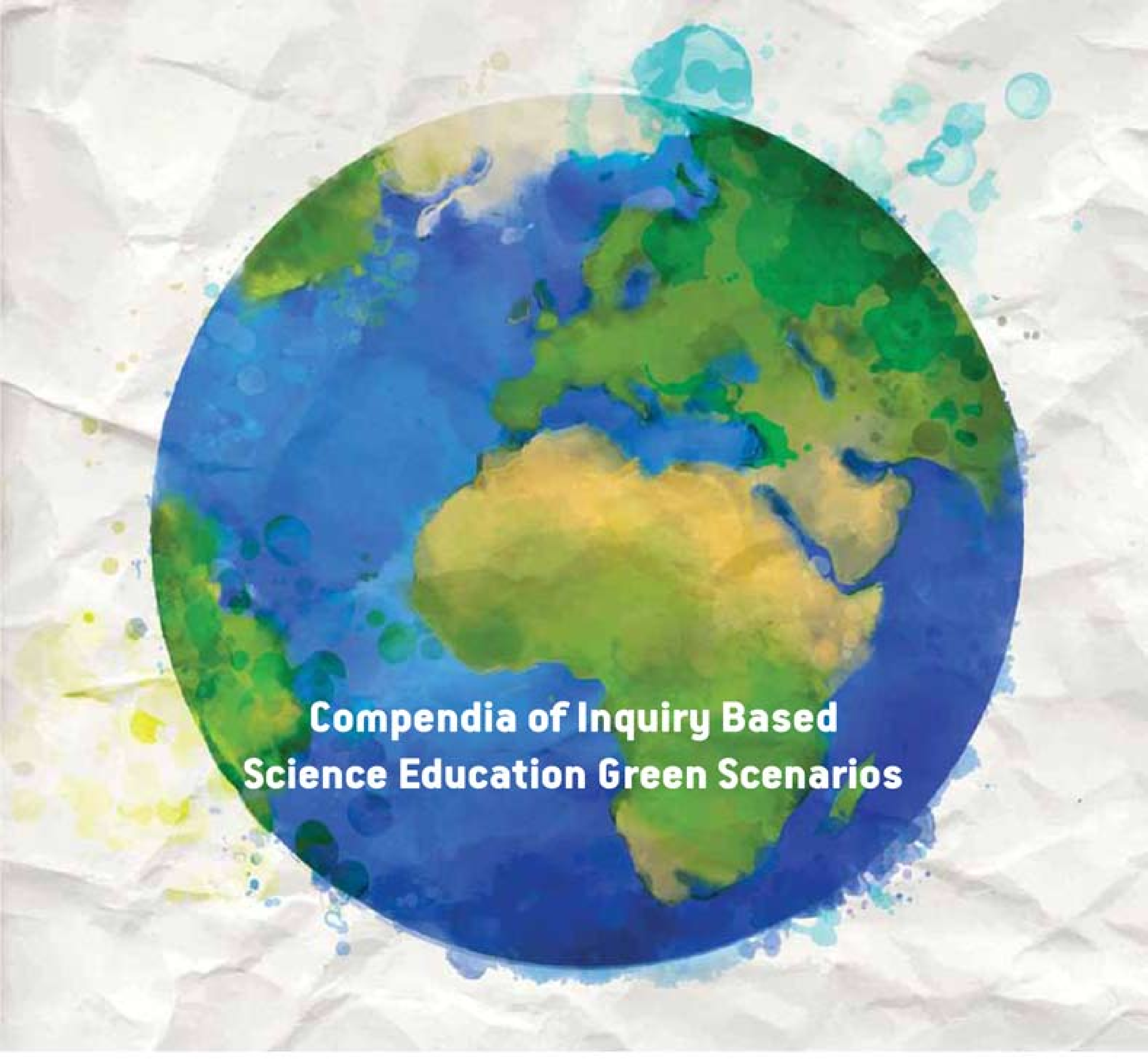

Compendia of Inquiry Based Science Education Green Scenarios

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REPORT

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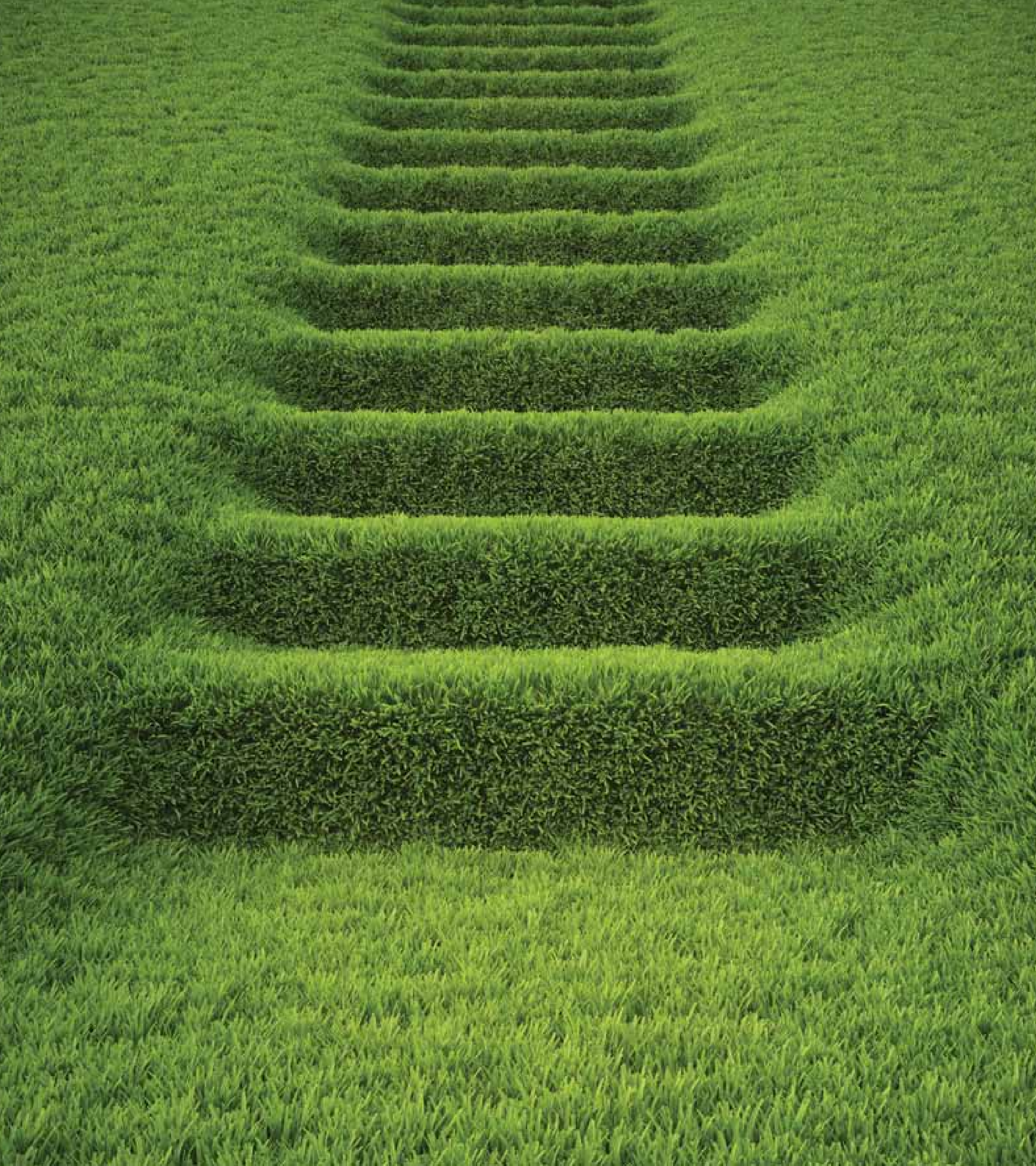

Contents

1

Summary

This deliverable will take the form of a report on the compendia of educational scenarios developed by the network and their relevance to the network and the wider context of the use of green educational resources. The Green Learning Network scenarios *(first version)* are described in detail in Deliverable D2.1. The current document will be re produced at the end of each project year and will be updated with new input or updated scenarios based on the feedback from the implementation work of the project. The compendia will emphasize the benefits of inquiry based learning by structuring its examples in the manner of a challenge and a set of responses. This will allow educators the chance to identify the appropriate case study and scenario and then to structure a lesson plan appropriate to their level from the information within the compendium. For this purpose in the first release of the deliverable we are presenting in detail the proposed framework of implementation and – taking into account the contextualized model of learning and the different categories of the project target groups – we will propose the pedagogical framework that will allow our partners to develop, adopt and share their scenarios, in their local contexts, following the inquiry based methodology.

In the framework of the development of the Green Learning Network pedagogical framework this document discusses the following issues:

In Chapter 2 we are describing the inquiry approach as the most suitable method to introduce environmental and green issues in the school curriculum and the Contextual Model of Learning as the most effective methodology to expand the learning experience in the framework of field trips in science centers and museums to cope with the quite demanding task to provide a common framework of reference for the different Green Learning Network target groups.

Chapter 3 describes the essential features of scientific methodology as an educational methodology. To shift toward a more inquiry-oriented classroom that builds on the strengths of both formal and informal learning and promotes green education, we have to consider five essential features: Student engages in scientifically oriented questions, student gives priority to evidence in responding to questions, student formulates explanations from evidence, student connects explanations to scientific knowledge and student communicates and justifies explanations.

Chapter 4 presents and extended literature review on the use of inquiry learning as the most effective approach to introduce the scientific methodology in the school practice. The Green Learning Network project is being taken forward against a background of widespread reform in science education at European level. The reform movement accords inquiry-based learning and teaching methods a central role in the motivation of students and in the development of their scientific literacy.

Chapter 5 is moving forward by presenting a series of elements of effective practice for the introduction of green issues in the educational practices. How can teachers support students to make hypotheses, to form scientific oriented questions, how can teachers design projects and complex educational activities that are moving across specific subjects? How can the new tools support the students' conceptual change? How can teachers assess the real educational outcomes? How can teachers use resources that are available on the web to support students learning at every occasion? This chapter identifies all the important elements that will be used to help the Green Learning Network consortium to design the proposed pedagogical approach that is materialized by the Green Learning Network Educational Pathways and Creativity Sessions that will be described in Chapter 6.

Chapter 6 presents the Green Learning network Educational Pathways Patterns. The concept of Educational Pathway in Green Learning Network reflects the priority given by the project to responding to the needs of the diverse communities of potential users of the Green Learning Network platform. Thus, an Educational Pathway in the Green Learning Network project describes the organization and coordination of various individual science learning resources into a coherent plan so that they become a meaningful science learning activity for a specific user group (*e.g. teachers, university students, farmers, museum visitors, etc.*) in a specific context of use. Further, Educational Pathways directly serve the priority assigned by the project to the integration of resources scattered in various repositories into the same learning experience rather than the mere selection of resources from a single source.

2

Contextualized model of learning

The pedagogical framework of Green Learning Network is based on the Contextual Model of Learning (*Falk & Dierking, 2000*). This model suggests that three overlapping contexts – the Personal Context, the Socio-cultural Context, and the Physical Context – contribute to and influence the interactions and experiences that people have when engaging in learning activities such as visiting informal learning settings.

2.1 Personal context

The Personal Context describes all the personal characteristics that a person brings to an informal learning situation including his or her interests and motivations, learning style preferences, prior knowledge and experience, each very critical component of successful experiences *(and learning)*. Motivation and emotional connection also play an important role in this context. Four important lessons are at the heart of the Personal context: 1) informal learning flows from appropriate motivational and emotional cues; 2) informal learning is facilitated by personal interest; 3) "new" knowledge is constructed from a foundation of prior experience and knowledge; and 4) learning is expressed within appropriate contexts.

2.2 Socio-cultural context

However, personal factors are not the only influence on successful informal learning experiences. Learners rarely engage in informal learning alone and the Socio-cultural Context encompasses factors that recognize that learning is both an individual and a group experience. What someone experiences and learns, let alone why and how someone engages in such experiences, are inextricably bound to the social, cultural and historical context in which that experience and learning occurred. More often than not, informal learning experiences are shared experiences, opportunities for collaborative learning. And even those learners that choose to learn alone become a part of the socio-cultural milieu of the learning setting itself, in the case of a museum, a world of other visitors, staff and volunteers. In addition, there are all of the cultural overlays of what these informal learning institutions represent in a society *(e.g., elitist or inclusive, modern or antiquated)*. Interestingly, not only is learning a socio-cultural process in the here and now, but the historical and cultural modes of communicating ideas are also socio-cultural in nature. This helps to account for the fact that universally, people respond well and better remember information if it is recounted to them in a story or narrative form, an ancient socio-cultural vehicle for sharing information.

2.3 Physical context

An informal learning experience also does not happen in a vacuum, isolated from the real world. When executed well, informal learning takes place in rich physical environments, filled with many real world objects and connections that help to meaningfully contextualize the presented concepts/

ideas. Physical Context factors also transcend the specifics of the learning situation. The architecture and "feel" of a building or natural setting, the way learners are oriented, the design features which guide learners through the experience and the sights, sounds and smells, also strongly influence learning. The Contextual Model of Learning provides the large-scale framework within which to organize one's conceptualisation of free-choice learning; the details vary depending upon the specific context of the learner.

Thus, the experience, and any learning that results, is influenced by the interactions between these three contexts. In this approach, learning is a life-long dialogue between the individual and his or her environment through time. Visiting experience and learning can be conceptualized as a contextually-driven effort to make meaning in order to survive and prosper within the world. Following the Contextual Model of Learning, the approach of Green Learning Network is to promote a contextually-driven dialogue, i.e., a dialogue between the relevant green content and the individual's personal, socio-cultural and physical contexts. None of these three contexts is ever stable or constant; all are changing across the life of the individual. The scenario design approach will guarantee that the methodologies and the tools deployed will indeed provide users with enhanced access to the green education resources, so that they are offered genuine opportunities for contextual learning in and around science centres and knowledge repositories.

2.4 Inquiry-based learning

A Renewed Pedagogy for the Future of Europe

In June 2007, a group of experts published the report «Science Education Now: A Renewed Pedagogy for the Future of Europe» (*Rocard et al, 2007*). The group, set up by Commissioners Janez Potoč nik and Jan Figel, made a number of recommendations. In accordance with these recommendations all actors involved should support actions to promote the more widespread use of problem and inquiry-based science teaching techniques in primary and secondary schools as well as actions to bridge the gap between the science education research community and science teachers in order to facilitate the uptake of inquiry-based science teaching *(IBSE)*.

