes involved.

5.4 Student collaboration and student-scientist interaction; designing innovative classroom scenarios and extra school activities

In the state of the art description we indicated that collaboration is a common way of working in performing scientific experiments and also that collaboration between students, also in inquiry settings, is beneficial for learning. Therefore, there are diverse and several reasons to stimulate collaborative learning with Inspiring

Science Education online labs. To implement this we had to explore new avenues to introduce collaborative learning with online labs in the class. Our solutions were integrated in numerous classroom inquiry scenarios that were developed. In developing those innovative scenarios we took inspiration from existing scenarios such as for example the jigsaw approach (Aronson, Blaney, Sikes, Stephan, & Snapp, 1978) that has also been applied in STEM education (Springer, Stanne, & Donovan, 1999)

In the context of collaboration the project created numerous virtual learning communities of educators, students and researchers and involved them in extended episodes of playful learning in the framework of the large scale experimentation implementation. In this way we have involved teachers, students and researchers in collaborative learning activities that promoted the integration of inquiry-based activities in the school curriculum. Being part of a professional network encouraged interaction and provided them with opportunities to enrich their practices and professional context through cooperation within and between schools, universities, and frontier research institutions, collaborative reflection, development and evaluation of instruction, exchange of ideas, materials and experiences, quality development, cooperation between teachers, students and researchers and support and stimulation from research. The development of this community was the major parameter of success of the Inspiring Science Education project.

Another innovation of Inspiring Science Education that stimulates collaboration between students and students and scientist was the integration of Inspiring Science Education online labs in existing initiatives. Hands on Particle Physics Masterclasses, for example, (http://www.physicsmasterclasses.org), initially implemented at a European scale in 2005 in the framework of the World Year of Physics is demonstrating to the students how science works (Johansson, Kobel, Hillebrandt, Engeln, & Euler, 2007). Each year about 6,000 high school students in 23 countries come to one of about 110 nearby universities or research centres for one day in order to unravel the mysteries of particle physics. Lectures from active scientists give insight in topics and methods of basic research at the fundaments of matter and forces, enabling the students to perform measurements on real data from particle physics experiments themselves. At the end of each day, like in international research collaboration, the participants join in a video conference for discussion and combination of their results. The Hands on Particle Physics Masterclasses is a powerful illustration of how rich and meaningful opportunities for people to participate in and learn about science can be offered. With the appropriate guidance from the research teams, students can use tools of science as they learned the practices, goals, and habits of mind of the culture of science. Similarly, in the framework of this initiative the scientific community responded to participants, modifying their project design as a result of feedback and continued interest in the project (Lewis, et al., 1993). Through this fruitful collaboration, the relationship between scientists and students evolved, resulting in all members contributing and gaining valuable scientific knowledge.

The Inspiring Science Education project has worked in cooperation with these successful initiatives and went one step further, by proposing ways that (through the effective use of existing remote labs and virtual experimentations) could scale them up to include more students and teachers. In this framework the joined Summer Academies in cooperation with FermiLab (USA) were organised in 2015 and in 2016. European and US teachers who are active in developing such initiatives came together and worked to develop new ideas and scenarios. By utilizing the use of existing applications, the project brought into the classroom activities that are based on real-world problems and involved students in finding their own answers and solutions, testing their ideas, receiving feedback, and working collaboratively with other students and researchers beyond the school classroom. For example following the model of Hands on Particle Physics Masterclasses, a series of virtual collaboration activities, called e-Masterclasses were designed and implemented, promoting inquiry based and problem solving processes in virtual and blended learning environments. In this case students performed the assigned tasks from their schools, allowing for more schools to be involved in the process. To this end, the Inspiring Science Education Federation offered innovative, interactive, collaborative and context-aware functionalities.

5.5 Teacher communities: Developing a “pull” rather than “push” approach

A major goal for the Inspiring Science Education initiative is to create efficient and effective teacher communities. The Inspiring Science Education Policy Support Action has implemented for a period of 3 academic years a large scale experimentation to mainstream the use of online tools and labs in STEM lessons in primary and secondary schools in Europe. There is plenty of evidence pointing to the difficulty of incentivising and empowering teachers to engage in innovation, especially in tightly accountable systems based on performance targets. On the other hand in education there is no shortage of energy and expertise, and certainly no lack of commitment or moral purpose amongst teachers. How could we support them, and give them the creative space and incentives they need to be innovative? What sort of interventions could both release professional imagination, whilst encouraging work that is disciplined and system relevant? How can the system learn from the resultant innovation and its process characteristics so that these can be taken to scale? Taken together, the evidence set out above and the questions and issues it raises suggest some assumptions, which in turn have influenced the educational design of the Inspiring Science Education project.

