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Report on mapping the development of key skills and competencies onto skills developed in IBSE

SAILS
Strategies for Assessment of Inquiry Learning in Science

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D 1.1 Report on mapping the development of key skills and competencies onto skills developed in IBSE

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Introduction

The SAILS project aims to support teachers in adopting inquiry based science education (IBSE) approaches in their teaching at second level (students aged 12-18 years) across Europe, through adaptation of existing resources and models for teacher education already developed through other projects. In addition to SAILS partners adopting IBSE curricula and implementing teacher education in their countries, the SAILS project will develop appropriate strategies and frameworks for the assessment of IBSE skills and competencies and prepare teachers not only to be able to teach through IBSE, but also to be confident and competent in the assessment of their students' learning. Through this unified approach of implementing all the necessary components for transforming classroom practice, i.e. teacher education, curriculum and assessment around an IBSE pedagogy, a sustainable model for IBSE will be achieved.

The drive towards IBSE has been an educational priority since the publication of the Rocard report in 2007. In addition to this recent drive to implement IBSE in the classroom, at a more general level there has been a push to develop so-called Key Skills and Competencies or 21st Century Skills within the educational programmes. These 21st century skills can be viewed as the characteristics that are desirable by particular stakeholders, such as employers, in students on leaving their formal education.

The purpose of this report is to review key skills and competencies desirable for young people in the 21st Century as identified by different international sources and map these against those developed through IBSE. There are many skills and competencies identified and reported in national / international framework and policy documents as desirable and necessary attributes from 21st century citizens/learners. These cover a broad range of attributes covering skills relating to learning and innovation, information, media and technology, and life and career. Section 1 of this report outlines the skills and competencies identified.

Inquiry based science education (IBSE) has been promoted by international reports (such as Rocard report, (Rocard, 2007)) to encourage motivation and engagement of students with science. There have been several large scale projects funded under the European Seventh Framework programme focussed on the use and implementation of IBSE such as S-TEAM, ESTABLISH, Fibonacci, PRIMAS and Pathway. These projects have been reviewed to determine the range of understanding of what the term inquiry means, and to establish to what extent skills and competencies that are developed through inquiry practices have been identified. These reports and some international literature are presented in Section 2.

In Section 3 an attempt is made to map the 21st century skills and competencies as identified in Section 1 with those developed through IBSE in Section 2. The results of this mapping will be used to prioritise the skills and competencies for which assessment procedures will be developed and implemented.

In this document, the issue of transferability of skills is not discussed, as it is outside the scope of the SAILS project.

Section 1 Statements of Skills and Competencies for the 21st Century

In this section, an overview is presented of several frameworks and policy documents that describe the key skills and competencies identified as important for 21st Century citizens. There is a wide range of such documents, and only selected examples from different jurisdictions are presented here. We discuss in some detail the US Partnership for 21st century skills (P21), European Framework for Key Competencies for Lifelong Learning (European Parliament and Council 2006), The OECD report - 21st Century Skills and Competencies for New Millennium Learners in OECD Countries (Ananiadou and Claro, 2009), and European Future Skills-Biotechnology (FS-Biotech) project 2009-2011. We identify common objectives across these framework/policy documents.

The widest ranging of these frameworks is that by Partnership for 21st century skills. This will be discussed in detail below and then the other frameworks will be mapped on to this.

We adopt the view that competencies typically comprise several skills, factual knowledge and attitudes. Thus a competency works at a higher level than a skill. It should be noted that competencies are defined in this project as an innate ability to carry out a task whereas a skill is a demonstrable ability.

1.1 Partnership for 21st Century Skills

The Partnership for 21st Century Skills (P21), is a US organization that advocates 21st century readiness for every student. P21 and its members provide tools and resources usable in every school in the U.S. education system by fusing the so-called 3Rs and 4Cs (Reading, Writing, Arithmetic; and Critical thinking and problem solving, Communication, Collaboration, and Creativity and innovation). (http://www.p21.org/overview)

P21's framework presents their view of 21st century teaching and learning that combines student outcomes (the acquisition of specific skills, content knowledge, expertise and literacies) with support systems. The top half of Figure 1.1 below (reproduced from http://www.p21.org/overview) shows the student outcomes envisaged by P21; the bottom half show the support system required. The latter could, in principle, be provided by any coherent method of teaching, including IBSE; hence support systems will not be discussed in this document.

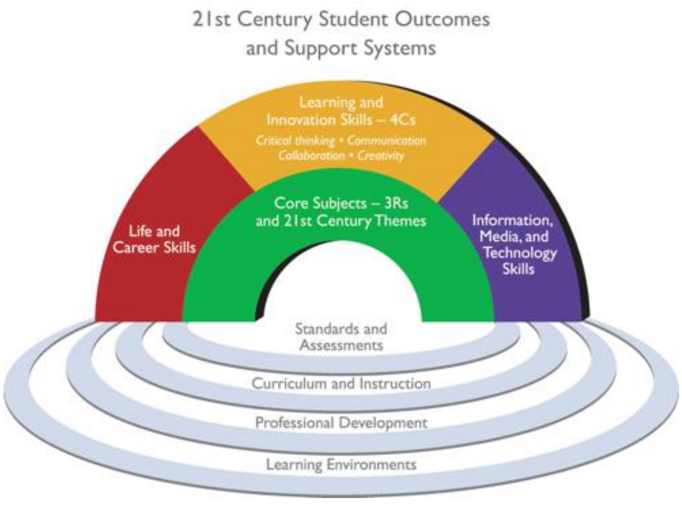

Figure 1.1: 21st Century student outcomes and support systems defined by P21.

The top half of Figure 1.1 identifies the 21st century student outcomes. Each of these is explained in detail below.