- More specifically the main priorities for the science education at school level are:
- A reversal of school science-teaching pedagogy from mainly deductive to inquiry-based *(inductive)* methods provides the means to increase interest in science.
- Improvements in science education should be brought about through the new forms of pedagogy: The introduction of the inquiry-based approaches in schools and the development of teachers' networks should actively be promoted and supported.
- Renewed school's science-teaching pedagogy based on IBSE provides increased opportunities for cooperation between actors in the formal and informal arenas.
- Specific attention should be given to raising the participation of girls in key school science subject, and to increasing their self-confidence in science.
- Teachers are key players in the renewal of science education. Among other methods, being part of a network allows them to improve the quality of their teaching and supports their motivation.
-

Inquiry based learning has been characterized in a variety of ways over the years (*Collins, 1986; DeBoer, 1991; Rakow, 1986*) and promoted from a variety of perspectives. Some have emphasized the active nature of student involvement, associating inquiry with «hands-on» learning and experiential or activity-based learning. Others have linked inquiry with a discovery approach or with development of process skills associated with «the scientific methodology.» Though these various concepts are interrelated, inquiry based learning is not synonymous with any of them.

From a science perspective, inquiry based learning engages students in the investigative nature of science. So, inquiry involves activity and skills, but the focus is on the active search for knowledge or understanding to satisfy a curiosity. Teachers vary considerably in how they attempt to engage students in the active search for knowledge; some advocate structured methods of guided inquiry (*Igelsrud and Leonard, 1988*) while others advocate providing students with few instructions (*Tinnesand and Chan, 1987*). Others promote the use of heuristic devices to aid skill development (*Germann, 1991*). A focus on inquiry always involves, though, collection and interpretation of information in response to wondering and exploring.

From a pedagogical perspective, inquiry based learning is often contrasted with more traditional expository methods and reflects the constructivist model of learning, often referred to as active learning, so strongly held among science educators today. According to constructivist models, learning is the result of ongoing changes in our mental frameworks as we attempt to make meaning out of our experiences (*Osborne & Freyberg, 1985*). In classrooms where students are encouraged to make meaning, they are generally involved in «developing and restructuring [their] knowledge schemes through experiences with phenomena, through exploratory talk and teacher intervention» *(Driver, 1989)*. Indeed, research findings indicate that, «students are likely to begin to understand the natural world if they work directly with natural phenomena, using their senses to observe and using instruments to extend the power of their senses» (*National Science Board, 1991, p. 27*). In its essence, then, inquiry-oriented teaching engages students in investigations to satisfy curiosities, with curiosities being satisfied when individuals have constructed mental frameworks that adequately explain their experiences. One implication is that inquiry-oriented teaching begins or at least involves stimulating curiosity or provoking wonder. There is no authentic investigation or meaningful learning if there is no inquiring mind seeking an answer, solution, explanation, or decision.

Inquiry based learning has been officially promoted as a pedagogy for improving science learning in many countries (*Hounsell & McCune, 2002; NRC, 2000; Rocard et al., 2007*). Inquiry can be defined as «the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments» (*Linn, Davis, & Bell, 2004*). It is often touted as a way to implement in schools the scientific method: «The crucial difference between current formulations of inquiry and the traditional «scientific method» is the explicit recognition that inquiry is cyclic and nonlinear.» (*Sandoval & Bell, 2004*).

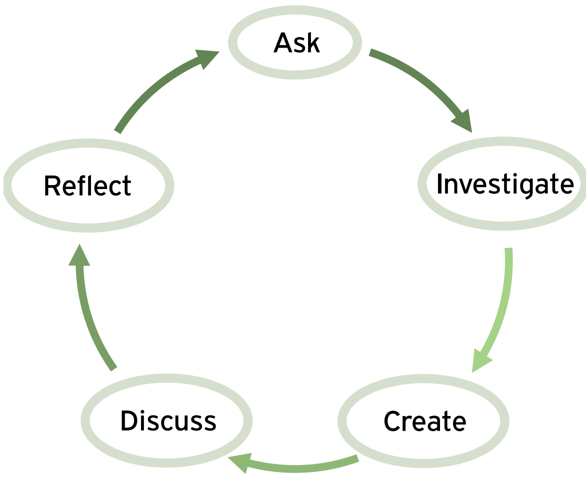

Figure 2.1:
The Inquiry Cycle (http://inquiry.uiuc.edu)

However, we use inquiry based learning in a more specific manner, referring to a specific teaching model: an iterative process of *(1)* question eliciting activities, *(2)* active investigation by students, *(3)* creation, these are *(4)* discussed already at early stages of the process, leading to *(5)* reflection about knowledge and the learning process, which in turn leads to new and refined questions *(1)* and the process goes on for another cycle. Here we have to mention that the Guided research teaching model of Schmidkunz & Lindemann *(1992)* is a rather similar approach that has been adopted in many primary school science curricula *(e.g. in Greece and in Cyprus)*. The word research in the model description reveals its aim to help students explore the research procedures themselves while the word "guided" emphasises that this research effort will take place as a structured discovery within the frame of organised teaching. This teaching model includes five teaching stages *(bringing up the phenomenon to a problem, suggestions for confrontation with the problem, implementation of a suggestion, abstraction of the finding, consolidation)* which are divided in several sub stages *(Schmidkunz & Lindemann, 1992)*. Still the implementation of this approach is also realised in a linear way in school practice.

Inquiry Based Science Education (*Rocard et al, 2007*)

Historically, two pedagogical approaches in science teaching can be contrasted. The first one, traditionally used at school, is the “Deductive Approach”. In this approach, the teacher presents the concepts, their logical —deductive— implications and gives examples of applications. This method is also referred to as ‘top-down transmission’. To be used, the children must be able to handle abstract notions, what makes it difficult to start teaching science before secondary education. In contrast, the second has long been referred to as the “Inductive Approach”. This approach gives more space to observation, experimentation and the teacher-guided construction by the child of his/her own knowledge. This approach is also described as a ‘bottom-up’ approach. The terminology evolved through the years and the concepts refined, and today the Inductive Approach is most often referred to as Inquiry-Based Science Education *(IBSE)*, mostly applied to science of nature and technology. By definition, inquiry is the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments *(Linn, Davis, & Bell, 2004)*. In mathematics teaching, the education community often refers to “Problem-Based Learning” *(PBL)* rather than to IBSE. In fact, mathematics education may easily use a problem based approach while, in many cases, the use of experiments is more difficult. Problem-Based Learning describes a learning environment where problems drive the learning. That is, learning begins with a problem to be solved, and the problem is posed in such a way that children need to gain new knowledge before they can solve the problem. Rather than seeking a single correct answer, children interpret the problem, gather needed information, identify possible solutions, evaluate options and present conclusions. Inquiry-Based Science Education is a problem-based approach but goes beyond it with the importance given to the experimental approach.

3

The essential features of scientific methodology in the school classroom

To begin shifting toward a more inquiry-oriented classroom, we have to consider five essential features:

- Student engages in scientifically oriented questions.
- Student gives priority to evidence in responding to questions.
- Student formulates explanations from evidence.
- Student connects explanations to scientific knowledge.
- Student communicates and justifies explanations.

3.1 Student Engages in Scientifically Oriented Questions

Scientifically oriented questions center on objects, organisms, and events in the natural world; they connect to the science concepts described in the school curriculum. They are questions that lend themselves to empirical investigation and lead to gathering and using data to develop explanations for scientific phenomena. Scientists recognize two primary kinds of scientific questions. Existence questions probe origins and include many «why» questions: Why the mean temperature of Earth increases? Why organic products are better for our health? In addition, there are causal and functional questions, which probe mechanisms and include most of the «how» questions: How can we produce healthier milk? How can we limit the air pollution? Students often ask "why" questions. In the context of school science and more specifically in environmental education and green education lessons, many of these questions can be changed into how questions and thus lend themselves to scientific inquiry. Such change narrows and sharpens the inquiry and contributes to its being scientific. In the classroom, a question robust and fruitful enough to drive an inquiry generates a need to know in students, stimulating additional questions of how and why a phenomenon occurs. The initial question may originate from the learner, the teacher, the instructional materials, the World Wide Web, some other source, or some combination. The teacher plays a critical role in guiding the identification of questions, particularly when they come from students. Fruitful inquiries evolve from questions that are meaningful and relevant to students, but they also must be answerable by student ob-servations and the scientific knowledge they obtain from reliable sources. The knowledge and procedures students use to answer the questions must be accessible and manageable, as well as appropriate to the students' developmental level. Skilful teachers help students focus their questions so that they can experience both interesting and productive investigations.

3.2 Student Gives Priority to Evidence in Responding to Questions

Science distinguishes itself from other ways of knowing through the use of empirical evidence as the basis for explanations about how the natural world works. Scientists concentrate on getting accurate data from observations of phenomena. They obtain evidence from observations and measurements taken in natural settings such as oceans, or in contrived settings such as laboratories. They use their senses; instruments, such as telescopes, microscopes or accelerators, to enhance their senses; and instruments that measure characteristics that humans cannot sense, such as magnetic fields. In some instances, scientists can control conditions to obtain their evidence; in other instances, they cannot control the conditions since control would distort the phenomena, so they gather data over a wide range of naturally occurring conditions and over a long enough period of time so that they can infer what the influence of different factors might be. The accuracy of the evidence gathered is verified by checking measurements, repeating the observations, or gathering different kinds of data related to the same phenomena. The evidence is subject to questioning and further investigation. In their classroom inquiries, students use evidence to develop explanations for scientific phenomena. They observe plants, animals, and rocks and carefully describe their characteristics. They take measurements of temperature, distance, and time and carefully record them. They observe chemical reactions and moon phases, and chart their progress.

3.3 Student Formulates Explanations from Evidence

Although similar to the previous feature, this aspect of inquiry emphasizes the path from evidence to explanation, rather than the criteria for and characteristics of the evidence. Scientific explanations are based on reason. They provide causes for effects and establish relationships based on evidence and logical argument. They must be consistent with experimental and observational evidence about nature. They respect rules of evidence, are open to criticism, and require the use of various cognitive processes generally associated with science— for example, classification, analysis, inference, and prediction—and general processes such as critical reasoning and logic. Explanations are ways to learn about what is unfamiliar by relating what is observed to what is already known. So explanations go beyond current knowledge and propose new understanding. For science, this means building on the existing knowledge base. For students, this means building new ideas on their current understandings. In both cases, the result is proposed new knowledge. For example, students may use observational and other evidence to propose an explanation for the phases of the moon, for why plants die under certain conditions and thrive in others, and for the relationship of diet to health.

3.4 Student Connects Explanations to Scientific Knowledge

Evaluation, and possible elimination or revision of explanations, is one feature that distinguishes scientific inquiry from other forms of inquiry and subsequent explanations. One can ask questions such as: «Does the evidence support the proposed explanation?», «Does the explanation adequately answer the questions?», «Are there any apparent biases or flaws in the reasoning connecting evidence and explanation?», and «Can other reasonable explanations be derived from the evidence?» Alternative explanations may be reviewed as students engage in dialogues, compare results, or check their results with those proposed by the teacher or instructional materials. An essential component of this characteristic is ensuring that students make the connection between their results and scientific knowledge appropriate in their level of development. That is, student explanations should ultimately be consistent with currently accepted scientific knowledge.

3.5 Student Communicates and Justifies Explanations

Scientists communicate their explanations in such a way that their results can be reproduced. This requires clear articulation of the question, procedures, evidence, and proposed explanation and a review of alternative explanations. It provides for further skeptical review and the opportunity for other scientists to use the explanation in work on new questions. Having students share their explanations provides others the opportunity to ask questions, examine evidence, identify faulty reasoning, point out statements that go beyond the evidence, and suggest alternative explanations for the same observations. Sharing explanations can bring into question or fortify the connections students have made among the evidence, existing scientific knowledge, and their proposed explanations. As a result, students can resolve contradictions and solidify an empirically based argument.

This approach does not culminate with the characterization of inquiry learning and teaching outlined in this section. It is also necessary to characterize the learning environments *(in and outside school)* that provide suitable contexts and opportunities for ISBE *(for learners and for teachers)* and the professional development programs that can support the desired change in teachers' practice towards ISBE.

By characterizing desired features of these four aspects *(inquiry learning, inquiry pedagogy, inquiry learning environments and effective PD programs)* it is possible to develop a standard-based framework for identifying Best-Practices of ISBE which can be disseminated and adapted to the local scenes. Moreover, by examining existing practices of ISBE against this framework, it is possible not only to identify the extent to which the practice conforms to the features outlined by the framework, but also to identify how it can be improved. For example, if the PD aspect is missing or does not possess recommended features of effective PD programs it can be enhanced.

4

Inquiry learning and teaching: Introducing the scientific methodology in school practice

4.1 Historical and policy development and the Standards

The Green Learning Network is being taken forward against a background of widespread reform in science education at European level. The reform movement accords inquiry-based learning and teaching methods a central role in the motivation of students and in the development of their scientific literacy. As described by *Beerer & Bodzin (2004)* scientific literacy is seen as essential to knowledge work and informed citizenship in contemporary society and can be defined as

> *… the knowledge of significant science subject matter, the ability to apply that knowledge and understanding in everyday situations, and an understanding of the characteristics of science and its interactions with society and personal life.*

Many commentators describe the history of current policy developments relating to inquiry learning as beginning with the work of John Dewey in the early 20th century. According to Barrow *(2006)*, Dewey encouraged science teachers to use a model of inquiry-based teaching that emphasised the importance of student activity and the teacher's role as a guide and facilitator of the inquiry process; this provided the basis for recommendations on science education made by the US Commission on Secondary School Curriculum in 1937 and later was adapted by Dewey to incorporate a greater emphasis on fostering students' reflective thinking and on the principle that inquiry questions should relate closely to students' experiences. According to Bybee *(2000)*, John Dewey was among the first who articulated the objectives of inquiry teaching in science as "developing thinking and reasoning, formulating habits of mind, learning science subjects, and understanding the process of science". The work of Joseph Schwab built on this in the 1960s and introduced the concept of student science inquiry as 'enquiry into enquiry'.

One of the most influential contributions to the current reform movement was the publication of the Next Generation Science Standards *(2013)* a major follow up of the National Science Education Standards of the US National Research Council *(NRC 1996)*, extending prior policy development by the American Association for the Advancement of Science *(AAAS)* in publications such as Science for all Americans *(1989)*[1], Benchmarks for Scientific Literacy *(AAAS 1993)*[2] and the Atlas of Scientific Literacy *(AAAS 2001)*[3]. The Next Generation Science Standards identify what experts in the

[1] http://www.project2061.org/publications/sfaa/default.htm
[2]http://www.project2061.org/publications/bsl/online/index.php?txtRef=&txtURIOld=%2Ftools%2Fbenchol%2Fbolintro.htm
[3] http://www.project2061.org/publications/atlas/

field believe to be the essential knowledge that all students need in order to become scientifically literate. The Standards identify inquiry as an important approach to science teaching although it is important to note that they do not present it as the only valid approach. The Standards emphasise that different approaches to inquiry teaching exist, and that the five essential features can be placed on a continuum of approaches from student-directed to teacher-directed. A key tenet of the Standards perspective is that every inquiry must engage students in an authentic question that must be of sufficient interest to them as to allow for students to experience genuine ownership of the learning process. The US Standards and related documents are points of reference for much of the current international literature on inquiry, and are the basis for the Green Learning Network's conceptualisation of inquiry raising awareness in green education.