The combination of a methodology derived from the available evidence base, with a mobilised group of empowered practitioners motivated by a compelling purpose, supported by the key national bodies in the framework of existing initiatives that aim to mainstream both eLearning (A Digital Agenda for Europe, Action 68) and Inquiry Based Science Education (Rocard, et al., 2007) in the Member States, resulted in emergent Inspiring Science Education pilots that according to our opinion had system significance.

More than **10.000 teachers**, from more than **5.000 schools** were involved in this experimentation. These teachers have developed more than **6,000 educational scenarios and activities** which were implemented in their schools. More than **20,000 students were involved** in focused evaluation experiments using scenarios that included problem solving competence assessment tasks. More than **11,000 data sets were acquired** providing the largest data base of its kind in Europe.

In the framework of the Inspiring Science Education project the right group to work with was drawn from those practitioners who are already pushing at the boundaries of current practice in the chosen areas. They were well aware of practice deemed “best” – will perhaps have generated/adopted/adapted it. But they were conscious too of its limits, and have experienced the need to push on further, or in new directions. Skilled and self-confident, these are likely to be practitioners whose deep immersion, and success, in their work give them the platform upon which to contemplate risk and to lead others. Visionary and energetic, their ideas spring from immersion in practice: not in theory or in ideology. They may well be alert to and interested in such fields, but the practical applications for their own “day jobs” are paramount. Indeed, it is likely that they have a wide field of vision. They had a lively interest in the overall direction of the service in which they work, and be constantly scanning the environment for ways in which both to influence and exploit it. The development of the Inspiring Science Education users’ community was based on the effective integration of already established strong educational communities. These communities included: Galileo Teachers (8,000 teachers from different European Countries), COSMOS Community (more than 2000 teachers from many European countries are developing educational activities that promote inquiry based science education), DSPACE and Faulkes Telescopes users communities (more than 5,000 teachers and 10,0000 students are using the network of robotic telescopes of these virtual observatories), Masterclasses (every year, more than 6,000 students and their teachers are experiencing how science works), Learning with ATLAS@CERN Community (1,000 teachers are transferring the results of frontier research taking place at CERN to their classrooms). Such an innovation programme holds great potential. If we want a powerful innovative culture in schools which is self-sustaining we have to empower system-aware practitioners, working ever more closely with the service users, to create it. And to avoid simply creating interesting but isolated pockets of experimentation, we have to design in collaborative ways of learning and inquiry between professionals – a “pull” rather than “push” approach.

6 Recommendations for the integration of the Inspiring Science Education online labs in the school classrooms

This chapter presents a set of recommendations for the design of the Inspiring Science Education scenarios and for implementing and introducing the inquiry process in a science classroom. The recommendations are primarily based on the extended experimentation with more than 5,000 schools, 10,000 teachers and more than 20,000 students who were involved in the project's validation and evaluation activities conducted during the last two academic years (2014-2015, 2015-2016).

In conducting these evaluation and validation activities project members have been in close contact with teachers and with students when being present in different activities in the actual classroom settings or through the data collected from the Inspiring Science Education dashboard tool. In these contacts many informal but still very valuable impressions were gathered and these were used to complement the recommendations that could be formulated on the basis of the formal validation and evaluation.

The recommendations are grouped into three main categories: One set of recommendations focuses on ***how to design engaging inquiry scenarios*** and includes lessons learned from student interactions and outcomes from learning with the Inspiring Science Education demonstrators, so these recommendations focus on how to optimize the scenarios and the activities for students. The second set of recommendations concern ***ways to support the work of teachers in designing and implementing scenarios***. The recommendations here are coming from the extended community building process and the effectiveness of the community support mechanism that was developed. The third, and final, set of recommendations focuses on ***how to include inquiry scenarios into a curriculum*** so that students and teachers experience it as part of an integrated school approach. Following these recommendations lays the basis for the sustainability of the Inspiring Science Education Federation.