A. **Core Subjects and 21st Century Themes**
B. **Learning and Innovation Skills**
    a) Creativity and Innovation
    b) Critical Thinking and Problem Solving
    c) Communication and Collaboration
C. **Information, Media and Technology Skills**
    a) Information Literacy
    b) Media Literacy
    c) ICT Literacy
D. **Life and Career Skills**
    a) Flexibility and Adaptability
    b) Initiative and Self-Direction
    c) Social and Cross-Cultural Skills
    d) Productivity and Accountability
    e) Leadership and Responsibility

A. Core Subjects and 21st Century Themes

P21 value the mastery of core subjects, notably English, reading or language arts, World languages, Arts, Mathematics, Economics, Science, Geography, History, Government and Civics. In addition to these subjects, they believe schools should promote understanding of academic content at much higher levels by weaving interdisciplinary themes into core subjects such as global awareness; financial, economic, business and entrepreneurial literacy; civic literacy; health literacy, and environmental literacy.

B. Learning and Innovation Skills

P21 identify learning and innovation skills as the skills that separate students who are prepared for increasingly complex life and work environments in the 21st century, and those who are not. They feel that a focus on creativity, critical thinking, communication and collaboration is essential to prepare students for the future.

These skills are subdivided into three categories:

a) Creativity and Innovation

- Understanding that creativity and innovation is a long-term, cyclical process of small successes and frequent mistakes
- Inclusion of idea creation techniques (such as brainstorming)
- Creation, analysis and refinement of new and worthwhile ideas (both incremental and radical concepts)
- Acting on ideas and understanding real-world constraints
- Communication of new ideas
- Group work: openness and responsiveness to new and diverse perspectives

b) Critical Thinking and Problem Solving

- Using various types of reasoning (inductive, deductive, etc.) appropriately
- Analyze how parts of a whole interact with each other to produce overall outcomes in complex systems
- Effectively analyze and evaluate evidence, arguments, claims and beliefs

- Analyze and evaluate major alternative points of view
- Synthesize and make connections between information and arguments
- Reflect critically on learning experiences and processes
- Solve non-familiar problems in conventional and innovative ways
- Identify and ask significant questions that clarify various points of view and lead to better solutions

c) Communication and Collaboration

- Use communication for a range of purposes and in diverse environments
- Articulate thoughts and ideas in oral, written and nonverbal communication
- Listening
- Utilize multiple media and technologies effectively
- Team working skills

C. Information, Media and Technology Skills

People in the 21st century live in an environment characterised by access to an abundance of information, rapid changes in technology tools, and the ability to collaborate and make individual contributions on an unprecedented scale. This necessitates the acquisition of a range of functional and critical thinking skills related to information, media and technology, as follows:

a) Information Literacy

- Access information efficiently and effectively
- Evaluate quality of information critically and competently
- Use information accurately and creatively
- Manage the flow of information from a wide variety of sources
- Understand the ethical/legal issues surrounding the access and use of information

b) Media Literacy

- Media analysis: how and why media messages are constructed, and for what purposes
- Examine how messages are interpreted and how media can influence beliefs and behaviours
- Media creation tools, characteristics and conventions
- Ethical/legal issues surrounding the access and use of media

c) ICT Literacy

- Use technology as a tool to research, organize, evaluate and communicate information
- Use digital technologies appropriately
- Ethical/legal issues surrounding the access and use of information technologies

D. Life and Career Skills

P21 assert that current life and work environments require far more than thinking skills and content knowledge; the development of adequate life and career skills is also crucial, as follows:

a) Flexibility and Adaptability

- Adaptability to varied roles, jobs responsibilities, schedules and context
- Working in an uncertain climate with changing priorities
- Dealing with feedback and setbacks
- Workable solutions, particularly in diverse environments

b) Initiative and Self-Direction

- Managing long-term and short-term goals with tangible and intangible success criteria

- Managing time and workload
- Work independently
- Commitment to self-directed learning and advancing professional skills on completion of education
- Learn from past experiences

c) Social and Cross-Cultural Skills

- Interact effectively and respectfully with others
- Work effectively with people from a range of social and cultural backgrounds
- Openness to and gaining from different ideas and values arising from social and cultural differences

d) Productivity and Accountability

- Set and meet goals despite obstacles and competing pressures
- Prioritize, plan and manage work
- Produce Results
- Ability to work professionally and accountably

e) Leadership and Responsibility

- Guide others toward a goal
- Leverage strengths of others to accomplish a common goal
- Inspire others to reach their very best
- Demonstrate integrity and ethical behaviour in using influence and power
- Act responsibly with the interests of the larger community in mind

1.2 European Framework for Key competencies for lifelong learning

The European Framework for Key Competencies (EFKC) for Lifelong Learning (European Parliament and Council, 2006) identifies and defines eight key competencies necessary for personal fulfilment, active citizenship, social inclusion and employability in a knowledge society. We find that these can easily be mapped onto the P21 framework competencies: (the letters refer to the classification given above under P21 project)

1. **Communication in the mother tongue.** The competency to express and interpret thoughts and ideas in an appropriate and creative way, while respecting a range of socio-cultural values, maps directly on P21's competency listed under Bc, Communication and Collaboration, with some representation in Dc, social and cross-cultural skills.
2. **Communication in foreign languages.** In essence, this extends the range of socio-cultural differences to people from different countries with different (first) languages.
3. **Mathematical competency and basic competencies in science and technology** is a subset of the core subjects mentioned in A.
4. **Digital competency** maps directly onto Cc.
5. **Learning to learn** maps directly onto Db.
6. **Social and civic competencies** maps onto Dc.
7. **Sense of initiative and entrepreneurship** maps onto some of the themes identified in A, and to a lesser extent Dc and De.
8. **Cultural awareness and expression** again maps onto Dc.

These key competencies are seen as being interdependent, and the emphasis in each case is on critical thinking, creativity, initiative, problem solving, risk assessment, decision making and constructive management of feelings. While on the face of the EFKC this framework appears to cover a small subset of the competencies identified explicitly by P21, it is probably fair to say that the groupings adopted by EFKC are more concise, and many of the remaining P21 skills are subsumed or implicit. We note that none of the competencies explicitly identified in these frameworks are contradictory or mutually exclusive.