Science education reform based on the adoption of inquiry methods has not, of course, only been taking place currently in the US. The theme of inquiry in science education is significant in science curriculum policy and development in many countries around the world *(see Minner et al 2010, for details of specific initiatives)*, although as Khalik et al *(2004)* note, different views of science and of science inquiry education are reflected in different contexts. In Europe, a key EC publication entitled Science Education Now: A Renewed Pedagogy for the Future of Europe presents recommendations for "actions to promote [inquiry] teaching techniques; actions aimed at helping teachers present the subject in an exciting and relevant manner; and actions that stimulate inquiry-based learning among young people" *(Rocard 2007)*. In the UK, student experience of scientific inquiry is identified as essential for the development of scientific literacy in Beyond 2000: Science Education for the Future *(Millar and Osborne 1998)* which contains recommendations for UK science education.

It is clear that there is considerable consensus internationally among stakeholders including policy-makers, researchers, science teacher educators and many teachers, that students should, for both educational and socio-economic reasons, experience learning through inquiry *(Asay and Orgill 2010; and, for critique of the educational assumptions underpinning inquiry see Shayer and Adey 1993)*. At the same time, many commentators point out that despite this agreement in principle and the relatively long history of reform initiatives, there has been as yet relatively little impact on teacher practice. For example, Wilson et al *(2010)* report widespread international research findings that show that inquiry-based teaching is infrequent in science education internationally. Whereas in reality scientists "investigate the world in diverse ways and in situations where they are presented with open-ended problems with no data, known methods or established goals", much current teaching of science focuses on "recipe-style laboratory exercises and a 'control of variables' or 'fair testing' model of science investigation" *(Hume and Coll 2008)*.

4.2 Defining inquiry

'Inquiry' is referred to in the science education literature to designate at least three distinct but interlinked categories of activity: what scientists do *(investigating scientific phenomena by using scientific methods in order to explain aspects of the physical world)*; how students learn *(by pursuing scientific questions and engaging in scientific experiments by emulating the practices and processes used by scientists)*; and, a pedagogy, or teaching strategy, adopted by science teachers *(designing and facilitating learning activities that allow students to observe, experiment and review what is known in light of evidence) (Minner et al 2010)*. For the purposes of the Green Learning Network, our focus is on developing the students' environmental culture by using inquiry as an active learning process engaged in by students and modelled on the inquiry practices of professional scientists *(Anderson, 2002)*.

The US National Research Council definitions of inquiry in science education highlight the close connection between inquiry as scientific practice, and inquiry as student learning:

> Inquiry is a multifaceted activity that involves making observations; posting questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in the light of experimental evidence; using tools to gather, analyse and interpret data; proposing answers, explanations and predictions; and communicating the

results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations *(NRC 1996: 23)*.

Inquiry is a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a rich understanding of concepts, principles, models and theories...and learn science in a way that reflects how science actually works (*NRC, 1996: 214*).

The concept of authenticity in the learning process is key to many definitions. For example:

Inquiry refers to diverse ways in which scientists study the natural world, propose ideas, and explain and justify assertions based upon evidence derived from scientific work. It also refers to more authentic ways in which learners can investigate the natural world, propose ideas, and explain and justify assertions based upon evidence and, in the process, sense the spirit of science (*Hofstein and Lunetta 2002: 30*).

The *Galileo Educational Network (2008a)* similarly describes inquiry in terms of the importance of focusing on authentic problems and issues that are relevant to students in relation to the real world. It also takes a key feature of IBSE to be the role that students play in defining their own questions as well as the direction of their learning. Learning is taken to be achieved through collaborative knowledge creation through active investigations that lead students to new insights. Teachers are responsible for facilitating students' efforts to learn by appropriately structuring and scaffolding the learning environment. Other commentators also identify students' roles as designers of their own inquiry investigations as a defining feature of the inquiry approach (*e.g. Deters 2004*) but this is not a universally-held view.

Inquiry learning approaches in science education are designed to focus on both subject and process learning. For example:

The inquiry-based approach to science education [...] introduces students to the content of science, including the process of investigation, in the context of the reasoning that gives science its dynamic character and provides the logical framework that enables one to understand scientific innovation and evaluate scientific claims. Inquiry is not process versus content; rather it is a way of learning content (*Drayton and Falk 2001: 25*).

While definitions of inquiry learning in primary and secondary level science vary, there is agreement that its central characteristic is the emphasis on the inquiry question as the driver of students' learning experiences (e.g. *Crawford 2000; Cuevas et al 2005; Deters 2004; Drayton and Falk 2001*). There is often an emphasis on students engaging in collaborative inquiry with peers (e.g. *Hmelo-Silver 2006*) and on the development of student inquiry communities. Students' results of their inquiries may be shared with other groups in the wider context of scientific discussions, debates and presentations.

A number of authors draw a distinction between learning and teaching science 'as inquiry' and 'by inquiry' (e.g., *Chiappetta 1997; Jarrad and Schroeder 2010; Zion et al 2004*). The meanings ascribed to these terms vary, but in general the former is used to refer to learning about what scientific inquiry entails without *(necessarily)* involving students themselves in the process of scientific inquiry. In contrast, learning by inquiry emphasises the construction of knowledge through scientific activity. Learning and teaching science by inquiry always takes the conduct of some form of scientific investigation as its point of departure and its central process, using methods used by scientists to investigate the natural world. Learning and teaching by inquiry is the approach with which the Green Learning Network is concerned.

There is no 'one way' to implement inquiry learning in the science classroom. *Keys and Bryan (2001: 632)* note that inquiry is not "a specific teaching method or curriculum model, although it may be embedded within or overlap various models, such as the learning cycle or conceptual change". There is broad recognition in the literature that it should be seen as a flexible pedagogy that allows teachers to tailor their approaches to the desired learning outcomes and specific circumstances of different classroom contexts. "Multiple modes and patterns of inquiry-based instruction" are seen as desirable so that teachers are empowered to develop inquiry teaching in ways that fit their own educational beliefs and teaching styles *(Keys and Bryan 2001: 632)*. At the same time, there is evidence to suggest that teachers may often hold limited conceptions of inquiry, with negative impact for its development in their classrooms (e.g. *Asay and Orgill 2010; Kang et al 2008*).

Alongside the plethora of definitions of the concepts of inquiry provided in the research literature and policy statements, both research and accounts of practice show that individual teachers hold differing views or may be uncertain about what is meant. Recently researchers have argued that inquiry should be distinguished from other, looser concepts such as 'hands-on' instruction or active learning *(Lee et al 2010)*. These authors propose that the distinctive hallmarks of successful inquiry approaches are: driving questions that are often refined by students; complex and open-ended investigations; explorations of realistic settings; selection among experimental methods; connections between alternative representations; formulation of explanations.

4.3 Educational theory

As a pedagogical approach, inquiry has philosophical and theoretical roots in the work of theorists including John Dewey and Jean Piaget and in the constructivist educational paradigm. Constructivism takes learning to be an active, situated and social process; informed by this perspective, inquiry learning is seen to enable students to construct their own knowledge about science, about how scientists work, and about the science inquiry process, through engagement with inquiry questions and interactions with peers, teachers, resources, and the learning environment.

Personal construction of meaning resulting from individuals' interactions with a learning environment is the core commitment of a constructivist position. The influence of theories of social constructivism and situated cognition, which place emphasis on the inter-subjective, dialogical negotiation of meaning in knowledge-construction, and on learning as an act of participation in authentic communities of practice *(Lave and Wenger 1991)*, can be seen in the emphasis on group-work and collaboration in much of the current literature and reported practice of IBSE *(e.g. Lee and Songer 2003)*. The social perspective on inquiry recognises that an important way in which students are introduced to scientific thinking and knowledge is through discussions in the context of authentic, community-based activities. From this perspective, learning science through inquiry can be seen as involving a process of enculturation or apprenticeship into scientific practices and community by more experienced members *(Bybee 2000)*. More experienced members can support less experienced members by providing and structuring tasks, allowing less experienced members to internalise processes and practices. Vygotsky's ideas about scaffolding learning in the 'zone of proximal development' - that is, the gap between the level a learner can reach without assistance from more knowledgeable others and the level s/he can reach with assistance - often are drawn on in the inquiry literature to explain how a more experienced peer or teacher can work with a less experienced as the latter learns to take greater control of the inquiry process. Scaffolding strategies include reciprocal teaching, modelling, self-assessment, reflective assessment among others.

These inquiry classroom practices may differ from those that take place within communities of professional scientists. This difference has been recognised by science education researchers (e.g. *Brown 2006; Hume and Coll 2008; Sadeh and Zion 2009; Khalick et al 2004; Lin et al 2009*) who attempt to explore ways of using collaborative inquiry learning that can support students in gradually mastering some of the practices and norms that characterise scientific communities. A key challenge as Driver et al see it, is "one of how to achieve such a process of enculturation successfully in the round of normal classroom life… [and] there are special challenges when the science view that the teacher is presenting is in conflict with learners' knowledge schemes" *(2004: 63)*.

4.4 Aligning learning outcomes, teaching strategies and assessment

There is wide consensus in the literature that the desired learning outcomes of scientific inquiry learning are essentially threefold, as established, for example, by the United States National Science Education Standards *(NRC 1996: 21)*. The Standards promote inquiry as having a central role to play in developing students' "abilities necessary to do scientific inquiry" and their "understandings of scientific inquiry" as well as their learning of scientific content.

Achieving alignment between desired outcomes, and teaching and assessment strategies, is taken here to be a fundamental characteristic of effective inquiry pedagogy. This is consistent with the principle of 'constructive alignment' *(Biggs, 1996)* in constructivist educational theory.

Table 4.1: Examples of teaching and assessment that support inquiry-oriented outcomes (source Bybee 2000: 39-40)

Standards-Based Educational Outcomes - what should students learn?	**Teaching Strategies -** what are the techniques that will provide opportunities to learn?	**Assessment Strategies -** what assessments align with the educational outcomes and teaching strategies?
1. Understanding Subject Matter (e.g., motions and forces; plate tectonics; The role of water in Earth surface processes; Energy in the Earth System).	Students engage in a series of guided or structured laboratory activities that include developing some abilities to do scientific inquiry but emphasize subject matter (e.g. law of motion, F=ma, etc.).	Students are given measures that assess their understanding of subject matter. These may include performance assessment in the form of a laboratory investigation, open response questions, interviews, and traditional multiple choice.
2. Developing Competencies Necessary to Do Scientific Inquiry (e.g., students formulate and revisescientific explanations and models using logic and evidence).	Students engage in guided or structured laboratory activities and form an explanation based on data. They present and defend their explanations using (1) scientific knowledge and (2) logic and evidence. The teacher emphasizes some inquiry abilities in the laboratory activities used for subject-matter outcomes.	Students perform a task in which they gather data and use that data as the basis of an explanation.
3. Developing Competencies Necessary to Do Scientific Inquiry (e.g., students have opportunities to develop all the fundamental abilities of the standard).	Students carry out a full inquiry that originates with their questions about the natural world and culminates with a scientific explanation based on evidence. The teacher assists, guides and coaches students.	Students do an inquiry about a question of personal interest without direction or coaching. The assessment rubric includes the complete list of fundamental abilities.

4. Developing Understandings about Scientific Inquiry (e.g., scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide the rules of evidence; it must be open to question and possible modification; and it must be based on historical and current knowledge).	The teacher could direct students to reflect on activities from several laboratory activities. Students could also read historical case studies of scientific inquiry (e.g., Copernicus, Galileo). Discussion groups pursue questions about logic, evidence, scepticism, modification, and communication.	Students are given a brief account of a scientific discovery and asked to describe the place of logic, evidence, criticism, and modification.

We identify a need for small clarification of the framework illustrated in Table 4.1, on the assumption that Educational Outcomes 2 and 3 are intended to distinguish between 'basic' and 'more advanced' levels of competency; this clarification has been added to Table 4.2.

Table 4.2: The Green Learning Network framework for learning outcomes in Green Education (adapted from Bybee 2000)

Intended Learning Outcomes		
A	Understanding scientific subject matter	e.g. energy; living systems; diversity, energy in the earth system;
B	Developing basic competencies necessary to do scientific inquiry	e.g. the ability to design a simple experiment
C	Developing more advanced competencies necessary to do scientific inquiry	e.g. energy; living systems; diversity, energy in the earth system;
D	Developing understandings about scientific inquiry	e.g. the understanding that Green Learning network 2013-1-FR1-LE005-48937 Page 23 scientific explanations must adhere to a range of established criteria, such as: a proposed explanation must be based on historical and current scientific knowledge

The Green Learning network pedagogical framework thus identifies four broad educational outcomes for inquiry learning: understanding of subject-matter; development of problem solving competencies *(at less and more advanced levels of performance)*; and, development of understandings about the nature of scientific inquiry. It may be assumed that all inquiries will be designed with the goal of improving students' understanding of some aspect of scientific subject-matter. In addition, it is likely that most inquiries will be designed with some - smaller or greater - degree of emphasis on students developing process-related learning outcomes: that is, on student learning of competencies necessary to carry out scientific inquiry. Perhaps less typically learning outcomes associated with understanding the nature of scientific inquiry also may be identified.

4.5 Inquiry types: structured, guided, open, coupled

Inquiry learning science activities encompass a broad spectrum ranging from strongly teacher-directed to strongly student-directed *(Martin-Hansen 2002; NRC 2000; Sadeh and Zion 2009)*. Since science teachers need to adopt different strategies according to different intended learning outcomes, the needs of students, and the specific circumstances of their own *(diverse)* science classrooms, understanding different types of inquiry learning and teaching will help them to create learning activities that are appropriate in context. One fundamental pedagogical decision relates to the degree of structure and guidance with which students will be provided in any given inquiry activity *(Brown et al, 2006)*. A continuum of types of science inquiry, which we refer to as 'structured', 'guided', and 'open', based on usage in the literature, is often described *(e.g., Krajcik et al 1998; NRC 2000; Zion et al 2007)* and is reflected, although not systematically, in the Examples of Teaching and Assessment provided by Bybee *(2000)* and illustrated in Table 4.3.