6.1 Recommendations on how to design engaging inquiry scenarios (for teachers and teachers trainers)

6.1.1 Put the lab work in a context

Students do experiments but don't see what the results mean and what the connection is with things they experience in daily life. Put the lab work in a context. Don't let the students do plain experiments. Presenting a context is not an aim in itself. By putting the experiment in a context the students can see why the experiment is important and see what their findings mean and where they can be applied.

6.1.2 Consider blended Learning

Consider designing scenarios for learning activities involving a blended combination of real and online labs, or even for lessons involving only real labs. A scenario and the inquiry based learning paradigm can still be useful for aspects such as orientation material, hypothesis generation, experimental design, recording and analysing results, revisiting hypotheses and reflecting on learning. A scenario using virtual labs can also be useful as a preparation activity for a real lab lesson, or for revision, learning reinforcement after a real lab lesson etc. Do not limit your vision.

6.1.3 Make students aware of the fact that there is no 'correct' answer

For many students the inquiry approach is new. In traditional education there is usually one good answer to a question. Often students also learn only one procedure to arrive at this correct answer. When they follow the procedure, and arrive at the correct answer, they know they have done well. With inquiry learning there is not just one 'correct' answer and there are many routes a student can take towards an answer. For many students, this is confusing. Students need to understand that there is not one way to go about an investigation. It is important to explain this to them extensively. Make clear that it doesn't matter whether their hypothesis is true or false, if it is well formulated. Explain that there is not a fixed number of experiments that they have to carry out, as long as they do enough to validate their hypothesis. Explain that there is not one way to design a good experiment, as long as they make sure the experimental design is sound. Students have to change their way of thinking, and this may take some time and effort to achieve.

6.1.4 Make scenarios which are mainly sequential

Where possible, even if this means repeating a lab or a tool, design scenarios in which the student will normally progress downwards through each phase and from left to right through the phases.

6.1.5 Organize text, tools, and videos in meaningful units

Inspiring Science Education scenarios include by default five phases. In some cases, the content per phases can become very extensive. If a phase contains very much information in the form of text, tools and videos students can easily get lost. Students need to scroll a lot and get lost and are be unable to find the information that they need. Or they are uncertain when to continue to the next phase. The risk that they accidently skip parts is considerable. Think carefully about how to organize text, tools, and videos. Make sure to restrict the amount of information per phase and limit scrolling to a minimum. To achieve this, split up tasks for your students. Make sure to balance text, videos and tools wisely. If an image, tool or video is mentioned in the text, it should be just above or below the corresponding text. Both should be visible on the screen at the same time and students should not have to scroll down to find the tool or image corresponding to your instruction. Add prompts or motivational comments to guide your students through the scenario. Especially information on when to proceed to the next phase, or go back to a previous one, is useful. For example, '*Well done, you now finished your first assignment'* or '*When you have done enough experiments to answer your research question you can continue to the conclusion phase'.* Check always the students view before implementing the scenario.

6.1.6 Introduce students to virtual or remote laboratories

Plan to introduce the online experiment before performing the activity. Demonstrate all the variables available in the experiment (such as dependent, constant and independent) ahead of time. Reduce the original instruction associated with laboratory usage and present it as a screen recorded video, set of images or short notes. Show only the laboratory features needed for the performance of the implied experiment. Create if necessary different scenarios each implementing unique features of remote and virtual experiments. To build excitement and engagement in the learning process, use different but connected physical mechanisms to investigate the scientific variables of interest.

6.1.7 Give students clear instructions

Students (especially the younger ones) need more instructions (guidance) than you would expect. Things that might seem obvious for a (more) experienced user (pressing a button or tab, clicking on an item to change its appearance or characteristics) are often not clear to new users. Put in the text explicit statements about what students are expected to do. For instance: "Now you have reached the end of the specific phase, press the tab to go to the next phase" or "Click on the tube when you want to change the characteristics of the fluent or from the ball in the tube. Then use the sliders in the top of the window to actually change the characteristics."