1.3 OECD report: 21st Century Skills and Competencies for New Millennium Learners

The OECD report, 21st Century Skills and Competencies for New Millennium Learners in OECD Countries (Ananiadou and Claro, 2009), focuses on real-life challenges rather than curricular outcomes. It identifies three different dimensions, i.e. information, communication and social. Each of these dimensions is divided into two sub dimensions as given below. These are now mapped onto the P21 framework and the letters given below refer to the classification given above under P21 project.

- i-a) **Information as a source.** This involves searching, selecting, evaluating and organising information, and maps onto Ca.
- i-b) **Information as a product**. This involves restructuring and modelling information, and developing one's own ideas and knowledge. The former maps onto Cc; the latter can be mapped to Db.
- ii-a) **Effective communication.** This sub dimension is about sharing information using appropriate tools and language. Critical thinking is included here. This dimension maps onto a number of areas: Ba, Bb, Ca, Cb, and Dc.
- ii-b) **Collaboration and virtual interaction** maps onto Bc.
- iii-a) **Social responsibility** particularly in terms of the consequences of taking action or not taking action. This could be mapped onto De.
- iii-b) **Social impact** refers to digital citizenship. This probably maps well onto Cc.

Just like the EFKC framework, it appears that the OECD framework is somewhat more limited in scope and somewhat more concise than the P21 framework, without any inconsistencies.

1.4 European Future Skills-Biotechnology

It is interesting to see whether a much smaller subset of stakeholders identify similar competencies to the pan-EU or pan-US organisations. As an example, we take the European Future Skills-Biotechnology (FS-Biotech) project 2009-2011 (Europe Future Skills-Biotechnology (FS-Biotech), 2009) which has presented a 2010 report on the Top Transferable Skills sought by Biotech Employers in Europe.

In this report the responses of 206 European employers in the biopharmaceutical and biotechnology sector are collated. The top transferable skills that these employers seek in graduates are listed below and are compared to the equivalent skills listed under P21: (the letters given below refer to the classification given above under P21 project)

- I. **Oral Communication**: Together with (ii) and (vi) below, this constitutes the communication skills and competencies identified in Bc.
- II. **Listening**: See (i) above.
- III. **Continuous Improvement and Excellence**: The report lists "being able to work properly in a precise way and paying attention to details. If necessary, being available to do extra work in order to guarantee that tasks are well executed. Looking for new tasks and responsibilities". This is a subset of competencies listed mainly under Db and De.

IV. **Teamwork**: Highlighted are ability to collaborate and accept suggestions and recommendations from other team members; to develop good relations between colleagues and promote morale; to work cohesively to find better solutions. This maps onto Dc and De.
V. **Personal Strengths**: this includes maintaining a high energy level, self-motivation, functioning in stressful situations, maintaining a positive attitude, ability to work independently, and responding appropriately to constructive criticism. Together with (vii) below, this maps onto Da and Db.
VI. **Written Communication**: See (i) above
VII. **Personal Organisation and Time Management**: See (v) above.

Not surprisingly, the scope of the competencies identified is somewhat narrower, but again entirely consistent with the P21 and EFKC frameworks.

1.5 Conclusion

The main frameworks reviewed here can be matched to the P21 framework and therefore this framework will now be used to link skills and competencies with those attributes that are developed through inquiry based teaching methods.

Section 2: Statements of Inquiry

This section outlines what is meant by inquiry and then reviews the various interpretations of inquiry as used in some EU inquiry projects.

2.1 What is Inquiry?

The term *inquiry* has figured prominently in science education, yet it refers to at least three distinct categories of activities—**what scientists do** (e.g., conducting investigations using scientific methods), **how students learn** (e.g., actively inquiring through thinking and doing into a phenomenon or problem, often mirroring the processes used by scientists), and a **pedagogical approach that teachers employ** (e.g., designing or using curricula that allow for extended investigations) (Minner, 2009). However, whether it is the scientist, student, or teacher who is doing or supporting inquiry, the act itself has some core components.

What is Inquiry Based Science Education?

Inquiry based science education is an approach to teaching and learning science that is conducted through the process of inquiry. Some of the key characteristics of inquiry based teaching are:

- Students are engaged with a difficult problem or situation that is open-ended to such a degree that a variety of solutions or responses are conceivable.
- Students have control over the direction of the inquiry and the methods or approaches that are taken.
- Students draw upon their existing knowledge and they identify what their learning needs are.
- The different tasks stimulate curiosity in the students, which encourages them to continue to search for new data or evidence.
- The students are responsible for the analysis of the evidence and also for presenting evidence in an appropriate manner which defends their solution to the initial problem (Kahn & O'Rourke, 2005).

These characteristics are reflected in the NRC's "essential features of classroom inquiry". These include:

- "*Learners are engaged by scientifically oriented questions.*
- *Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.*
- *Learners formulate explanations from evidence to address scientifically oriented questions.*
- *Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding*
- *Learners communicate and justify their proposed explanations"* (NRC, 2000, p. 25)

2.2 IBSE Related Projects

Over the past decade, there have been a variety of different European projects related to inquiry based science education. These projects have expressed inquiry, and consequently IBSE, in different ways. However, the central ideas of inquiry based science education are consistent throughout. This section will compare and relate the different expressions of inquiry that have been adopted by these projects.

2.2.1 ESTABLISH

The ESTABLISH project (2010-2013) selected the definition of inquiry given by Linn, Davis and Bell (2004) as *"[Inquiry is] the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, discussing with peers and forming coherent arguments."* (www.establish-fp7.eu).
The understanding adopted by ESTABLISH of each of these attributes of inquiry is presented in Table 2.1.