Structured science inquiry is strongly teacher-directed. Students follow their teacher's direction in pursuing a scientific investigation to produce some form of prescribed product. For example, they investigate a question provided by the teacher through procedures that the teacher determines, and receive detailed step-by-step instructions for each stage of their investigation. Guided science inquiry is somewhat more loosely scaffolded in that students take more responsibility for establishing the direction and methods of their inquiry. The teacher helps students to develop inquiry investigations in the classroom, for example offering a pool of possible inquiry questions from which students select those they wish to pursue and proposing guidelines on methods *(Sadeh and Zion 2009)*. Open science inquiry approaches enable students to take the lead in establishing the inquiry question and methods, while benefiting from teacher support. For example, in open inquiry, students initiate the inquiry process by formulating topic-related questions. They make their own decisions about the design and conduct of the inquiry and the communication of results. High-order thinking and the ability to apply the necessary scientific processes are emphasised during open inquiry (*Sadeh and Zion 2009*).

Coupled inquiry is a term that sometimes is used to refer to approaches that combine two types of inquiry, for example guided with open. In such an example, it could be characterised as an intermediate stage between the two. A coupled guided/open inquiry cycle might entail: (a) an invitation to inquiry; (b) a preliminary, teacher-initiated, guided inquiry; (c) a follow-up, student-initiated, open inquiry; (d) sharing of findings; and, (e) assessment of student performance (*Martin-Hansen 2002*).

There is a substantial literature on the merits and problems of different types of inquiry *(structured, guided, open)* but little consensus on the practical implications of research findings. Some research suggests that highly structured inquiry may constrain the development of critical and scientific thinking *(Berg et al 2003; Kaberman and Dori 2008)*. Berg et al *(2003)* compared outcomes of a structured and open version of a chemistry laboratory experiment and showed that the latter helped students to understand the experiment better while also showing positive effects regarding preparation time, time spent in the laboratory, and other learning outcomes.

Both guided and open inquiry are identified as helping students to develop understanding of complex scientific concepts and, at the same time, to acquire scientific process skills, or competencies, necessary for conducting scientific investigations, and understand the nature of science *(e.g. Krajcik et al 1998)*. However, the type of inquiry that is more suitable for teaching science in schools remains controversial *(Zion and Slezak 2005)*. Individual teachers may prefer either guided or open inquiry methods. It is argued that guided inquiry offers specific teaching techniques to achieve particular learning outcomes, and clear assessment strategies, which reduce the chance of failure *(Trautmann 2004)*, whereas the risk of failure may be greater in open inquiry (*Zion et al 2007*).

Guided inquiry can be used as a means to help students to transit to open inquiry *(Martin-Hansen 2002)*. Those who prefer open inquiry perceive that by using this method, students have more opportunities to experience the authentic nature of science and in this way learn to confront complex scientific phenomena *(Zion et al 2007)*. When students are engaged in open inquiry, high-level science process skills are employed and high-level thinking is developed *(Krystyniak and Heikkinen 2007)*. Cuevas et al *(2005)* found that elementary students' abilities to ask scientific questions, record findings, design scientific processes and draw conclusions increased after completion of two open inquiry units. Wu and Krajik *(2006)* investigated use of data tables, graphs and diagrams in an open inquiry environment, in research that showed how less scaffolding is necessary for supporting open inquiry processes. Sadeh and Zion *(2007)* compared the effects of open versus guided inquiry among high-school students. Their study's results indicated that students engaged in open inquiry were more likely to demonstrate advances in conceptual and procedural understanding. In sum, while some researchers are positive about adopting open inquiry approaches, others argue that there is a need for further investigation of open inquiry practices and outcomes *(Berg et al 2003; Crawford 2000; Krystyniak and Heikkinen 2007)*.

Although guided and open inquiry types are discussed predominantly in relation to classroom contexts, some authors have discussed their application specifically in laboratory experiments. In guided-inquiry laboratories students follow directions, gather data for specific variables and reflect on the relationships among the variables from their own data. In open inquiry laboratories students design their own experiments and procedures for investigating a question. Chatterjee et al *(2009)* studied the incorporation of both guided and open inquiry experiments in a science laboratory course. The study found that students had a more positive attitude towards guided inquiry than open inquiry laboratories because they believed that they learned more with the former.

Key distinctions between structured, guided and open inquiry not uncommonly are poorly understood by scholars and practitioners alike. For example, Kirschner et al *(2006)* characterise inquiry learning as 'unguided' or 'minimally guided' and base their strong critique of the approach on that misconception *(Hmelo-Silver et al 2007)*.

Table 4.3: Inquiry types to be used in Green Learning Network (adapted from NRC 2000)

Inquiry types		
A	Structured	Strongly teacher-directed. Students follow their teacher's direction in pursuing a scientific investigation to produce some form of prescribed product, e.g. they investigate a question provided by the teacher through procedures that the teacher determines, and receive detailed step-by step instructions for each stage of their investigation.
B	Guided	More loosely scaffolded. Students take some responsibility for establishing the direction and methods of their inquiry. The teacher helps students to develop investigations, for example offering a pool of possible inquiry questions from which students select, and proposing guidelines on methods.
C	Open	Strongly student-directed. Students take the lead in establishing the inquiry question and methods, while benefiting from teacher support. For example, students initiate the inquiry process by generating scientific questions and take their own decisions about the design and conduct of the inquiry and the communication of results.
D	Open	A combination of two types of inquiry, for example a guided inquiry phase followed by an open inquiry phase.

5

Elements of effective practice

5.1 Inquiry questions and problems

Engaging students with scientific questions is central to IBSE and students themselves need opportunities to generate questions *(Kaberman and Dori 2009)*. As already noted, the Standards draw particular attention to the need to use student experience as the point of departure for formulating inquiry questions, stating that "inquiry into authentic questions generated from student experiences is the central strategy for teaching science" *(NRC 1996: 31)*.

Clifford and Marinucci *(2008)* explore the character of questions that trigger students' attention, provoke wonder, and lead to further questions. These include questions arising from real-world phenomena - for example, 'Why cannot people drink salt water?' - and questions such as 'How is this possible?' These authors argue that an inquiry does not have to evoke 'big questions' about the world, and that the topic itself may matter less than the attitude students take toward it. Controversial issues or ill-structured topics can be used by teachers to help students formulate questions *(van Rens and van der Schee 2009)*. The literature provides examples of a wide range of activities designed to encourage and help students to formulate meaningful questions including group discussion tasks and concept-mapping among others. For example, teachers might assign the role of raising questions to some members of a student group while others have the role of responding (Osborne et al 2004).

Developing questioning skills that will enable students to increase scientific understanding is seen as critical in inquiry learning. However, posing questions is challenging for students. Some studies have illustrated the difficulties that students may experience in this respect *(e.g., Kracjik et al 1998; Kuhn et al 2000)*. Differences in students' approaches to learning may explain variation in their approaches to questioning in IBSE. For example, a study by Chin and Brown *(2000)* revealed variation in students' approaches to posing questions in a chemistry lab. Students using a 'surface' approach to learning were more likely to pose factual or procedural questions, while those using a 'deep' approach posed questions that would help them clarify their conceptions.

Development of scientific questioning skills is an important learning outcome for IBSE. Inquiry-based chemistry laboratories were shown in one study to help students to ask higher-level questions in comparison with students who were engaged in non-inquiry laboratory work *(Hofstein 2004; Hofstein and Lunetta 2004)*. However, as already noted, in their analysis of a large body of reported real-life examples of IBSE, Asay and Orgill *(2010)* found few that explicitly described a scientific question designed to drive the students'

inquiry activity and where these were described they were usually teacher-directed. These authors comment that while it may be that "not all classroom inquiry activity needs to start with a question in order to be effective" *(p.71)* but that this needs to be confirmed by research. Their study shows that teachers may not perceive questions as an essential feature of inquiry activity, or alternatively may have difficulty designing questions and therefore need practice in doing so: "Pre and in-service teachers may need explicit examples of and experiences with helping students develop this skill" *(Asay and Orgill 2010: 71)*. Crawford *(1999)* suggests that science teachers do not allow students to generate questions because of concerns that students may not know enough to ask appropriate questions.

Problems and problem-solving are conceived as central to IBSE in many contexts. For example, in mathematics teaching, PBL is used as an approach to engage students in problem identification and solution for resolving real world problems that are personally meaningful. A problem-based rather than an inquiry-based approach may be more easily implemented because mathematics involves strategies of problem-solving in relation to unfamiliar tasks *(NRC 2001)*. Mathematical investigations involve extended problem explorations which aim to engage students in deep learning through problem identification, data collection and exploration of multiple strategies *(ACME 2011)*. Due to the problem-based nature of mathematical investigations, teachers can create relevant tasks to provide students with a range of mathematical abilities and interests whilst allowing them to apply their mathematical skills and learn new skills. For example, Watters and Diezmann *(2004)* show how students developed a range of key mathematical processes such as problem finding, problem posing and constructing hypotheses by participating in complex tasks. The authors claim that students became scientifically and mathematically literate by engaging in hypothesis testing and evaluation of mathematical concepts or structures.

5.2 Authenticity

Authenticity is a central concept in conceptualisations of IBSE. Studies emphasise the importance of using authentic situations to develop rich understandings about scientific knowledge *(Lee and Sogner 2003)*. Authentic tasks have been defined as 'ordinary practices of the culture' *(Brown et al, 1989: 34 cited in Lee and Sogner 2003)* or what students need to explain in relation to the real world (NRC 1996). Authentic tasks are seen to engage students in scientific activity that promotes how scientists conduct scientific experiments, but in ways that are meaningful for students and with appropriate support *(Edelson et al 1999)*. Authentic practices associated with the culture of science communities include asking questions, planning and conducting investigations, drawing conclusions, revising theories, and communicating results. Authentic tasks described as such in the literature encompass observation, investigation and explanation of real-world phenomena that aim to enable students to formulate and connect explanations to their real world *(Harris and Rooks 2010)*. Lee and Sogner *(2003)* identify a key challenge for IBSE educators: to design inquiry learning that both emulates inquiry in science disciplines and is accessible to students. Since different science communities have developed specific ways of carrying out inquiry, there is no one way of carrying out authentic scientific inquiry across scientific disciplines *(NRC 2000)*.

The concept of authenticity is sometimes linked to open-endedness of questions and problems, and student ownership of these. Open-ended problems where there may be no existing data, established goals or known methods are seen as authentic *(Hume and Coll 2010)*. Successful engagement with open-ended questions depends on students' ability to tackle ill-defined problems. Anderson *(2002)* comments that scientists perform such activities intuitively, using their own personal experiences and cognitive abilities as well as their capacity to change their current knowledge to accommodate new scientific understandings and experiences of how to do science. Thus, from this perspective to experience authenticity in inquiry, students need to have a sense of ownership of, and commitment to, open-ended problem solving. Authentic tasks help students to clarify their ideas and explanations and improve their argumentation *(Hofstein and Lunetta 2004)*.

A study by Hume and Coll *(2008)* found that the assessment requirements of a 'high stakes' national qualification negatively influenced teachers' approaches to designing inquiry, limiting the authenticity of tasks and resulting in student learning that was mechanistic, superficial and promoted a narrow view of the nature of scientific inquiry as fair testing. A follow-up study also found that over-emphasis on testing limited the authenticity of the task and constrained students' exposure to the full range of methods that scientists use in everyday practice. Learning about experimental design was reduced to an exercise where students were following teachers' instructions *(Hume and Coll 2010)*.

Teachers also may be challenged in developing authentic science tasks if they are not familiar with how authenticity can be addressed, if they do not understand the practices and processes of scientists, or if they have never participated in authentic science inquiry themselves *(Harris and Rooks 2010)*. However, there is extensive guidance on ways to add authenticity to science tasks. The use of real-world problems that scientists need to address in their everyday practice is one very widespread approach. For example, the 'The Scientists in Action Series' created by the Cognition and Technology Group at Vanderbilt *(CTGV)* introduces real-world aspects of scientific investigation. Students are asked to explain scientific phenomena after watching a video on a particular real-world scientific topic. Authenticity can also be obtained through students' tackling scientific problems that emerge from their own normal life and that can be addressed in a form of a class project *(Fogleman 2011; Krajcik et al 1998)*. Lee and Sogner *(2003)* suggests that real-world situations that map closely on to students' content understandings, rather than those with naturally occurring complex patterns, help students conduct inquiry effectively. Another recommended approach is to establish a community of practitioners between students and real scientists for data sharing, exchange of scientific methods and direct communication *(Simsek and Kabapinar 2010)*.

Orchestrating and sequencing teaching around learning goals is also perceived as an important aspect of designing authentic inquiry tasks *(Lunsford 2007)*. If teachers have a learning outcome in mind and organise teaching and learning around that outcome students are more likely to succeed in pursuing the learning activity *(Harris and Rooks 2010)*.

5.3 Conceptual change

The Standards *(NRC 2000)* argue that conceptual change is achieved if students are dissatisfied with or challenged in their current understandings while having access to new ideas with which to replace these. Inquiry tasks should be designed in a way that promotes new scientific ideas in an understandable, reasonable and useful way *(Harlen 2004)*. It is recommended that tasks that focus on conceptual change should de-emphasise an existing idea and emphasise the conceptualisation of a new one (*Crawford 2007*). Inquiry tasks generally involve creating opportunities for students to make their own ideas explicit, share them with others and test their robustness by observation and scientific experiments. To provide an initial trigger, a teacher might begin a scientific investigation or a scientific topic by posing a question, stating a problem or involving students in a laboratory-based or outdoor/field activity. Students' responses and interpretations can be elicited by a variety of means, including teacher questioning, group discussion and writing tasks. Through role-play, simulations, laboratory activities, discussing, reading and writing, students explore their own understandings and begin to appreciate the views and understandings of other peers (*So-Wing and Kong 2007*).

5.4 Laboratory and other experiments

The laboratory is important in IBSE especially 'if used properly' *(Hofstein & Lunetta 2004: 31)*. Inquiry approaches to laboratory work should be differentiated from 'cookbook' lists of tasks for students to follow. These authors note that,

> *Well-designed science laboratory activities focused on inquiry can provide learning opportunities that help students develop concepts and frameworks of concepts. They also provide important opportunities to help students learn to investigate, to construct scientific assertions, and to justify those assertions in a classroom community of peer investigators in contact with a more expert scientific community.' (p. 47)*

The literature offers many examples of structured inquiry activities in laboratory settings, often described as 'hands-on' investigative activities *(e.g. Poon et al 2009)*. Another example of hands-on quasi-experimental activity includes two investigative tasks for fifth-grade students described by Lin et al *(2009)*. In the first task, students were asked to design experimental procedures to produce bubbles from detergent, metal, wire, beakers and a cylinder. In the second, students were provided with six different sizes of paper parachutes, a pair of scissors and a stop watch. After the teacher showed, using a guided inquiry approach, how to measure the time required for the parachute to fall, the students were asked to define researchable questions by considering these materials. During both tasks students were encouraged to establish their own hypothesis, design inquiry procedures, draw conclusions from evidence and justify explanations. The students presented their ideas and responded to questions from the science teacher and peers, and clarified their thinking through feedback. This is an example of a relatively highly structured laboratory activity in which students were provided with investigation procedures and followed instructions to carry out the experiments. Rowell *(2004)* describes a similar structured approach in which students were provided with supportive resources including a scientific guide to help them write up an experiment to investigate the general properties of air, with guidance provided on the statement of the problem, hypothesis, materials, procedure, observations and inference.