6.1.8 Monitor students' learning to estimate how much time is needed for inquiry instruction

Open-ended inquiry takes longer than structured and guided inquiry, and is most appropriate for students already comfortable with completing inquiry activities. For novice learners it is useful to adapt a scenario to fit the time constraints of a classroom lesson. To determine which parts of a scenario may take too long for beginners, it is useful for a teacher to use the Inspiring Science Education learning analytics apps to monitor the progress of students, and if a section is found to take too long then revise it appropriately. The Inspiring Science Education delivery environment offers teachers unique learning analytics apps to monitor the real-time progress of students, as well as easily visualise the recorded actions of students after they have finished working with a scenario. Monitoring students' progress and outcomes with Inspiring Science Education learning analytics is one useful way for teachers to become more aware of what and how well students are learning in the classroom, and to adjust teaching if necessary.

6.1.9 Stimulate students' critical thinking

Critical thinking is a higher-order cognitive skill that is not directly related to a specific subject. It is not effective to train those skills on their own. They should be integrated in subjects. Stimulate critical thinking for instance about reliability and repeatability of experiments. As with each skill, critical thinking needs practice. So regularly pay attention to this skill in your scenario.

6.1.10 Gradually increase complexity of the inquiry tasks

Students often find it difficult to start with a scenario that covers the whole inquiry circle because they are not used to inquiry learning. Make sure that students get a good introduction in the inquiry approach and the tools to be used. If you plan to do lab work and inquiry tasks regularly, be sure there is a gradual increase in complexity. Start with cookbook like experiments and end with real inquiry. For instance, you could start with inquiry tasks in which you give the students (parts of) the hypothesis/research question or limit the set of options. In this way the students can gradually get used to the inquiry approach.

6.1.11 Configure apps for less experienced students

For less experienced students, configure tools to provide increased support and guidance for students. For instance, you could offer many words in the Hypothesis for less experienced students to formulate their hypotheses. As students become more experienced, this support might be gradually removed. For instance, offer fewer words in the Hypothesis for more experienced students to formulate their hypotheses. If students succeed in formulating their hypotheses with lesser words, then this would be an indication that they had progressed in the skill of formulating hypotheses.

6.1.12 Enact on-the-fly formative assessment

For effectively executing an experimentation, hypotheses and experimental designs might be quite insightful in revealing student progress. The Inspiring Science Education assessment tools which are embedded in the scenarios offer a unique way to monitor the progress of the class over the whole period of implementation.

6.1.13 Configure apps by filling them (partially) with domain content

For less experienced students, configure scaffolds to provide them increased support and guidance. For instance, you would offer many words in the Hypothesis for less experienced students to formulate their hypotheses. As students become more experienced, this support might be gradually removed. For instance, offer lesser words in the Hypothesis for more experienced students to formulate their hypotheses. If students succeed in formulating their hypotheses with lesser words, then this would be an indication that they had progressed in the skill of formulating hypotheses.

6.1.14 Stimulate students to spend sufficient time on an lab or tool

Students sometimes tend to use too little time for an app or the design stimulates them to use too little time. Let students interact with labs and tools adequately and allocate enough time in the learning activity sequence so that students could have this necessary interaction. There seems to be a minimum amount of time that should be spent on a task, while working with a tool or in a virtual laboratory, so that students would effectively execute a series of learning activities. When less time than this threshold had been spent during a learning activity sequence, then the remainder should be devoted to working with tools and labs, when students re-visit former steps in their trajectories to re-work their learning products. For instance, if students had not identified all variables needed to undertake an experimentation or if they had not concluded all experimental trials to address a hypothesis, then they would need to move backwards in the activity sequence and devote additional time to working with the Hypothesis or the Experimentation and the virtual laboratory. This retrospective action might compensate for the time required to complete basic requirements of designing or executing a valid experiment. Retrospective action might also be beneficial in terms of facilitating metacognitive awareness of the learning activity sequence. However, enough time for interaction with apps and laboratories does not mean as much as one wishes to have! There is not only a minimum time requirement to handle apps and laboratories but there is also a maximum threshold, after which no learning gains are detected any more or after which student performance might even deteriorate. Increased time spent on an app or laboratory might indicate that students might be trapped in an unproductive trajectory.