Diagnosing problems	• Students identify the core of the problems/ questions • Understand and use their prior knowledge to be able to form working hypothesis
Critiquing Experiments	In order to critique experiments intentionally and effectively, students need: • Experience • Analytical skills • Reflective Skills • Formulating arguments • State outcomes in a comparative way • Suggest further developments
Distinguishing Alternatives	• Identify key elements of the problem • Identify ranking level for key elements • Express alternatives in suitable form • SWOT analysis
Planning Investigations	• Establishing the hypothesis in a realistic way towards a goal • Consider the hypothesis and methods of answering the hypothesis • Planning involves setting time frame, steps involved, resources required and training in use of any equipment • Monitor and review of approach
Researching conjectures (hypothesis testing)	• Follows from observations/ facts previously gathered and some preliminary theory / hypothesis that is to be tested • Not just observing but considering why!! • Open ended
Searching for information	• To define what you need to search using the right resources and how to do this and where • To identify possible sources of information relating to possible intervening variables
Constructing models	Students try to find something which: • Enables description, understanding, explaining, prediction • Can be different types and levels (qualitative, quantitative, computer simulations...) • May be checked, proved, disproved, adapted, improved, or abandoned
Discussing with peers	• Discussion regarding different interpretations of experimental results/interpretation/

	• Cooperative/collaborative
Forming coherent arguments	Putting forward logical reasons • Students building on evidence/ information so as to be able to present this as a logical, evidence-based communicative format...e.g. Model, solution/conclusion to the process that explains and may include evidence for and against

Table 2.1. Summary of the skills to be developed by IBSE as identified by the members of the ESTABLISH project

2.2.2 S-TEAM

The S-TEAM project (2009-2012) also adopted the definition of IBSE given by Linn, Davis and Bell (2004) as a common basis for discussion. Additionally, the S-TEAM project characterises inquiry based science teaching as having activities that engage students in the following:

- authentic and problem based learning activities where there may not be a correct answer ;
- a certain amount of experimental procedures, experiments and "hands on" activities, including searching for information;
- self regulated learning sequences where student autonomy is emphasised;
- discursive argumentation and communication with peers ("talking science").

These activities can be related to the Linn and Davis elements of inquiry as follows:

- authentic and problem based learning activities where there may not be a correct answer ; related to elements of “Diagnosing Problems”, “Distinguishing Alternatives”, “Researching Conjectures”, “Constructing Models” and “Planning Investigations”.
- a certain amount of experimental procedures, experiments and "hands on" activities, including searching for information; related to elements “Planning Investigations”, “Searching for Information” and “Researching Conjectures”
- self regulated learning sequences where student autonomy is emphasised; related to elements “Diagnosing Problems”, “Critiquing Experiments”, “Planning Investigations”, “Researching Conjectures” and “Searching for Information” can all emphasise the students’ autonomy.
- discursive argumentation and communication with peers ("talking science"). related to elements “Debating with Peers” and “Forming Coherent Arguments”.

S-TEAM working in partnership with teachers and in cooperation with policymakers has set up professional development programmes, including introductory courses designed to bring teachers up to speed with current practice in inquiry-based teaching. The project also provides specialised programmes or resources in areas such as: Argumentation; Collaborative working; Dialogic teaching; Drama in Science education; Inquiry for Initial Teacher Education; Nature of Science and media; Pupil Motivation; Scientific Literacy and Web resources.

2.2.3 Fibonacci

The Fibonacci project (2010-2013) is a European based project focusing on Inquiry based science and mathematics education (IBSME). The project recognises that some of the features of IBSME are similar to those of traditional scientific education, but they believe that it differs in numerous ways. The Fibonacci project emphasise three key characteristics of IBSME: (The Fibonacci Project, 2012)

- Through IBSME, students are developing concepts that enable them to understand the scientific aspects of the world around them through their own thinking, using critical and logical reasoning about evidence that they have gathered.
- Through IBSME, teachers lead students to develop the skills necessary for inquiry and the understanding of science concepts through their own activity and reasoning. This involves exploration and hands-on experiments.
- While doing science, the teacher focuses on the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching

conjectures, searching for information, constructing models, discussing with peers and forming coherent arguments.

Fibonacci concerns both primary and secondary teachers, and explicitly provides teacher education in the area of the Nature of Science. Fibonacci recognises that doing science inquiry requires that students are taught many skills, such as asking questions, making predictions, designing investigations, analysing data and supporting claims with evidence. Of these skills, one of the most important skills is observing closely and determining what is important to observe. In addition, learning science is not only acting on and with objects, it is also reasoning, talking with others, and writing both for one-self and for others. Science is more often a collaborative endeavour than an individual activity. When students work together in small groups, they are working as many scientists do, sharing ideas, discussing and thinking about what they need to do and how they need to do it. Thus the key skills of collaboration and communication are also important aspects of effective IBSE.

2.2.4 PRIMAS

The PRIMAS project (2010 – 2013) is an international project whose aim is to promote inquiry based learning in mathematics and science at both primary and second level schools throughout Europe (Primas, 2012). Primas states that inquiry learning *"aims to develop and foster inquiring minds and attitudes that are vital for pupils being able to face and manage uncertain futures"* (Primas, 2012).
PRIMAS adopts the understanding that inquiry-based learning (IBL) involves exploring the world, asking questions, making discoveries, and rigorously testing those discoveries in search of new understanding. Inquiry-based learning can have many faces, dependent on context, target group and learning aims. However, IBL approaches all have the shared characteristics of aiming to promote curiosity, engagement and in-depth learning.
Primas examines the classroom under the headings of "Valued Outcomes", "Teachers", "Classroom Culture", "Learning Environment" and "Students" to describe inquiry based learning, as follows:

- "Valued Outcomes" -Inquiring minds which are critical and creative, prepared for uncertain future, with an understanding of the nature of science and maths,with an interest in and having positive attitudes towards science and maths;
- "Teachers" - Foster and value students' reasoning, moving from trom telling to supporting & scaffolding, connect to students' experience
- "Classroom Culture" - Shared sense of purpose, justification & ownership, value mistakes, contributions (open-minded), dialogic
- "Learning Environment" - Problems: open, multiple solutions, experienced as real and relevant, access to tools and sources, from problems to explanations (instead of from examples to practicing)
- "Students" - Pose questions, inquire: engage, explore, explain, extend, evaluate, collaborate.

The PRIMAS project is thus carried out according to this multi-faceted understanding IBL that is not only characterized by the relevance of the processes of inquiry but also by the classroom atmosphere, the role of the teacher, the tools used and the desired outcomes.