5.5 Discussion and argumentation

Strategies that stimulate negotiation of ideas, argumentation and reflection are emphasised in the literature *(e.g. Branan and Morgan 2010; Osborne et al 2004)*. Triggers for discussion may be verbal/written *(e.g. reading stories, newspapers reports)*, visual *(e.g. scientific photos, Internet images, diagrams, concept maps)*, multimedia *(e.g. video, movies, PowerPoint presentations)* and personal *(e.g. based on students' experience and viewpoints, captured through mind-mapping, critical incidents, reactions to an issue through 'voting' etc)*. Branan and Morgan *(2010)* found that students enrolled on mini-lab activities had more chance to work as a group and to discuss and reflect on questions than in labs that offered no inquiry activities. At the conclusion of discussions and debates, the teacher can summarise emerging issues whilst explaining the process of meaning making through quality arguments *(To-im and Ruenwongsa 2009)*.

Ratcliffe and Grace *(2003)* provide examples including ethical scientific analysis *(i.e. a process which can help students decide on scientific issues of right and wrong as applied to people and their actions)*, evaluation of media reports *(e.g. print media: radio, Internet: collecting reports of science stories for highlighting and discussing the features of doing science and thereby developing conceptual understanding)*, risk-benefit analysis *(e.g. students can be asked to consider the extent to which they are prepared to engage in a dangerous scientific experiment and then compare their conceptions with risk statistics; or through the provision of a decision-making framework for helping to structure a decision-making discussion critically and systematically)*. Other possible ways to help students to externalise and express ideas is by creating artefacts representing a particular scientific topic, for example by creating a picture that represents a student's understanding *(Singer et al 2000)*, building a computer model *(Manlove et al 2006)* and developing a concept map *(Stoddart 2000)*.

Scientific argumentation tasks involve proposing, supporting, criticizing, evaluating, and refining ideas about a scientific subject. From their examination of ways to engage students in, and improve, their scientific argumentation, Taasoobshirazi and Hickey *(2005)* propose three important factors for effective practice: detailed description of the argumentation task with specific guidelines; formation of student discussion groups of optimal size *(group sizes of three to six: large enough to expose students to a diversity of opinions, but small enough for all students to participate)*; and, a curriculum that helps students to acquire the necessary background knowledge since students are likely to be more capable of arguing about a topic when they have knowledge about it.

5.6 Discrepant events

A discrepant event is a demonstration of a scientific phenomenon which causes students to wonder why the event occurred as it did *(Chiappetta 1997)*. The intention is to stimulate surprise, puzzlement and curiosity. Discrepant events can capture students' attention and stimulate interest, as well as motivate them to challenge their existing conceptualisations in a way that creates cognitive dissonance *(Chiappetta 1997; Jarrad and Schroeder 2010).*

An illustration of the use of a discrepant event is provided by Huber and Moore *(2001)* with the 'Dancing Raisins' activity. The task is designed in such a way that allows students to discover the discrepant event rather than having the teacher demonstrating it. A discrepant event arises when a raisin is dropped into a glass of carbonated beverage. The teacher or the student presents the challenge by posing a question, 'Can you think of a way to make the raisins dance faster? The question acts as trigger for a brainstorming session facilitated by the teacher. The brainstorming session is important because it moves students into designing an experiment before realising how the experiment is implemented in practice. The teacher can change the focus of inquiry from theory *(can you think of a way)* to practice *(can you find a way)* and guide towards discussion of experimental design involving different conditions and variables. Students then present and defend the results of their investigations to the class using graphical representations to represent their findings.

5.7 Projects

Much IBSE is carried out through projects that may address all or some of the learning outcomes of the Standards-based framework and that differ widely in scale. Possible science project topics include *(Ratcliffe and Grace 2003):*

- Exploring scientific advances *(encouraging students to research, discuss and evaluate scientific issues - students may be evaluated against the 'understanding subject matter or against 'developing basic competencies necessary to do scientific inquiry' learning outcome);*
- Citizenship projects *(addressing socio-scientific issues within citizenship - e.g. an environmental issue - students may be expected to develop 'more advanced competencies necessary to do scientific inquiry);*
- Consensus projects *(exploring a scientific issue of public concern, for example climate change, including hearing and considering the views of experts and then producing public reports, addressing the intended learning outcomes related to 'developing more advanced competencies to do scientific inquiry and/or 'developing understandings about scientific inquiry)*, community or cross-curricular projects. Community projects aim to deliver science curriculum requirements combined with the features of the local community, addressing the learning outcome 'developing understandings about scientific inquiry'.

5.8 Formative and Summative assessment

The National Science Education Standards *(NRC 1996)* indicate that all assessment should be 'authentic'. In the context of IBSE, this has been described in the following way: 'students should be assessed, formatively and summatively, in the context of whole investigations' and that this should 'include a holistic assessment of process skills' *(Hume and Coll 2008: 1204)*. Assessment should be tied to authentic activities and aim to enhance student learning. The goal of inquiry assessment is often not only to test the knowledge that has been acquired but also the processes and skills that students have used in order to perform an inquiry task. Teachers need to be able to design formative and summative assessments that are tailored to the learning outcomes and circumstances of the inquiry, and the characteristics of the students.

Research shows that formative assessment is a powerful means of improving student learning in IBSE. Formative assessment encompasses all those activities that can provide information to be used as feedback for modifying learning activities *(Marshall et al 2009)*. Formative assessment practices inform teachers about students' understandings and skills and can, for example, be implemented through observations or note-taking. Measuring the impact of formative assessment in mini-lab activities, Branan and Morgan *(2010)* found that students were able to assess their own level of understanding and knowledge and as a result formative assessment brought benefits to both teacher and student.

The focus of summative assessment is on the skills and practices that students have developed as well as the degree to which they have developed scientific content knowledge *(Poon et al 2011)*. Black et al *(2004; cited in Poon et al 2011)* distinguish between assessment for learning where the focus is to promote students' learning and assessment of learning which serves the purposes of accountability and/or of ranking.

The Galileo Educational Network *(2008b)* proposes particular elements that teachers need to consider when designing assessment for inquiry learning:

- Students need to be taught about how assessment works;
- Students need to be actively involved in creating rubrics by helping to set the assessment criteria;
- Students should be provided with the strategies, skills and opportunities to assess their own learning;
- Students should be provided with the strategies, skills and opportunities to provide meaningful feedback to their peers;
- The broader school community should participate in assessment. There are opportunities for other educators and peers to be involved in the assessment of the work;
- Communication about assessment should be regular and clear;
- Students should set goals, next steps or develop strategies to improve learning and understanding;
- Procedures should be in place to regularly review and improve summative and formative assessment.
-

Barnea et al *(2010)* developed 'authentic assessment tools' for assessing student achievement in inquiry-based laboratories. These include students' laboratory portfolios and pre- and post- questionnaires to assess students' acquired knowledge and thinking skills. These approaches were found to increase student motivation and enable them to improve their cognitive achievement and skills. Stoddart et a*l (2000)* used concept maps as assessment tool combined with a rubric for assessing students' understanding. Important aspects of learning from the concept map assessment tool were identified in a practical and reliable way.

Taasoobshirazi et al *(2006)* developed an assessment strategy for inquiry learning in astronomy. Three levels of assessment were developed: activity-oriented quizzes, curriculum-oriented exam, and standards-oriented tests. The quizzes were developed in relation to scientific investigations and closely aligned to specific activities that students had already completed. They assessed the main concepts of the investigation and directly addressed astronomy content. The quizzes were not specific to any particular activity in the investigation but rather focused on the main idea of the topic. The idea was to encourage students to perceive the overall objective of the investigation, which is identified as an important inquiry skill. Formative 'feedback conversations' were used to directly clarify students' misconceptions. After completing the quiz, students working in groups reviewed their answers using a four-step rubric and answer explanations that pointed to underlying solutions without stating answers. Students discussed their individual answers with group members with a view to reaching a common agreement. Finally students agreed on a solution to each question. The exams were designed with the aim of assessing the broader scientific content. They were graded and returned to the students the next day. Students then engaged in feedback discussions using a rubric. Students' prior experiences of the feedback discussions about the quizzes were intended to prepare students to participate in the exam feedback conversation. In developing the standard-oriented test, an astronomy content-item pool of multiple-choice questions was created, some of which were inquiry-based in that they were aligned to standards of inquiry. The authors suggest that this assessment framework could be used by many other inquiry-oriented science curricula as a means of enhancing 'authentic' assessment in science education.

5.9 Reflection

As emphasised in the Standards it is seen as essential for students to have opportunities and support to reflect on the inquiry activities in which they engage *(NRC 2000)* and to develop meta-cognitive skills; that is, skills in 'the understanding and control of one's cognitive processes' *(Marshall et al 2009)*.

Many inquiry-based frameworks include a stage of reflection or review on the changes of understanding that have taken place. For example, Eisenkraft *(2003)* argues that reflection or elaboration on findings and how these were reached is fundamental for transfer of learning. Hodson

(1998) proposes that inquiry tasks should allow students to compare before and after views, for example by keeping learning logs that help students to reflect on their own learning as a way of becoming aware of the process of conceptual change. By learning how to monitor and reflect on scientific processes, students are encouraged to become responsible for their own learning and for correcting their own errors *(Hume and Coll 2010)*.

Huber and Moore *(2001)* identify two main ways of engaging students in reflection: a) group discussions; and, b) journal writing. To highlight the link between the activity and real scientific research, the teacher may point out to students that scientists often conclude a research activity by considering the implications of their study for future research. One reflective writing task is the 'minute papers' approach *(Wilke and Straits 2005)* which involves short writing assignments that take 'only one minute' to do. Minute papers serve to review material, or evaluate misconceptions and are used as means for students to express their understandings in relation to content knowledge. Students may be asked to summarise the points of a lecture, describe a scientific experiment, or reflect on the scientific inquiry process. Questioning strategies can be used to direct students' attention to identifying research implications. For example, questions such as 'did the inquiry answer all of our questions? Did the inquiry raise new questions?' Teachers also can ask students to make explicit how they used various inquiry skills during their activity *(such as representing data, observation, and forming hypotheses) in a written report at the end of their project. Students can also use inquiry-learning diaries in which they may record their ideas as a means to reflect on tasks and on other inquiry processes for formulating scientific explanations (Rowell 2004)*. Other tasks supporting reflection include drawing flow charts and concept maps *(Kollofel et al 2011)*, structuring diagrams *(Wolf and Fraser 2005)* and creating notes with self-generated headings *(Schinske et al 2008)*. Although reflective discussions can occur throughout the investigation process, they are especially valuable near the end of inquiry when students have experienced all the processes and knowledge necessary for conducting the inquiry. Reflective discussions may have the potential to enable students to construct more complex scientific understandings of the scientific community *(Hofstein and Lunetta 2004)*. Yacoubian and Boujaoude *(2010)* investigated the effect of reflective discussions following inquiry-based laboratories activities. Their findings indicated that explicit and reflective discussions enhanced students' views of science more than merely using an inquiry-based approach in which reflection was implicit.

To-im and Ruenwongsa *(2009)* used a guided inquiry approach to help students understand new ecological principles in aquatic ecosystems through mini-aquaria experiments. The authors observed that after participating in tasks that concentrated on constructing explanations about interrelationships in ecosystems, students changed their views in response to counter experiences but needed a period of reflection while the teacher guided and supported the process. When the teacher stimulated a discussion in the class, misconceptions located in common sense could be resolved.

Other tasks to help students to monitor their own learning include using question checklists given for students to comment on their understandings *(Jarrad and Schroeder 2010)*. Student portfolios also can be used to record evidence of conceptual changes that have occurred in different points of time and thereby can be used as stimulus for meta-cognitive thought *(Hodson 1998)*. Volkman and Abell *(2003)* propose a number of ways to help students reflect on their understandings including over an extended period of time.

The process of presenting and interpreting results is an important part of full-inquiry investigations *(NRC 2000)* and may also be used to promote reflection. For example questions like 'how will you communicate this in your class?' may encourage students to reflect on how to present their findings in a comprehensive and understandable way. The teacher can then provide feedback on issues that need further improvement on the oral presentation component.

5.10 Information literacy

Some approaches to IBSE require students to engage very actively with a wide range of scientific information sources, both digital and other, for example involving independent and guided information-gathering, evaluation, analysis and synthesis. In this context, there is value in explicitly embedding *(scientific)* information literacy development activities into IBSE, to support students to further develop their competencies in this area. Science teachers can enhance students' experiences of inquiry by integrating information literacy development into the science curriculum *(Dennis 2001)*. In this section we offer a brief overview of the concept of information literacy, its connection with IBSE, and the existing evidence-base about information literacy development within IBSE practice.

The concepts of scientific literacy and information literacy both emphasise curiosity, reasoning and critical thinking *(Cowan and Cipriani 2009)* and may be seen as complementary. The concept of information literacy encompasses capabilities that are deemed essential for inquiry learning as students have to identify their information needs, plan and implement a search for information, evaluate the information they have found and present it effectively. These skills are necessary for inquiry learning in all subjects, including science. Librarians see value in integrating information literacy development within the subject curriculum to support students in their inquiries, but have faced barriers in their attempts to collaborate with teachers.

Information literacy has been defined as "the adoption of appropriate information behaviour to identify, through whatever channel or medium, information well fitted to information needs, leading to wise and ethical use of information in society» *(Webber 2003)*. A useful model for understanding the scope of information literacy has been produced by SCONUL *(2011)*. This was designed primarily for use in HE, but it has value for school-level education as well. The diagrammatic representation of the model is reproduced below, and further detail of the competencies included in each 'pillar' can be found on the SCONUL website[4].

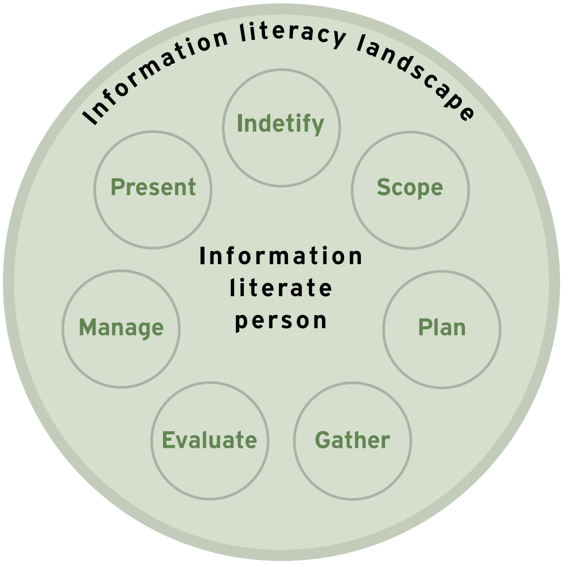

Figure 5.1:
The seven pillars of information literacy

The importance of information literacy in today's complex, information oriented society has been recognised internationally as an essential set of competencies for modern life. In 2003 UNESCO published the Prague declaration which defined information literacy as a "prerequisite for participation in modern society" and stated the integral role that information literacy should play within the education system. In 2006 the International Federation of Library Associations *(IFLA)* Alexandria proclamation identified information literacy as "a basic human right". Explicit reference was made to the relationship between information literacy and education stating "information literacy lies at the core of lifelong learning."