6.1.15 Offer students a series of scenarios to reach an effect on inquiry skills

Be aware that whereas knowledge effects are immediate, inquiry skills effects take a longer time. Prepare an introductory scenario just before the one that you would wish to implement. For students who have their first encounter with a tool or a laboratory, there must be a time period of getting familiarized with it. This might take a whole scenario, which could be designed for familiarization of students with demanding apps or laboratories. Under this assumption, it would take at least two scenarios in a row to see some first positive effects on student inquiry skills. Taking a student-centered approach to assessment, we would need to evaluate student ability to undertake learning activities in different contexts, instead of just using pre- and post-test (both pre-specified) instruments. In that regard, we would expect that any gains in student inquiry skills would be revealed as long as they would effectively deal with a novel context of inquiry. This would mean that we should plan at least two scenarios in a row to be able to track student progress in the first scenario.

6.1.16 Consider that some tools may not work for some students but will be beneficial for others

Students with distinct levels of prior knowledge need different amounts and forms of support. If the topic of the scenario is entirely new to students, they need to orient on the topic before starting with their experiments. Make sure that each student has a basic understanding of the topic before they start. If they have this basic knowledge, provide them with tools that structure the task, but that also allow them to explore the topic without too many restrictions. Learners with higher levels of prior knowledge do not need additional support but adding advanced tools doesn't hamper their learning, too.

6.1.17 Giving higher levels of support is not always beneficial

It is not always the case that giving more support is beneficial for learning. When designing a scenario it may seem the best to give always the highest level of support. However this may not be the case. There seems to be a delicate interplay with domain and student characteristics that determine the effectiveness of an app. So, always observe very well how apps work with your students and don't be afraid to go to lower levels of support.

6.1.18 Create facilities in a scenario to revive prior knowledge

Misconceptions and gaps in student knowledge can greatly impact student learning. If the gap is too big students will not be able to relate the content of the scenario to their prior knowledge. This will make it difficult for them to give meaning to the things they do in the scenario. Apart from raising curiosity and gaining attention an important element of the Orientation phase is activation of the prior knowledge. This can be done in several ways. For instance, by giving students a quiz with questions that refer to things they have already learned. Or by asking students to make a concept map which graphically organizes the concepts that they already know (and their relationships). By doing this the students get a kind of mental hooks to which they can connect the new information.

6.1.19 Design scenarios suitable for a range of abilities

For a scenario delivered in the classroom context, different students will (rightly) work at different paces, and will benefit from different levels of intellectual challenge. To have bored students who finish early and have had little challenge is not a good outcome. If you have mixed ability classes, design scenarios which have mandatory activities for all students and some more challenging optional activities for those who finish the mandatory parts early.

6.1.20 Encourage collaborative work by students where appropriate

"Traditional" science teachers and especially those in countries where on-going student assessment is a high requirement, sometimes bring forward rather individualistic models of pedagogy into their implementation of Inspiring Science education scenarios. This approach leads to students becoming disengaged by traditional teaching and in the long-term, hampers the ability of students to work collaboratively, one of the most critical skills for today's society. Explore the potential of Inspiring Science Education Demonstrators for a combination of individual and group work. For any sections of the lesson where the students have to be assessed individually, a scenario should support individual efforts, but where collaboration is beneficial, design and write the scenario to encourage this. Imagine the student's experiential and learning journey through a scenario while you are preparing it.

6.1.21 Balanced mix of collaborative and individual work for students

Students are not engaged by traditional teaching anymore (with the student working individually) and most of the times, technology in the classroom is not used adequately to support student collaboration, as a skill for the future. Make sure that during the implementation and depending on the phase, students get the possibility to work both individually and collaboratively.

6.1.22 Create scenarios with much interactive content

As soon as students are using a computer (or other interactive device) they appear to expect a high degree of interaction. Design scenarios which are as interactive, stimulating, and enjoyable as possible, for the target age groups of students. Avoid long chunks of text reading wherever possible.

6.1.23 Make prudent and considered use of audio content

If a scenario is to be used in a classroom context, consider carefully whether, when and how to include any video or audio material, and how to deliver it. The use of headphones or earbuds can possible create a rather isolationist learning environment and may reduce the ability of the teacher to gain people's attention. If the video/audio material is in the Orientation phase, it may be worth the teacher playing it from the front to the whole group at once. In some cases, a silent video with subtitles may be better than an audible one.