2.2.5 Pathway

The aim of the Pathway project (2010-2013) is to set the pathway toward a standard-based approach to teaching science by inquiry, to support the adoption of inquiry teaching by demonstrating ways to reduce the constraints presented by teachers and school organisation, to demonstrate and disseminate methods and exemplary cases of both effective introduction of inquiry to science classrooms and professional development programmes, and finally to deliver a set of guidelines for the educational community to further explore and exploit the unique benefits of the proposed approach in science teaching. In this way the project team aims to facilitate the development of communities of practitioners of inquiry that will enable teachers to learn from each other.

The central characteristics of inquiry learning as expressed by Pathway are presented below:

- Learning through an emergent process of inquiry, often collaboratively with peers and using digital information and technologies;
- Applying principles and practices of academic or professional (e.g., scientific) inquiry and research;
- Engaging with questions and problems that may be open-ended;
- Exploring a knowledge base actively, critically and creatively;
- Participating, at more advanced levels, in building new meaning and knowledge in a domain;
- Developing process knowledge and skills in inquiry methods and in other areas including information literacy, reflection and group-work;
- Participating in sharing the results of inquiries with peers and wider audiences.

2.2.6 SINUS Transfer

SINUS Transfer was the largest school development project that has ever been carried out in Germany with the aim of improving the competency in both mathematics and science subjects based on inquiry-based methods. The competencies identified by SINUS that students should develop in the mathematics and science classroom are:

Professional competency	Methodological competency	Self-competency
Critical thinking	Problem solving ability	Ability to motivate one-self and others
Structural competency	Self-learning ability	Responsibility
Soft skills	Decision making	Ability to cooperate
Intercultural competency	Media literacy	Ability to communicate
Ability to manage knowledge		

The SINUS group suggest a more concise list that combines many of these competencies, which can be represented diagrammatically as shown in Figure 2.1. All four outer competencies feed into and develop decision-making and responsibility.

SINUS defines soft skills as “willingness and ability to work with others, be tolerant and empathetic and be able to handle conflicts” while self-competency is noted as “willingness to perform, recognising one's own strengths and weaknesses, confidence and independence”. SINUS defines professional competency as “besides domain knowledge, it also includes associative thinking and the ability to apply knowledge according to the goals” (Sinus-transfer, 2011). Methodological competency is understood as including “abilities to gather knowledge, work rationally and solve problems methodically as per the situation and structure results accordingly”. Each of these competencies may be related to elements of the Linn and Davis model of inquiry.

Figure 2.1. Summary of the skills to be developed by IBSE as identified by the SINUS project.

2.2.7 Summary of European projects

A large degree of commonality can be found among these different projects. Some projects focus on primary or secondary teaching only, some combine the two; some promote open inquiry while others cover the full inquiry spectrum; some explicitly advocate use of technology in education (through on-line repositories and learning activities, or classroom equipment); some focus on experimentation while others cover a wide range of minds-on activities. However, the impression that remains is how much these projects have in common: they all seem to include a large extent of focussing on how students learn, encouraging metacognition and metaprocess skills, and the different role of the teacher within the inquiry classroom.

As a result of these projects, there is a large number of high-quality inquiry activities that have been translated into many European languages, are being implemented in classrooms in different European countries, and that are now available to the SAILS project.

2.3 Inquiry Based Science Instruction

In the Inquiry Synthesis Project (Minner, 2009) a framework for describing inquiry-based instruction included reviewing 138 studies reported in literature that had been written over the course of the past 30 years to arrive at a set of descriptive characteristics of the essential characteristics of inquiry science instruction. In this framework, inquiry science instruction can be characterized as having three aspects: (1) the presence of science content, (2) student engagement with science content, and (3) student responsibility for learning, student active thinking, or student motivation within at least one component of instruction— question, design, data, conclusion, or communication. The categories and descriptions of Science Content used in the conceptual framework are among those articulated in the National Science Education Standards (NRC, 1996).

Student responsibility for learning relates to the students' role as learner; therefore, inquiry instruction that embodies this element demonstrates the expectation that students will participate in making decisions about how and what they learn, identify where they and others need help in the learning process and ask for that help, and/or contribute to the advancement of group knowledge. *Student active thinking* refers to how students engage with the content itself. Thus, inquiry instruction that exemplifies this element demonstrates the expectation that students will use logic, think creatively, build on prior knowledge, and/or make deductions. Finally, *student motivation* is about students' personal investment in the learning process; inquiry instruction within this element intentionally builds on and develops students' curiosity, enthusiasm, and concentration. A study was considered inquiry-based and included in the synthesis if at least one of the instructional treatments was about life, earth, or physical science; engaged students with scientific phenomena; instructed them via some part of the investigation cycle (question, design, data, conclusion, communication); and used pedagogical practices that emphasized to some extent student responsibility for learning or active thinking.

<table>
<tr><td colspan="2">Presence of Science Content</td><td colspan="3">• Science as Inquiry
• Life Sciences
• Physical Science
• Earth and Space Science</td></tr>
<tr><td colspan="2">Type of Student Engagement</td><td colspan="3">• Students manipulate materials
• Students watch scientific phenomena
• Students watch a demonstration of scientific phenomena
• Students watch a demonstration that is NOT of scientific phenomena
• Students use secondary sources (e.g. reading material, the Internet, discussion, lecture, others' data)</td></tr>
<tr><td rowspan="2">Components of Instruction</td><td rowspan="2"></td><td colspan="3">Elements of the Inquiry Domain</td></tr>
<tr><td>Instruction emphasizes Student Responsibility for Learning when it demonstrates the expectation that students will:</td><td>Instruction emphasizes Student Active Thinking when it demonstrates the expectation that students will:</td><td>Instruction emphasizes Student Motivation when:</td></tr>
</table>