The role of information literacy within education has long been recognised. In 2001 the American Association of College and Research Libraries *(ACRL)* published a set of competency standards that act as a framework for assessing an individual's information literacy abilities. In addition the standards document discusses the role information literacy plays in inquiry learning, and states that information literacy competencies are essential for student-centered pedagogies and that information literacy development must take place within the context of the subject curriculum. Inquiry learning requires students to engage with information sources in their self-directed learning, and they must be skilled in finding, evaluating and managing information *(ACRL 2001)*. If information literacy teaching is integrated within the subject curriculum then information literacy development happens at the point at which students require it, and enables students to link information literacy with their subject *(Chen 2010)*.

The American Association for School Librarians in their

[4] http://www.sconul.ac.uk/

"standards for the 21st Century learner" explicitly recommend using inquiry as a framework for learning and state that librarians should collaborate with others to embed information literacy development within the subject curriculum *(Armone 2010)*. Gordon *(2010)* recommends that school librarians take a reflective, evidence-based approach to information literacy teaching, and that information literacy development should be integrated within content-specific learning tasks, which necessitates a strong collaborative relationship between teachers, librarians and learners.

One strategy for information literacy development in IBSE is the use of WebQuests as inquiry exercises for students involving information search, evaluation and use. WebQuests can be applied to almost any subject context, and have been described as "a framework for teachers to structure student-centered learning using Internet resources" *(MacGregor and Liu 2006)*. WebQuests typically involve the investigation of an authentic problem using resources available on the Internet, and are based on a learner-centered, resource-based pedagogy that involves the development of search and critical evaluation skills. MacGregor and Liu *(2006)* report on a study of WebQuests used in a 4th grade science class. Students demonstrated higher levels of cognition and were required to analyse and synthesise information in order to complete the WebQuest. The authors recommend appropriate scaffolding for students in the form of a study guide and concept mapping techniques.

Aquino and Levine *(2003)* report on the GLOBE *(Global Learning and Observations to Benefit the Environment)* programme that aims to support librarians *(school media specialists)* to "bring earth science, math, information literacy, information technology, and student inquiry into the classroom". The project was also seen as a way to increase collaboration between school librarians and teachers and to draw on the expertise of school librarians in terms of building confidence with research skills.

Eisenberg and Robinson *(2007)* designed the Super 3 model used by science teachers and researchers to integrate information literacy into inquiry-based instruction for young learners. The model provides a framework for young students to learn how to search for information, make a decision, or complete a task. It has three stages: Plan, Do and Review. In the Plan stage students are learning how to search for valuable and reliable information from physical resources in the library and from digital resources on the Internet. They learn about search processes and sources of evidence in the context of a small group-activity. In the Do stage they conduct the search, changing the search parameters, use different key words, and read books, articles and manuscripts found in the library and online for the purpose of conducting an assignment. In the Review stage, students explain their search strategies for finding relevant information and discuss best practices for accessing, retrieving and evaluating information. At this stage, students are engaged in self-assessment and reflection of their performance for further refining the inquiry process.

Herring *(2009)* presents findings from a project in which students engaged in inquiry learning and then reflected on their information literacy development. The teacher and librarian collaborated to design information literacy related inquiry tasks to support students in their inquiry projects. Students engaged in a mind-mapping task and it was found that students placed great value on concept-mapping as a basis for question formulation - a key activity in inquiry learning.

Chen *(2010)* investigated information literacy in first-grade inquiry science learning using the Super 3 model described above. The author used quasi-experiments in two first-grade classrooms, with one class receiving specific information literacy support in their inquiry learning and the second receiving traditional teacher-centered instruction. The research found that by integrating information literacy into the science curriculum, there were positive effects on memory, comprehension and higher-order thinking skills.

5.11 Formal and informal spaces

A key argument of the Green Learning Network is that IBSE is part of a broader student learning experience. In this section we focus on the association of inquiry learning with the broader learning experience across formal *(classroom learning, school laboratories and the like)* and informal learning spaces *(field trips to science museums and science centres)*. The success of inquiry learning may largely depend on how successfully a school and/or science teacher will design inquiry activities that combine informal as well as formal inquiry activities. Current literature in science education echoes the need for greater coherence and integration between informal learning spaces and science classrooms, and urges a careful analysis of the objectives of learning science in informal learning environments *(e.g. Falk and Dierking 2000; Gerber 2001)*.

There is some sense that in-school learning is formal learning and out of school is informal learning. Formal learning spaces are characterised by their highly structured nature while informal are less structured and learning is shifted from the teachers to the students with a more obviously student-directed inquiry approach *(Eshach 2006)*. Gerber et al defined informal learning as, "The sum of activities that comprise the time individuals are not in the formal classroom in the presence of a teacher" *(2001: 570)*.

In conceptualising the difference between formal and informal learning Eshach *(2006)* describes a field trip to a science museum. In the museum students are invited to free unguided visits and may approach different exhibits, themes or spaces. Then students enter the science class or the laboratory to hear a lecture, or conduct a scientific experiment while the science teacher is guiding the process. Eshach (2006) considers not only the general differences of the physical spaces (in or out of school) but also other factors such as social context, motivation, interest and assessment to distinguish between formal and informal learning. Sharp distinctions between formal and informal learning are perceived by some authors as inappropriate *(e.g. Hofstein and Rosenfeld 1996)* as learning is learning and it is influenced by setting, social interaction, individual beliefs, knowledge and attitudes *(Dierking 1991)*.

The literature also discusses outdoor learning *(Rickinson et al 2004)* and free choice learning *(Bamberger and Tal 2006)*. One common characteristic of these ideas is that they all address out-of-school learning spaces. The idea of informal learning emphasizes the nature of out-of-school environments that allow the student to identify varied learning options, in different spaces, and finally to select a personal option, theme or space for learning *(Bamberger and Tal 2006)*. Therefore, the concept of informal learning can be used to include all out-of-school activities within museums, zoos science centres and so forth. Informal learning has no authority figure and the learner determines how the desired knowledge will be acquired.

Science museums and science centres are popular informal learning spaces. Falk and Dierking *(2000)* found that school trips to museums and other informal environments promote long-term recall of science content. However, despite the attention to the educational potential of museums and science centres, the nature of learning is perceived as difficult to define, and consequently difficult to measure *(Cox-Petersen et al 2003)*. There have been some attempts to identify the factors that affect learning in science museums, especially from a sociocultural context. Falk and Dierkin *(2000)* suggest that the sociocultural context and the context of personal experience as well as the physical environment interact in shaping student's experience. The underlying assumption of the need to focus on social context is that learning is taking place (a) within a group and (b) is facilitated by others; the personal context is influenced by (a) motivation and expectations, (b) prior knowledge, interests and beliefs and (c) choice and control. The physical context is influenced by (a) advance organisers and orientation, (b) Design and (e) reinforcing events and experiences outside of the museum.

Other researchers exploring learning in informal spaces include Griffin and Symington *(1998 cited in Cox-Petersen et al 2003)* who identified specific characteristics for museum visitors that would result in effective learning closely reflecting the tenets of inquiry learning: (a) taking responsibility for learning, (b) active involvement in learning, (c) purposeful manipulation of objects, (d) making links between exhibits and ideas, (e) sharing links between peers and experts, (f) showing confidence in learning by asking questions and explaining to others (g) responding to new information or evidence. These indicators, according to Griffin and Symington *(1998)* have the potential for measuring inquiry learning outcomes.

While such characteristics and conditions help to build a vision of learning designs that potentially would enhance collaborations among formal and informal organisations, we may require a description of the particular affordances of the different learning spaces. Bevan et al *(2010)* present details of the structural and social properties of formal and informal settings. They assert that the structural properties of schools afford consistency, time and sequencing that will allow students to develop deep conceptual understanding while at the same time schools are structured primarily around providing and transferring scientific content knowledge in isolation with real-world scientific practice. They suggest that the structural properties of science-rich cultural organisations *(i.e. museums, science centres, zoos, etc)* include both hands-on and interactive exhibits *(i.e. hands-on exhibits are passive, interactive exhibits are active and respond to the visitor's action, see for example Rennie and McClaffery 1996)* as well as three-dimensional exhibits that may afford more adaptive, authentic learning as practiced by real scientists. The social properties of informal settings may afford greater opportunities for collaborative learning as well as for exchanging opinions and ideas with the wider scientific community. Bevan et al 2010 also argue that the objective of creating formal-informal collaborations is not only the objects or collections that are more accessible from a quantitative point of view, but a more meaningful, rich and contextualised approach of accessing scientific material. They conclude that formal and informal collaborations can be designed to draw upon:

- The ways in which informal learning environments support direct multi-modal experiences with multi-faceted portrayals of science, presented within their cultural context, and using authentic objects and phenomena;
- The ways in which school contexts can provide the sustained time, and developmental and pedagogical expertise, to build increasingly complex understandings of science phenomena and processes.

(Bevan et al 2010: 14)

Most obviously collaborations between formal and informal organisations are influenced by the teacher's motivations when designing fieldtrip activities to science museums or similar sites. Kisiel *(2005)* identified eight motivations that bear on science teachers' approaches when deciding to design field trip activities:

1. Connect with the curriculum - teachers see fieldtrips as opportunities to reinforce classroom curriculum by providing meaningful connections between theory and practice.
2. Providing new learning experiences – teachers perceive fieldtrips as an opportunity to provide new learning experiences which are believed to have a positive impact on student understanding and development.
3. Providing general learning experiences – teachers see fieldtrips as opportunities to provide engaging and unforgettable learning experiences.
4. Stimulating interest and motivation – teachers perceive fieldtrips as intriguing events that increases stimulus for further scientific investigation.
5. Change the teaching and learning setting – teachers perceive fieldtrips as opportunities to leave the classroom and change the routine.
6. Promote lifelong learning – teachers perceive fieldtrips as opportunities to help students understand that learning can be achieved beyond school and from different persons or groups such as friends, family, museum educators etc.
7. Providing to students' enjoyable experiences and/or reward – teachers recognise that should be a positive experience for the students.
8. Satisfying school demands-teachers are expected to conduct fieldtrips, due to institutional policies or pressure from their senior colleagues.

However, teachers create science inquiry-based activities predominantly for school settings *(Gutwill and Allen 2010)*. Inquiry learning in informal settings has not been widely adopted for a number of reasons: Randol *(2005 cited in Gutwill and Allen 2010)* found that the most common inquiry behaviours in interactive exhibits were constrained to manipulation and observation of the exhibit, while more advanced inquiry strategies such as connecting explanations to scientific knowledge or justifying explanations were relatively rare. Prediction and metacognition were absent in visitors' discussions at a science museum exhibition of frogs. Crowley and Jacobs *(2002)* showed that visitors' interaction with curators and seeking explanations on a scientific exhibit tended to be short and isolated rather than extended and meaningful. In general studies have shown that visitors use interactive exhibits for short times, approximately for one minute or less *(Gutwill 2008)*. This lack of inquiry-based processes in museums may be caused by the myriad visual distractions which can undermine the focus required for sustained inquiry *(Adamson 2008 cited in Gutwill 2008)*. Exhibit design may inhibit opportunities for inquiry as some exhibits do not offer enough variables for visitor manipulation and thereby they adopt a 'do, notice, read' behaviour *(Gutwill and Allen 2010)*. Another possible explanation is that visitors may lack the necessary inquiry skills that would allow them to investigate scientific phenomena in museums in a more productive way. For example Allen *(1997)* found that visitors were not able to create or revise a simple model in light of scientific evidence. This suggests that some inquiry skills are unknown to the visitors or difficult to acquire. Furthermore, there is little research-based evidence about the scientific characteristics that support either individual or collaborative inquiry learning at science museums *(Gutwill 2008)* and even less is known about how inquiry-based science museum programs may assist visitors to build inquiry skills that can be applied at new exhibits, outside a particular programme or museum *(Gutwill and Allen 2010)*.

Inquiry project examples of school field trips in out-of-school settings, mostly in museums, science centres and open field illustrate a wide range of collaborations including curriculum-based inquiry learning activities with the use of technology, collaborative inquiry activities, teacher practice, professional development, after-school summer programs and family and community events whereas some of them are designed for students and others for teachers *(Bevan et al 2010)*.

The Personal Inquiry project[5] aims to understand how effective inquiry learning can be with the use of technology across formal and informal settings *(Scanlon et al 2009)*. Students are guided through a process of posing inquiry questions, gathering and assessing evidence, conducting experiments and engaging in debate on themes relevant with the secondary level UK national curriculum. A software application called an 'Activity Guide' supports students to carry out the inquiry. A formal inquiry learning script specifies how the inquiry is organised and presented, helping students to organise their work as well as enabling teachers to orchestrate the learning activities by altering the content and availability of activities. Students' investigations have concerned topics such as diet, urban heat islands and microclimates. For example, during the 'urban heat island intervention' *(see Scanlon et al 2009)* students went out into the field and collected data. A handheld GPS (Global Positioning System) receiver was used to determine the location of data. Students worked in groups and scientific sensors were provided to them to automatically capture data and for later downloading for analysis. Data were checked in classroom sessions for students to revisit their field notes or fill in any missing data. Students at this point moved from working in groups to working individually and reflected on their data in preparation for improving and presenting them in class. A data-analysis section was also presented to them and asked to generate tables and graphs. Finally, students prepared and presented their reports encompassing their research design and the field trip activities with the use of technology to the rest of the class. The particular interest of the Personal Inquiry project, as claimed by Scanlon et al 2009 is its blended support for evidence-based inquiry learning, supporting students to understand the inquiry learning process both in formal and informal settings.

In an Ecology Inquiry Project, Rozenszayn and Assaraf *(2011)* utilized collaborative inquiry learning among high school students who participated in collaborative learning sessions in the open field. The Ecology Inquiry Based project is compulsory for Israeli high-school students in the biology curriculum, and it is also part of the assessment process. Students design their own inquiry, which is carried out in the natural field. Small groups of three students are required to synthesise ecological concepts and principles acquired in class and transfer them to the natural field. Students are also required to design collaboratively the research questions as well as the research approach including measuring assignments and data analysis. Students share their knowledge and results of the different measurements conducted to the natural field in order to answer their research questions and then submit a report at the end of the field trip inquiry activity that includes at least four inquiry questions, as well as details about the inquiry methods, results and conclusions. A grounded theory approach was used by researchers to analyse the collaborative inquiry learning processes in schools and fieldtrips. The results showed that students were more focused on discussing the methods of measurement and observation in the open field, rather than on the known methods from class or from the

[5] http://www.pi-project.ac.uk/

laboratory. This was mainly because the methods of measurement and observation in the informal setting are different from those that are used in the school laboratory. Also students seemed to be highly task-oriented and interested in the field-trip tasks and less interested in the activities implemented during classroom.