6.1.24 Support students in setting up their experiments

Check students' experiments and their understanding of the topic of investigation when they have finished their investigations. If they have designed and/or conducted meaningless experiments, point out where and how they can improve their experiment design. Help by asking them what they did and give them suggestions on how to set up experiments that allow them to draw conclusions on research questions. For example, using extreme numbers in their experiments may help them to explore the boundaries of a domain; designing and conducting an experiment, then observe what happens, and based on the outcome design a new experiment also helps them to get a first understanding of the domain; varying just one variable and controlling for all other variables may help them to understand the effect of the varied variable on the results when they have a first understanding of the domain.

6.1.25 Encourage students to perform sufficient experiments

Monitor students' behaviours and knowledge. If you notice that someone has incorrect ideas about the domain, make sure that they conduct enough experiments to be able to adjust their initial ideas and draw correct conclusions instead.

6.1.26 Stimulate students to look at their data from different angles

If students have conducted enough useful experiments, but fail to analyse their results, show them how to better organise their data to draw meaningful conclusions. One way to better organise data is to sort the data in ascending or descending order. Also help them formulate their conclusions by asking them questions about their data. Make sure that students do not draw incorrect conclusions.

6.1.27 Don't use too many tools

If students work with Inspiring Science Education environment for the first time, make sure not use too many tools. Most of the Inspiring Science Education tools are quite intuitively and an effort is made to make sure that the user interface of each tool is similar. Still, students have to get familiar with each tool. Students need to put effort in to figure out how to work with them. That effort consequently won't be spent at the actual learning task at hand. Choose carefully which tools are included in a scenario. Make sure not to only include the tools that are easy to work with, but the tools that are most beneficial for students. This will help them realize the added value of the tools. Once your students are more familiar with the process, you can include more tools.

6.1.28 Add instruction videos about the tools

Include instruction videos about the tools. Inspiring Science Education repository offers very good short videos that explain exactly how to use a tool. Though these videos are aimed at teachers, they can easily be used in a scenario to benefit your students as well. These videos will display the sequence of task just as your students will and are easy to follow. Students can choose to watch the videos or not, depending on their own needs, and can choose to fast forward to the parts that are useful for them.

6.2 Recommendations to support the work of teachers in designing and implementing scenarios (for school headmasters and teachers trainers)

6.2.1 Teachers have to be the focal point

Choose a few (or even one) skilful and eager teachers in the school as ambassadors for Inspiring Science Education developments in your school. Teachers also have the flexibility to organize trainings and workshops to their colleagues, to informally share their practices with Inspiring Science Education and to disseminate the project activities further. Another critical point we have noticed is that, through teachers, the language barrier is bypassed. They can make their colleagues feel more comfortable to engage with Inspiring Science Education and can act as mentor and supporter.

6.2.2 Teachers have to utilise help and support facilities

Some teachers are daunted by the amount or complexity of work involved in designing and writing their own scenarios. Teachers should be encouraged to utilise the wide range of help and support facilities and opportunities for engagement afforded by the Inspiring Science Education environment.

- Use the support page (How to use ISE) or the online manual
- Make good use of (and contribute to) support resources: pre-written / recorded; self-helping community forum; tutoring
- Share and watch success stories
- Participate to current Inspiring Science Education activities
- Participate to the upcoming Inspiring Science Education trainings

6.2.3 Support teachers and students to adapt to and embrace new pedagogical style and roles in learning

Most of the learning material is either in the scenario or will be discovered by the students during the lesson. Therefore, teachers do not need to be seen as dispensers of knowledge adopting a didactic style; instead they will adopt a role of facilitating, supporting, encouraging, monitoring and assisting, but not one of leading or dictating. Similarly, students need to accept more responsibility for the direction and pace and effectiveness of their own learning. Teachers should be aware of this in advance, be personally prepared for a *change* of teaching style, and prepare their students for a change of learning style. One teacher wrote, reflecting on her implementation of scenarios for more than 10 lessons:

"I was able to step back as a teacher, more than I was expecting. As students progressed through the scenario my role became increasingly guide and facilitator rather than instructor. The students' own creativity began to show during the lessons, and they became more inquisitive … the fact that I can adapt my teaching to incorporate a new teaching style has also boosted my confidence. I feel that, with additional use of Inspiring Science Education, I can encourage students to become more independent thinkers, with myself as a mediator and support in the lessons. "

6.2.4 Encourage collaborative work by teachers

Many teachers don't think they have enough ICT skills (and time) to develop their own scenarios. And although there is an extensive support section on the web site this thought keeps them from trying to develop their own lesson material. Let teachers work collaboratively on a scenario so they can divide tasks and support each other, and to better root the experience in the organization.