	Question	Decide which questions to investigate; seek clarification of the investigation question(s).	Generate investigation question(s); using prior knowledge to inform the question(s); consider or predict possible outcomes of the question; explore the reasons question(s) are being asked to determine if they are appropriate for scientific investigation; refine questions so that they can be investigated; discuss questions based on the previous study or data collected.	demonstrates the expectation that students will: display/ express interest, involvement, curiosity, enthusiasm, perseverance, eagerness, focus, concentration, pride (all affective).
	Design	Indentify when and where they need help understanding the design; ensure that they (or the class/group/partner) grasps the design and how to implement it; decide what investigation design to use; ensure that the design addresses the research question.	Use prior knowledge to inform the design; determine if the design is an appropriate match for the question including variables and procedures; discuss the merits of different investigation designs and whether it is "doable" and will result in needed data; consider where and how issues of bias may need to be addressed; generate investigation designs.	
	Data	Decide the data organization strategy; decide what data collection strategy to use and/or how to adapt it; identify if they or others need hep collecting or organizing data; seek out clarification and advice on what is needed.	Alter and refine their approach to gathering, recording, or structuring the data based on information they acquire as they proceed.	
	Conclusion	Decide what strategies to use to summarize, interpret, or explain the data; identify when they or others need help in summarizing, interpreting or explaining; seek out other relevant information to assist in drawing conclusions.	Ensure that their conclusions are supported by their data; apply prior knowledge to summarize, interpret, or explain the data; construct conclusions' reasonableness and credibility; identify applications of their findings to other situations and/or contexts; offer explanations for variations in the findings among the class and/or within their working groups; generate new questions that arise out of their explanations.	
	Communication	Decide how to structure their communication; seek advice and suggestions from others about how/what to communicate; provide feedback to others about their communication.	Engage in sound discussion and debate; demonstrate the logic they used to draw conclusions and interpretations; articulate the reasonableness and credibility of others' work; discuss appropriate communication mechanisms including language, visual aids, technology, etc.; articulate the merits and limitations of their work.	

Table 2.2. Inquiry science instruction conceptual framework (Minner, 2009)

In addition to coding the inquiry characteristics of instruction, the Inquiry Synthesis Project developed a coding scheme to capture the effect of that instruction on students. Six different finding types were coded: student understanding of science concepts, facts, and principles or theories; and student retention of their understanding of science concepts, facts, and principles or theories. Each study had at least one of these finding types, and many had more than one. This synthesis reported that teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than are strategies that rely on more passive techniques. They did not find, however, that overall high levels of inquiry saturation in instruction were associated with more positive learning outcomes for students. However, this synthesis did not explore impacts on other kinds of student outcomes beyond student understanding and retention of science concepts.

2.4 Identifying scientific inquiry skills

It is frequently stated that achieving scientific literacy is the main goal of science education. Wenning (2007) suggests that it would therefore seem reasonable that an assessment instrument would exist for measuring progress toward that goal but acknowledges that such an instrument does not appear to exist. Therefore he proposes an operational definition of scientific inquiry suitable for guiding high school science teaching, presents a framework for teaching it, and describes a standardized test for assessing student knowledge and skills associated with scientific inquiry. For the purpose of operationally defining scientific inquiry at a level appropriate for secondary schools, he provides a listing of fundamental scientific inquiry skills in Table 2.3. These processes have been roughly organized into “stages” of scientific inquiry, and are patterned on the levels-of-inquiry spectrum (Discovery Learning-Interactive Demonstrations-Inquiry Lessons-Guided Inquiry Labs-Bounded Inquiry Labs-Free Inquiry Labs-Pure/Applied Hypothetical Inquiry) previously identified by Wenning (2005).

Stages of Scientific Inquiry
• Identify a problem to be investigated. • Using induction, formulate a hypothesis or model incorporating logic and evidence. • Using deduction, generate a prediction from the hypothesis or model. • Design experimental procedures to test the prediction. • Conduct a scientific experiment, observation or simulation to test the hypothesis or model: o Identify the experimental system o Identify and define variables operationally o Conduct a controlled experiment or observation • Collect meaningful data, organize, and analyze data accurately and precisely: o Analyze data for trends and relationships o Construct and interpret a graph o Develop a law based on evidence using graphical methods or other mathematic model, or develop a principle using induction • Apply numerical and statistical methods to numerical data to reach and support conclusions: o Use technology and math during investigations o Apply statistical methods to make predictions and to test the accuracy of results o Draw appropriate conclusions from evidence • Explain any unexpected results: o Formulate an alternative hypothesis or model if necessary o Identify and communicate sources of unavoidable experimental error o Identify possible reasons for inconsistent results such as sources of error or uncontrolled conditions • Using available technology, report, display, and defend the results of an investigation to audiences that might include professionals and technical experts.

Table 2.3. A limited framework defining scientific inquiry skills as a part of scientific literacy. This framework is intended to be suggestive, not definitive. (Wenning, 2007).

It is clear from this framework, that students require specific skills at particular stages of scientific inquiry and that an instrument for assessing these student knowledge and skills associated with scientific inquiry could have a significant impact on both curriculum design and instructional practice.

A 2006 report by Wu and Hsieh (Wu, 2006) on how sixth graders develop inquiry skills in an inquiry-based learning environment identified four inquiry skills that are relevant to students' construction of explanation - to identify causal relationships, to describe the reasoning process, to use data as evidence, and to evaluate explanations. After implementing a series of specially designed inquiry-based learning activities, they showed that while students made significant progress in identifying causal relationships, describing the reasoning process, and using data as evidence, they showed slight improvement in evaluating explanations. They surmised that while the students' lack of improvement in evaluating skill could be attributed to the design of the activities and curriculum materials, their findings also suggest that the inquiry skills for constructing explanations might involve different levels of difficulty and complexity.

The Exploratorium Institute for Inquiry Professional Development Curriculum (Exploratorium) has developed a workshop where participants work to develop their understanding of the central role of the process skills of science in learning scientific concepts. They identify seven process skills that are especially important in inquiry-based learning because these are the tools that students use to carry out scientific investigations, i.e., Observing, Questioning, Hypothesizing, Predicting, Planning and Investigating, Interpreting and Communicating. They acknowledge that there are many such equally valid lists of scientific process skills with more categories, but they include skills that can be subsumed under one or another of these seven.

The materials developed by the Exploratorium distinguish different degrees of inquiry, which they label Type A, B and C; this typology roughly corresponds to a progression from structured to guided to open inquiry.