In facilitating science teachers and museum educators' efforts to design inquiry-based activities that will allow school-museum collaborations, the Natural Europe project[6] aims to design a number of inquiry-based science educational pathways for a range of natural sciences and history topics and explore how these relate to school and Natural History Museum (NHM) settings. Two distinct types of educational pathways will be designed: (a) structured educational pathways which involve inquiry-based activities for schools and (b) open educational pathways which involve inquiry-based activities for NHMs. The project will provide the necessary technological infrastructure for science teachers and museum educators to search, store and retrieve learning objects and educational pathways through a web-based interface. Interactive installations equipped with 3D graphical interfaces that will facilitate the usage of the inquiry-based educational pathways will be adapted and tested within each NHM participating in the project.

Similar to the Natural Europe approach, the Open Science Resources *(OSR)* project[7] aims to design inquiry-based learning activities with content available on science centres and museums, and introduce an enhanced approach for science teachers to access digital science education content. The OSR adopts the inquiry and problem-based learning approach as a way of involving school students in science investigations which take place in schools and in science centres and science museums. As in the Natural Europe project, structured (for teachers and science museum educators) and open educational pathways (for science museum educators and general visitors) are authored, stored, accessed, retrieved and shared through a web-based portal[8] along with a plethora of science digital collections like scientific instruments, animations, exhibit images, interactive museum visit experiences and so forth.

The Science Center at School project *(cited in Bevan et al 2010)* aims at helping 11-12 year old students to design and create scientific exhibits for their own scientific centre within the school environment. Students are introduced to a set of exhibits and then make a technical drawing which is discussed back at school. Students are then supported by their teachers to build a tabletop version of the exhibit using a guide. The process emphasises the inquiry approach. The project includes a staff development session to prepare teachers to use inquiry-based processes, and having teachers to build a number of exhibits by themselves.

It is clear from the projects highlighted above that inquiry activities in both formal and informal settings are important for enhancing the student's experience. The general point is worth emphasising: when planning for inquiry learning, schools in general and science teachers in particular need to consider inquiry activities for both formal and informal settings. To do this, they need to have shared understandings of the social and the structural affordances that characterise formal and informal settings, as well as integrating the scientific curriculum, inquiry learning activities and intended learning outcomes to each setting. Schools are concerned with many different science subject areas and museums and/or science centres are concerned with students of all ages and with a large amount of digital resources and scientific collections *(Bevan et al 2010)*. By providing to teachers the necessary design tools to develop such inquiry learning activities that will afford scientific investigations in both formal and informal settings, it may be possible to empower teachers' and students' relation with science.

5.12 Digital technologies

As noted previously, there is an extensive tradition of development and research in computer-supported inquiry learning *(CSIL)* in school science education. An article by Bell et al (2010) offers a useful overview of this work at secondary school level, reviews a range of computer environments and tools that have been developed, and summarises beneficial impacts on student learning. Nine main science inquiry processes supported by different computer

[6] http://www.natural-europe.eu/

[7] http://www.openscienceresources.eu/

[8] http://www.osrportal.eu/

environments are identified: orienting and asking questions; generating hypotheses; planning; investigating; analyzing and interpreting; exploring and creating models; evaluating and concluding; communicating; predicting. Emphasizing that it is "a good balance of challenge and support" *(p.372)* that leads to enhanced learning outcomes in CSIL, the authors highlight the following challenges for the field:

- the need to balance opportunity for open-ended exploration with guidance to support the needs of individual learners, for example by using computer-based diagnostics or by strongly emphasizing peer collaboration and support;
- the need to structure environments in such a way that learners can use the full potential of embedded tools;
- the need to allow for more flexible learning, for example by enabling different modes of data-collection *(quantitative and qualitative)* and modelling, and by allowing for students to take different pathways towards solutions;
- and, the need to facilitate integration of different learning environments that have complementary tools.

Beyond the use of specialized software and environments, technology is an increasingly pervasive feature of IBSE. In many IBSE classrooms, teachers and students use resources including search engines, social software, databases, authoring software, handheld devices, synchronous and asynchronous communication tools and computer-based data collection and analysis tools. Increasingly, students are starting to use the same tools and resources that are used by scientists *(Harris and Rooks 2010).*

There is a growing body of evidence on the use of digital technologies in IBSE, including evidence that technology in science classrooms may fail to enhance learning where there is lack of guidance for teachers *(Anderson 2000; White et al 1999).*

As presented in more detail by Williamson, Kim et al *(2007)* propose a framework for teaching science using technology-based inquiry tools in everyday classroom settings *(see Figure 5.2)*. The framework assumes that knowledge is socially constructed and occurs through communities of inquiry. A range of influences *(inquiry Standards, school environment etc.)* represent the macro context. The middle frame represents the teacher community and professional development and the innermost frame represents the particular classroom settings as the micro context. The value of this framework as claimed by the authors is that it allows for exploration and contextualisation of the role of technologies in specific scientific activities.

Many studies have highlighted the role of the Internet can play in inquiry in the science classroom. *(e.g. Ucar and Trundle 2011; Ucar, Trundle and Krissek 2011; Windschilt 2002).* Student communication between peers and with teachers, access to information, and web-based activities that provide structure along with a certain amount of freedom are typically reported uses *(e.g. Bozdin and Shive 2004; Lee and Sogner 2003; Kleemans et al 2011)*. Web-based activities are used to encourage students to search, retrieve and share information, individually or collaboratively, as practicing scientists do. One study has suggested that online inquiry increases students' understanding of scientific content as long as they are directed to relevant scientific resources and as long as teachers discuss the information that students find on the Internet and provide meaning-

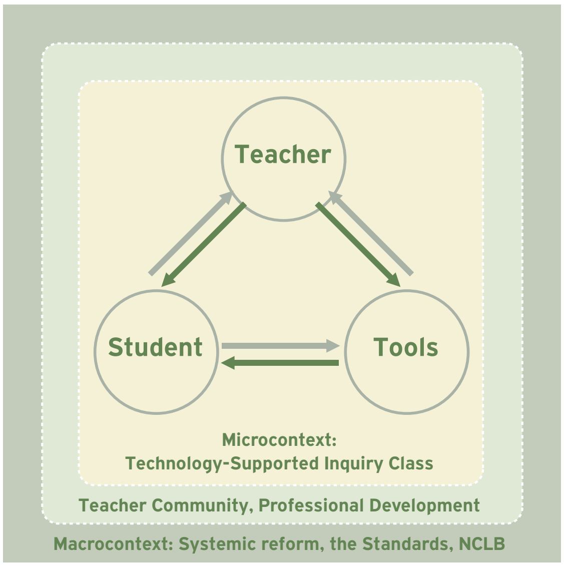

Figure 5.2:
A pedagogical framework for teaching and learning with inquiry tools (Source Kim et al 2007, p.1019)

ful feedback *(Hume and Coll 2010)*. However, the large amount of information available on the Internet may be overwhelming, and some data sets may be difficult to access and badly organised *(Ucar and Trundle 2011)*. Class homepages that contain links to quality-assured websites and resources, as evaluated by the teacher, are one way of addressing this problem, and attention paid to developing students' information literacy is another.

As already noted, WebQuests are designed to reduce the problems associated with information overload and complexity in the digital environment *(Kleemans et al 2011)*. A WebQuest is an inquiry-oriented activity in which some or all the information with which students interact comes from resources on the Internet *(Dodge 1998)*. Two types of WebQuest exist: the short-term WebQuest which engages students on tasks that require one to three class periods for students to interact with a number of resources and understand new information; and the long-term WebQuest which requires additional time *(Dodge 1998)*. A large amount of Webquests dealing with scientific issues can be found on the Web[9]. The standard structure of a WebQuest includes at least six parts: introduction, task, process, resources, evaluation and conclusion. Tasks in WebQuests should not be too directive but they should be structured enough to guide students to intended learning goals. The tasks used in WebQuests can be subcategorised as well-defined or ill-defined. It is recommended that before being used in the science classroom or made available online, WebQuests should be analysed by experts as regards content and technically and aesthetic aspects *(Leite et al 2007)*.

Hofstein and Lunetta *(2004)* reviewed developments in which technology was integrated in laboratory experiments and concluded that a major challenge for effective use of technology is inadequate professional development for teachers. Waight and Khalick *(2006)* stressed the importance of viewing technology as another component of the classroom and that more attention should be directed to how learning occurs with technology rather than learning about technology. On the other hand, developments in the use of ICT to carry out science mean that fluency with the application of digital technologies to scientific processes is part and parcel of what it means to be an inquiring scientist

5.13 Teaching roles

Learning science by inquiry is a complex process and success depends largely on how science teachers facilitate the inquiry process. Students are expected to work together to gather and analyse data and engage in discussions and debates with their peers and teachers. Teachers play critical roles in designing and scaffolding activities, asking questions to help students verbalise their thinking, and connecting students' ideas with those of the scientific community *(Morrison 2008)*. Drayton and Falk ***(2001)*** argue that checking for student understanding should not focus on removing misconceptions; rather it should allow students to take the time to explain their thinking and to improve their understanding by engagement with evidence from their own experience. However, a dilemma that IBSE teachers may experience is the degree of guidance or independence to give to students. Harlen *(2004: 7)* proposes key elements of the role of the teacher within IBSE:

- Providing experiences, materials, sources of information for students to use directly;
- Showing the use of instruments or materials that students will need in their inquiry;
- Asking open and person-centred questions to elicit understandings and how students are explaining what they find;
- Engaging students in suggesting how to test their ideas or answer their questions through investigation or finding evidence from secondary sources;
- Where necessary, helping students with planning so that ideas are fairly tested;
- Listening to students' ideas and taking them seriously;
- Asking questions that encourage students to think about how to explain what they find;
- Setting up opportunities for collaborative learning and dialogic talk;
- Scaffolding alternative ideas that may explain the evidence from their investigation;
- Gathering information, through observation, questioning and interaction, about students' developing skills and ideas.

[9] http://www.webquest.org/index.php

It is apparent from the above list that the teacher's role in these environments switches from one of transferring information to students, to guiding and facilitating the learning process by designing learning activities that focus on student involvement and interaction with peers and resources. The teacher inputs into the process in such a way as to allow students to experience the emergent process of investigation. There is a need for teachers to be aware of and responsive to potential frustration of the students in the face of inquiry activity that may be complex and ill-defined *(Branan and Morgan 2010)*.

5.14 Collaboration and group work

There is increasing research on collaborative inquiry learning in different science domains *(e.g. Bell et al 2010; Kolloffel et al 2011; Gijlers et al 2009)*. Studies have shown that collaboration can enhance the quality of the learning process and learning outcomes in science education *(Dillenbourg, 1999; van Joolingen et al 2007; Linn and Hsi 2000);* combining inquiry with collaborative learning can lead to engaging, interactive and powerful learning environments.

Students in working collaboratively in groups have the opportunity to share their thoughts and prior knowledge. Collaborative dialogue supports learning by clarifying thinking and consolidating ideas *(Hmelo-Silver et al 2002)*. The "classroom learning communities" approach seeks to operationalise the benefits of learning through participation in communities of practice *(Lave and Wenger 1991)*. Inquiry learning promotes the ideal of creating a learning community with a shared purpose of making sense of scientific ideas and practices *(NRC 1996; Harris and Rooks 2010)*. However, research suggests that knowledge and skill differences may lead to tensions in group-work situations. It is therefore recommended that teachers explain to students the process and ethos of collaborative inquiry learning *(Gijlers and de Jong 2009)*. Further, collaborative processes are difficult to enact in science classrooms in the physical space, time schedules and norms of interaction in schools *(Singer et al 2000)*.

Learning tasks structured for small groups in which students are engaged in interactions with peers pursuing a common scientific investigation are used extensively in IBSE and it is common in a collaborative situation for higher-skilled students to serve as more experienced peers and thereby help less experienced students. Studies *(see for example Rennie et al 2003; Manlove et al 2006)* indicate that inquiry collaborative learning in small groups is effective if certain components are present:

1. Interdependence between group members for accomplishing a mutual goal;
2. Collective responsibility of group members regarding the task and the difficulties that may arise during the learning activity;
3. Reciprocity between group members in the form of explanations and discussions for solving problems and considering each member's knowledge for producing something new and advanced from the whole group;
4. Social cooperation skills must be shared by each member in order to reach a common goal;
5. Social processes need to be defined in advance for achieving contribution to the group's success.

For students to benefit fully from an inquiry collaborative learning experience, it is important to be engaged in a task-focused and elaborated interaction *(Gijlers et al 2009)*. If students have conflicting or divergent ideas they must reach consensus before continuing with the discussion. Activities that promote the mere exchange of facts and provision of answers and solutions are not enough for collaborative learning *(Anjewierden et al 2011)*. Students need to plan and execute the inquiry process, but also to communally select, process, analyse, interpret, organise and integrate information into meaningful and coherent structures *(Chu et al 2011)*.

Collaboration is perceived as a scaffolding function in inquiry learning. School students have difficulties with several aspects of inquiry including asking questions, making decisions and understanding how information and concepts relate to the overarching question.

Think-pair-share tasks *(Wilke and Straits 2005)* allow students to work individually and with peers. Initially, students work independently, thinking about a scientific problem and provide a perceived solution. Then students work in groups to discussing the scientific problem and enhance their understandings based on fellow students' feedback.

6

Green Learning Network Educational Pathways

Learning science *(or learning about science)* is not the same experience and does not carry to same meaning for everyone. In addition to the varying perceptions of science learning, its nature, objectives and workings, the diversity of science learning instances is also attributable to the variety of personal and institutional circumstances in which it may occur. Thus, the characterisation of science learning objects alone cannot generate adequate momentum for effective and sustainable exploitation of the rich content of digital repositories, unless this content can be accessed by the intended users in purpose-appropriate, meaningful ways. This challenge is addressed by the Green Learning Network through the employment of the concept of Educational Pathways.

6.1 The concept of Educational Pathway

The concept of Educational Pathway in Green Learning Network reflects the priority given by the project to responding to the needs of the diverse communities of potential users of the Green Learning Network services. Thus, an Educational Pathway in the Green Learning Network describes the organization and coordination of various individual science learning resources into a coherent plan so that they become a meaningful science learning activity for a specific user group *(e.g. teachers, university students, farmers, museum visitors, etc.)* in a specific context of use. Further, Educational Pathways directly serve the priority assigned by the project to the integration of resources scattered in various science museums/centres into the same learning experience rather than the mere selection of resources from a single museum or science centre.