6.2.5 Provide teachers with the opportunities and time to create their own scenarios

Teachers report serious lack of time in developing their own scenarios. Provide teachers with dedicated time and space to create their own scenarios. In this way they can adapt them better to their own and their school's needs and experiences. For example, one hour covered in their working day dedicated to class/lesson preparation, taking place in the school laboratory. Another approach could be cross-curricular projects where teachers can work together to prepare and build and scenarios which can serve several classes with minor adaptations. Inspiring Science Education repository is offering numerous scenarios that can be used also as a reference or starting point.

6.3 Recommendations on how to include inquiry scenarios in the curriculum (for teachers, teachers trainers and school headmasters)

6.3.1 Consider using the scenarios in a variety of contexts

Many teachers think that the developed scenarios are intended for use only in formal lessons, in place of real labs. Exploit the full potential of the Inspiring Science Education system, forum and other media to raise awareness of the greater potential it can provide education in multiple contexts; e.g., homework, revising for exams, distance learning, self-directed study, detentions, individual or team project work, excluded pupils, sick pupils, and by teachers providing "cover" for an absent teacher. Provide example scenarios on the portal for these varied contexts of use. A scenario can be designed with varying paths through it, or slightly different copies of a scenario, to allow for different contexts and modes of use.

6.3.2 Support the introduction of an Open School Culture

Envisage Inspiring Science Education as an integral part of the school's science curriculum delivery infrastructure, and explore how it can be integrated with other technical and pedagogical components. E.g., secure password-protected logons for students providing identity authentication, email systems, systems for distributing learning materials such as photos, presentations etc., systems to allow students to submit work for assessment, and to access their marks and feedback, and sometimes other fully-specified learning management environments such as Moodle or Google Classroom. Support the parental engagement in scenarios that describe long term projects. Inspiring Science Education can support the development of an Open School culture in the school.

6.3.3 In school 'peer-review'

Teachers, especially beginners and those with little experience with the proposed approach, do not feel that confident when creating scenarios. It is also difficult for them to judge the quality of their scenarios and its proper functioning. At the same time, it is difficult for teachers to engage other colleagues when they haven't attended previous practical sessions or trainings. Another teacher to test newly created scenario, both for functioning and timing. This process will warrant the adequacy of the scenario for the students it was targeted while promoting the use of Inspiring Science Education within the school department. Comments and tips may be also attached to the internal school community or in a community that has been developed for such purpose from the school headmaster.

6.3.4 Creation of subject folders and a collection of department folders

Inspiring Science Education environment supports the creation of school department/division folders that will contain not only the links to the scenarios relevant to their subject area, but also an explanation of what preceded the scenarios (theoretical background, connection to the curricula), how they were implemented and other tips & best practices within the specific scenarios. A collection of department folders can be created with the goal of promoting possible cross curricular scenarios. This compilation could also be complemented by an “Announcements board” fostering interdepartmental collaboration. This space could be further developed into a common place for evaluation aspects, in this way, teachers from the different departments get to see how assessment is being done in other lessons/subjects and apply (if necessary), the same methods to their subject and/or adapt their scenarios so as to measure aspects which complement other assessment done by their colleagues.

6.3.5 Creation of regional clouds

When referring to scalability, it might be reasonable saying that the greatest challenge exists between schools. Teachers might encounter more or less difficulties when confronting dissemination within their own school, but in this scenario there is no existing contact between teachers or at least one reliable enough. Creation of regional clouds of communities, sections to be divided per school, per department and per subject. The idea would be for any teacher to be able to check for a scenario in his/her language that has been already adapted to comply with the regional curricula, together with other possible resources such as tips for implementation attached. These regional hubs might also include “School tutorials”, were teachers and Head of School get to explain how Inspiring Science Education was implemented in their schools.

6.3.6 Regional Inspiring Science Education Ambassadors

Consider the creation of a program of regional teacher exchange: This kind of activity would further foster interschool exchange, sharing of best practices and cross curricular activities, while harmonizing curriculum inclusion within the regions. This activity can be supported by the Inspiring Science Education Academy.

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