Other studies have focussed on the effect of of inquiry-based instruction on skills such as argumentation, reasoning and problem solving. Wilson's (2010) study found that students receiving inquiry-based instruction reached significantly higher levels of achievement than students experiencing commonplace instruction. The superior effectiveness of the inquiry-based instruction was consistent across a range of learning goals (knowledge, scientific reasoning, and argumentation) and time frames (immediately following the instruction and 4 weeks later). His findings contribute to the growing body of evidence demonstrating the effectiveness of inquiry-based instruction and support the advocacy for inquiry-based instruction stated in national and international science education reform documents.

For instance, the 2011 Eurydice report on Science Education in Europe: National Policies, Practices and Research, the review of science learning theories and teaching approaches considers the importance of argumentation in science teaching.

"Argumentation skills in the context of science teaching mean 'to persuade colleagues of the validity of a specific idea… Scientific argumentation is ideally about sharing, processing and learning about ideas'. Evidently, in this sense the development of such skills should also form part of the teaching content in science classrooms."

The Framework for PISA 2012 Problem Solving recognises that problem solving competency is a central objective within the educational programme of many countries and can be developed by high quality education. The report recognises that:
" Progressive teaching methods, like problem-based learning, inquiry-based learning, and individual and group project work, can be used to foster deep understanding and prepare students to apply their knowledge in novel situations. Good teaching promotes self-regulated learning and metacognition and develops the cognitive processes that underpin problem solving. "

2.5. Conclusion

It is clear that the statements of inquiry and IBSE are expressed differently but all of these approaches have the shared characteristics of aiming to promote curiosity, engagement and in-depth learning. Within an inquiry culture there is also a clear belief that student learning outcomes are especially valued. One characteristic of inquiry learning is that students are fully involved in the active learning process. Students who are making observations, collecting data, analyzing data, synthesizing information, and drawing conclusions are developing problem-solving skills. These skills fully incorporate the basic and integrated science process skills necessary in scientific inquiry. A second characteristic of inquiry learning is that students develop the lifelong skills critical to thinking creatively, as they learn how to solve problems using a logic and reasoning. These skills are essential for drawing sound conclusions from experimental findings. While many projects have focussed on the evaluation of conceptual understanding of science principles developed, there is a clear need to evaluate other key learning outcomes, such as process and other self-directed learning skills, with the aim to foster the development of interest, social competencies and openness for inquiry so as to prepare students for lifelong learning.

Section 3: Mapping of key skills and competencies

In the report for the National Center on Education and the Economy (Tucker, 2011), "***Standing on the Shoulders of Giants: An American Agenda for Education Reform"***, the question "What would education policies and practices of the United States be if they were based on the policies and practices of the countries that now lead the world in student performance?" is addressed. The leading countries - Finland, Singapore, Japan, Shanghai, China, and Canada - are those whose students score highest on the OECD's PISA exams in Math, Reading, and Science. It is noteworthy that these top-performing countries have placed a high value in their national policies on the mastery of complex skills and problem solving at a high level.

> *"All of these places have known for a very long time that their standard of living depends entirely on the knowledge and skills of their people. All now realize that high wages in the current global economy require not just superior knowledge of the subjects studied in school and the ability to apply that knowledge to problems of a sort they have not seen before (the sorts of things that PISA measures), but also a set of social skills, personal habits and dispositions and values that are essential to success. The Asian countries in particular are concerned that their students may not have as much capacity for independent thought, creativity and innovation as their countries will need. Though all these countries are concerned about developing the unprecedented levels of cognitive skills and non-cognitive skills required by the global economy, they are no less concerned about social cohesion, fairness, decency, tolerance, personal fulfillment and the transmission of the values that they feel define them as a nation."*

This report takes the Framework for 21st Century learning proposed by the Partnership for 21st Century Skills as a basis for identifying key 21st century skills and competencies and those that can be developed through scientific inquiry and this mapping is presented under the four themes of this framework.

1. Core Subjects and 21st Century Themes

It is clear that science, as well as mathematics and native language, is a core subject for 21st century learners and that science embraces understanding of many of the interdisciplinary themes required by the 21st century citizen, i.e. environment, health, energy, global awareness.

2. Learning and Innovation Skills

Learning and innovation skills increasingly are being recognized as the skills that separate students who are prepared for increasingly complex life and work environments in the 21st century, and those who are not. Benjamin Bloom (Bloom, 1956) developed a classification of levels of intellectual behaviour in learning. This taxonomy contained three overlapping domains: the cognitive, psychomotor, and affective. Within the cognitive domain of Bloom's taxonomy he identified six levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. A focus on creativity, critical thinking, communication and collaboration is essential to prepare students for the future. Critical thinking involves logical thinking and reasoning including skills such as comparison, classification, sequencing, cause/effect, patterning, webbing, analogies, deductive and inductive reasoning, forecasting, planning, hypothesizing, and critiquing. Creative thinking involves creating something new or original. It involves the skills of flexibility, originality, fluency, elaboration, brainstorming, modification, imagery, associative thinking, attribute listing, metaphorical thinking and forced relationships. The aim of creative thinking is to stimulate curiosity and promote divergence.

Learning and innovation are key skills that are required of science students across all of the elements of the inquiry domain, question, design, data, conclusion and communication, as presented by Minner (Minner, 2009). Student abilities to think creatively, work creatively with others and implement innovations are key skills that they should develop in an inquiry classroom through engaging in diagnosing problems, critiquing experiments, distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, discussing with peers and forming coherent arguments.

The following subsections discuss three attributes of learning and innovation skills mapped to the identification of the development of these skills thought IBSE, as reported in the synthesis by Minner 2009 and in the widely used definition of inquiry by Linn and Davis, 2004.

2a) Creativity and Innovation

Creativity improves students' self-esteem, motivation and achievement and students who are encouraged to think creatively and independently become more interested in discovering things for themselves, more open to new ideas, keen to work with others to explore ideas, willing to work beyond lesson time when pursuing an idea or vision. As a result, their pace of learning, levels of achievement and self-esteem increase. Innovation is about new products, processes and services and all the scientific, technological, organisational, financial and business activities that produce them.
It appears that certain kinds of creativity are more likely to come to the forefront when teaching through open inquiry, although all kinds of inquiry lend themselves to creative thinking (e.g., when students are asked to come up with alternative suggestions or procedures within a guided inquiry activity.)

Framework for 21st Century Learning	***Minner- Components of Inquiry Instruction***	***In IBSE, students engage in***
Think creatively	Question Conclusion	Diagnosing problems Critiquing experiments Distinguishing alternatives Researching conjectures
Work creatively with others	Communication	Discussion with peers Forming coherent arguments Searching for information
Implement innovations	Design Data	Planning investigations Constructing models

2b) Critical Thinking and Problem Solving

Critical thinking and problem solving skills are widely recognised as important societal skills that can be developed through science instruction and recent OECD have developed a framework for the assessment of individual problem solving competency for PISA 2012. Within all forms of IBSE students encounter copious opportunities to develop these skills, albeit often in a scientific context only.

Framework for 21st Century Learning	***Minner- Components of Inquiry Instruction***	***In IBSE, students engage in***
Reason Effectively	Question	Diagnosing problems Critiquing experiments
Use System Thinking	Design	Constructing models
Make Judgments and Decisions	Conclusion	Distinguishing alternatives Planning investigations
Solve Problems	Data	Researching conjectures

2c) Communication and Collaboration

Much inquiry teaching takes place in small groups, which necessitates the development of clear communication and collaboration strategies within the group. Inquiry based teaching can incorporate explicit assignment of roles (e.g., proposer, opponent, note-taker, moderator).

Framework for 21st Century Learning	***Minner- Components of Inquiry Instruction***	***In IBSE, students engage in***
Communicate Clearly	Question Design Data Conclusion Communication	Distinguishing alternatives Discussing with peers Forming coherent arguments
Collaborate with Others		

While recognising that the affective domain cannot and must not be divorced from the cognitive and psychomotor domains, SAILS will focus on the cognitive domain (and, implicitly, on the psychomotor domain e.g. through the development of some experimental skills such as accurate use of pipettes, optical alignment, etc.).

3. Information, Media and Technology Skills

In many implementations of inquiry instruction, the use of data logging, sensors, computational models and online resources/simulations/applets, is an integral part of the student's engagement in inquiry learning. Students' ability to research conjectures and search for information develop their skills to critically evaluate their own questions and design and plan appropriate scientific investigations. In particular the use of ICT for visualisation of scientific concepts enhances the student's conceptual knowledge and develops their skills in constructing appropriate models to represent their understanding and interpretation. ICT skills are also an invaluable attribute for effective communication and collaboration in science investigations.

4. Life and Career Skills

Today's life and work environments require far more than thinking skills and content knowledge. The ability to navigate the complex life and work environments in the globally competitive information age requires students to pay rigorous attention to developing adequate life and career skills. In an inquiry classroom, students are generally working in small groups, enacting what scientists do, conducting investigations using scientific methods. One of the key attributes of scientists is their ability to work in diverse, multi-disciplinary teams to explain and predict the world around us. For scientists to be effective in this endeavour they need to possess the personal attributes of flexibility and adaptability, initiative and self-direction, social and cross-cultural skills, leadership and responsibility and productivity and accountability. It is inherent through engaging in the inquiry process in science that students also start to develop these skills in the classroom.

4. SAILS: Assessment and inquiry

The preceding chapters have shown how 21st century skills and IBSE may be mapped onto one another, and that many different inquiry based activities are already in place within Europe. The recent change towards IBSE however seems to have largely ignored assessment in IBSE, a notable exception being the Principled Assessment Designs for Inquiry (PADI) project.

In this chapter, we argue that assessment in inquiry can be seen in two different ways: as being an integral part of what goes on in the classroom, and in terms of a diagnostic assessment of inquiry skills. We will first highlight the differences between the two. In the final section, we will outline how SAILS can bring the two together. Moreover, different types on inquiry – structured, guided, open – require different types of assessment.

4.1. Assessment as part of inquiry teaching

Location: classroom
Stakeholders: teachers, teacher educators

The interpretation of assessment in inquiry as described in this section is at the heart of good practice in inquiry. This assessment strategy can focus on effective Socratic dialogue, which allows the teacher to assess, probe and guide at the same time. It can also be through inspection of students' products: lab reports, homework, etc. Teacher education here then should focus on enabling teachers to ask appropriate questions at appropriate times, that allow them to gauge students' attainment and help students learn; and in giving effective feedback.

4.2. Diagnostic assessment of acquisition of inquiry skills

Location: examination
Stakeholders: teachers, assessment agencies

The interpretation of assessment in inquiry described in this section concerns the diagnostic assessment of whether students have acquired inquiry skills. This kind of assessment is prevalent in, but not limited to, examination environments. For example, students could be given experimental apparatus and an experimental question they need to answer; the assessment could comprise an investigation of whether students frame a hypothesis, gather evidence to support or refute the hypothesis, use appropriate equipment, make repeat measurements, report on their findings, etc.

4.3. SAILS: bringing it all together

IBSE is gaining wider prominence in schools throughout Europe. Typically students will take a terminal state exam, in addition to a continuous assessment component. It is often the case that what is considered inquiry-based teaching amounts to students carrying out a set of more or less unconnected inquiry activities; teachers may then not have developed the skills to effectively guide the students to a deeper understanding of the science content or processes. State exams often fail to probe students' inquiry skills but focus on content knowledge instead.

The SAILS project offers a unique opportunity to influence both inquiry in the classroom and how terminal state examinations are conducted. By looking at the large variety of inquiry activities that have been developed, we can initiate a Europe-wide holistic approach to IBSE – not just as a succession of individual activities, but as a coherent framework for teaching and learning of science. By developing a set of diagnostic assessment questions and strategies, the state examinations may be altered to probe students' knowledge and understanding of science and its specific skill set in a broader and more meaningful way. By developing and implementing a set of teaching strategies focusing on formative assessment through Socratic dialogue, teachers can become more effective practitioners of IBSE, helping students develop 21st century skills along the way, while they could feel that at the same time they are preparing students for the terminal state exam.

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