It should be kept in mind that an Green Learning Network Educational Pathway may include only the use of digital content at a distance, without physically visiting the field, the science museum or centre *('virtual visit')*, or a combination of using digital content (at a distance or onsite) with a physical visit to the science museum or centre *('physical visit')*[10].

In the Green Learning Network approach, a Pathway is understood as a dynamic rather than static conceptual tool. In the envisaged optimal function of the Green Learning Network community, creators of Pathways may revisit, revise and continually develop their Pathways, or even use Pathways created by others as a basis for creating their own new versions, in a process reflecting social learning as a course of personal and communal gradual development in the learning community.

[10] Physical visits without an element of use of digital content use are beyond the scope of the project.

6.2 Green Learning Network user roles and use contexts: Defining the dimensions of digital-resource-based science learning

Central to the definition of the Green Learning Network Educational Pathways is the definition of the user roles and use contexts anticipated. In other words, Pathways represent various combinations of users and contexts, with quite varying characteristics among them, sharing however an interest in using digital resources available in science museums and centres for science learning purposes – formally or informally.

The main Green Learning Network stakeholders are defined according to their roles as users of the Green Learning Network platform as follows:

- Teachers: school teachers wishing to integrate the use of such resources in their teaching.
- University Students: school students who may use such resources either as part of their curricular learning, or in out-of-school learning *(e.g. in free time or with family)*
- Other learners / farmers/visitors of museums ('life-long learners'): people of all ages who may use such resources out of professional or personal interest or by chance, either deliberately to learn science/about science, or simply learning informally as a by-product of leisure activities; a distinguishable part of this group may be parents / families interested in enjoyable science learning experiences.
- Science museum educators or science communication professionals: Staff who prepare science learning or awareness raising experiences for the visitors/users of their institutions *(science museums and centres).* An additional subgroup here might also be other professionals too related to science communication, including journalists who may search for content relevant to the promotion of informal science learning.

Correspondingly, then, the contexts of use of the Green Learning Network platform may be organised into the following three categories:

- In the school or university (combined with one of the following two categories)
- In the science museum/centre (physical visit)
- On the web (virtual visit), in the combinations presented in Table 6.1.

Table 6.1:
Contexts of use of the Green Learning Platform

On the field/In the science museum/centre (physical activity)	**On the web (virtual activity)**
In connection with the school/university	In connection with the school/university
In *no* connection with the school/university	In *no* connection with the school/university

In these contexts, individuals and groups may get involved in the use of digital content either in ways pre-designed by someone *(e.g. a teacher, or a museum educator)*, or employing their own creative ways of exploring and interacting with the digital content.

The Green Learning Network Educational Pathways can then be seen as instances located in a system of possible combinations of use contexts, user roles, and varying levels of user independence *(Table 6.2)*.

Table 6.2: Contexts of use, user roles, and user independence

	In connection with the school/university		**In *no* connection with the school/university**	
	In the science museum/centre (physical activity)	**On the web (virtual activity)**	**In the science museum/centre (physical activity)**	**On the web (virtual activity)**
Teachers	usually pre-structured (or exploratory)	usually pre-structured (or exploratory)	*As independent lifelong learners:* usually exploratory (or pre-structured)	*As independent lifelong learners:* usually exploratory (or pre-structured)
Students	usually pre-structured (or exploratory)	usually pre-structured (or exploratory)	*As independent lifelong learners:* usually exploratory (or pre-structured)	*As independent lifelong learners:* usually exploratory (or pre-structured)
(Other) lifelong learners			usually exploratory (or pre-structured)	usually exploratory (or pre-structured)
Science museum educators or science communication professionals	[structuring activities for others]	[structuring activities for others]	[structuring activities for others]	[structuring activities for others]

Such a system allows for possible dimensions of digital-resource-based science learning such as the following:

- **Use of museum and science centre digital resources in school science education**
  - Teacher-guided (top-down)
  - Student-driven (bottom-up)
- **Use of museum and science centre digital resources in non-formal[11] science learning**
  - Curator-guided (top-down)
  - Visitor-driven (bottom-up)
- **Use of museum and science centre digital resources in informal science learning**
  - Curator-facilitated (top-down)
  - Visitor-driven (bottom-up)

In this context, a distinction between pre-structured and open[12] pathways appears to be useful. A Green Learning Network Educational Pathway is defined as pre-structured when it provides a rigid pre-defined 'route' through a set of science learning resources *(mainly relevant to more formal learning contexts, e.g. the case of school science education, with specific curriculum references and teaching processes).* On the other hand, a Green Learning Network Educational Pathway is defined as open when it is more flexible and informal in its approach, allowing for considerable unbound user decisions, initiative and creativity in the ways the user will explore and exploit the science learning resources *(as in the case of an adult independent visitor or a family, or even a teacher who has decided to involve her/his students in an open-ended exploration of the resources).*

6.3 The Educational Pathway Patterns

Going one step closer to practical implementation, the Green Learning Network Educational Pathway Patterns are the templates offered by the project for designing, expressing and representing Educational Pathways for a certain user group and type of visit. Two main types of Patterns seem to be capable of describing the various possible pathways: a Pre-Structured and an Open Educational Pathway Pattern, corresponding to the pre-structured and open educational pathways as described in the previous section. The proposed two Educational Pathway Patterns correspond to the various user groups as presented in Table 6.3.

Table 6.3: Educational Pathway Patterns and user groups School community (teachers and students)

School community (teachers and students)	Pre-Structured Educational Pathway Pattern *(potentially also Open)*	Prepared by: • Teachers • Science museum educators etc.	Enriched with social metadata by: • Teachers • Students
'Lifelong learners'	Open Educational Pathway Pattern *(potentially also Pre-Structured)*	Prepared by: • Science museum educators etc. • Users / lifelong learners	Enriched with social metadata by: • Learners

[11] The terms 'formal', 'non-formal' and 'informal' learning are used on the basis of existing EU definitions [e.g. A Memorandum on Lifelong Learning. Brussels, 30.10.2000. SEC(2000) 1832], with the following meanings: Formal learning: Learning typically provided by an education or training institution, structured (in terms of learning objectives, learning time or learning support) and leading to certification. Formal learning is intentional from the learner's perspective. Non-formal learning: Learning that is not provided by an education or training institution and typically does not lead to certification. It is, however, structured (in terms of learning objectives, learning time or learning support). Non-formal learning is intentional from the learner's perspective. Informal learning: Learning resulting from daily life activities related to work, family or leisure. It is not structured (in terms of learning objectives, learning time or learning support) and typically does not lead to certification. Informal learning may be intentional but in most cases it is non-intentional (or 'incidental'/ random). NB: The distinction between non-formal and informal learning is not usual in the field of science learning, and in particular providers such as science museums or centres may not feel comfortable with the distinction. In the present context, when no distinction is made between 'non-formal' and 'informal', the term 'informal' refers to the usual kinds of provision offered by science museums or centres.

[12] The term 'semi-structured' has also been proposed as an alternative to the term 'open', as it is felt that 'open' may imply an approach that is too unspecific to Green Learning Network (e.g. implying an experience like using Google on the web). The term 'open' is retained at this stage, but will be revised if experience from the next project phases points to such a need.

Structure of the Green Learning Network Educational Pathway Patterns

In many cases, learning experiences should be ideally embedded in a context which provides the means for the preparation of the learner for the learning experience before it takes place, as well as for facilitating the retention and future exploitation of the outcomes of the learning experience for a longer time after it has taken place. This is a fundamental principle in formal education, but can also be seen as a useful dimension *(even if not that prescriptive)* in informal learning environments. For this reason, the Green Learning Network Educational Pathway Patterns propose the organization of the science learning experience in three steps:

1. Pre-visit[13]: activities preparing for the interaction with the digital learning science resources
2. Visit: activities involving interaction with the digital science learning resources in or outside the science museum/centre
3. Post-visit: activities rounding up and concluding the learning experience, after the interaction with the digital science learning resources.

From these, the Visit phase is the core of the learning experience and indispensable in any Pattern. The Pre-visit and Post-visit phases are absolutely essential for the realization of effective connections between school science education with learning activities involving work with science museum/centre content; however these 'auxiliary' preparatory and follow-up phases may well or may not be relevant to and desirable for open visits by any lifelong learner *(e.g. if the designer of an informal learning experience feels that the adoption of the three-phase scheme implies a linearity of sequential nature that does not correspond to the intended experience)*. Indeed, the degree of freedom or prescription in the design of a pathway has proven to be the most debated aspect of the Green Learning Networks approach in the consortium, which brings together three considerably separate 'worlds': those of formal school education, university education and informal learning in science museum and centres or in the field.

Thus, although each pattern should include sections corresponding to these three phases, in the case of an open pathway pattern the pre-visit and post-visit phases should be seen as possible but not obligatory. In addition to the three phases, there is an introductory section outlining the identity of the Educational Pathway and providing guidance for any preparations necessary before the launch of the learning activity. Each section consists of a number of fields, for each one of which a description and/or guideline is provided.

The Educational Pathway Patterns developed

From the various possible Educational Pathway Patterns that the project could develop, the most complex are those describing structured visits bridging formal and informal science learning through a school 'visit' *(physical or virtual)*. Open 'visits' by independent informal learners, on the other hand, can be seen as simpler, little pre-defined experiences. Structured visits of non-school users that may be offered by some science museums or centres fall somewhere between the two ends of the 'complexity and structure' spectrum, their exact position depending on the degree of formality applied to the design of the visit by the science museum/centre.

Therefore, the present document proposes two structures as tools for use and experimentation at this stage of the project[14].

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[13] The term 'visit' is used here metaphorically, and does not necessarily imply a physical visit to a science museum or centre. It is used in a technical sense in this document, to indicate processes before, during, and after interaction with the digital learning resource(s) in question. If felt necessary, in the next project steps it may be replaced by other more accurate or user-friendly terminology (e.g. 'pre-experience', 'experience', 'post-experience'; or 'engage', 'interact', 'find out more'; or even topic specifically, such as for example 'visiting a farm', 'virtual visit to European museums', 'more resources and ideas'; etc)

[14] An alternative terminology that has been proposed as more user-friendly is 'pathways for educators/mediators' (addressing those who will use the Green Learning Network content to 'educate' or 'inform' or 'involve' others) and 'surf and learn' (addressing those independent users who use the Green Learning Network content for their own benefit/pleasure). The need for and usefulness of this and other alternative terminology will be examined in the next project phases..

- The Green Learning Network Educational Pathway Pattern for a Pre-Structured Visit by the School
- The Green Learning Network Educational Pathway Pattern for an Open Visit by Lifelong Learners.

These two examples can guide the formulation of other Educational Pathways in the following project stages, based on the experience gained through the use of these initial tools.

6.4 Green Learning Network Educational Pathway Pattern for a Pre-Structured Visit by the School

Introductory note

From the various possibilities of interaction with the Green Learning Network resources, structured visits of the school community correspond to the most complex, detailed and pre-defined Educational Pathways, reflecting the mapping sought between formal and informal learning practices. In the case of an Educational Pathway for a Pre-Structured Visit by the School, the teacher or the museum educator selects school science subject matter *(e.g. complex physical phenomena typically causing difficulties to students)* to present it through student-centred and student-friendly multidisciplinary educational activities involving the use of digital science learning resources available through the Green Learning Network repository. The Educational Pathway should represent a learning experience connecting work in the classroom or school lab with virtual or physical visits to the science museums/centres. The integration of resources scattered in various science museums/centres into meaningful learning experiences is a priority ***(rather than selecting resources from a single museum or science centre).***

The underlying pedagogical approach for the structured visit

For the three steps of the learning process *(Pre-visit, Visit, Post-Visit),* the model of Inquiry-Based Learning is chosen as the guiding principle for structuring the activities foreseen by the structured Educational Pathways. Inquiry-Based Learning is currently the most influential approach to science learning, and particularly so in the field of school science education. According to it, learning should be based around learners' questions, as they work together to solve problems rather than receiving direct instructions from the teacher. The teacher should function as a facilitator helping students in the process of discovering knowledge themselves. In the science context in particular, learners use their background knowledge *(of principles, concepts, theories)* together with their science process skills to construct new explanations which allow them to understand the natural world; and learners are likely to begin to understand the natural world if they work directly with natural phenomena, using their senses to observe and using instruments to extend the power of their senses. This approach to science learning is part of a greater world of constructivist models of learning, which see learning as the result of ongoing changes in our mental frameworks as we attempt to make meaning out of our experiences. In classrooms where students are encouraged to make meaning, they are generally involved in "developing and restructuring [their] knowledge schemes through experiences with phenomena, through exploratory talk and teacher intervention" *(Driver, 1989).*

In practical terms, it is proposed that teacher and learner activity be described in the Educational Pathways as an iterative process consisting of the following five phases:

Teaching Phase 1:	Question Eliciting Activities

- **Provoke curiosity:** The teacher tries to attract the students' attention by presenting/showing to them appropriate material.
- **Define questions from current knowledge:** Students are engaged by scientifically oriented questions imposed by the teacher.

Teaching Phase 2:	Active Investigation

- **Propose preliminary explanations or hypotheses:** Students propose some possible explanations to the questions that emerged from the previous activity. The teacher identifies possible misconceptions.
- **Plan and conduct simple investigation:** Students give priority to evidence, which allows them to develop explanations that address scientifically oriented questions. The teacher facilitates the process.

Teaching Phase 3:	Creation

- **Gather evidence from observation:** Teacher divides students in groups. Each group of students formulates and evaluates explanations from evidence to address scientifically oriented questions.

Teaching Phase 4:	Discussion

- **Explanation based on evidence:** The teacher gives the correct explanation for the specific research topic.
- **Consider other explanations:** Each group of students evaluates its explanations in light of alternative explanations, particularly those reflecting scientific understanding.

Teaching Phase 5:	Reflection

- **Communicate explanation:** Each group of students produces a report with its findings, presents and justifies its proposed explanations to other groups and the teacher.

The above model is proposed as a guide of appropriate teaching practice built around the observation of objects or phenomena in the natural world – in this case physically or virtually, directly or indirectly, in the science museum/centre. Apparently, the Educational Pathway Pattern is flexible and open to other educational approaches, too, if considered more appropriate in certain circumstances. However, in any case it is advisable to retain the organization of the activities in a three-step scheme *(before, during, after the 'visit').*

The Educational Pathway Pattern for a Pre-Structured Visit by the School

A) Introductory section and preparatory phase

The following basic information about the intended learning experience is to be defined at the outset. This information should allow the teacher to assess the relevance of the resource to his/her teaching needs and particular circumstances, and provide him with guidance for the preparation of the learning experience. Note that most of this information can be directly linked to specific elements of the Green Learning Network Application Profile. The formalisation proposed there for certain elements is to be applied accordingly in this introductory section too.

Title:

Give a title that helps easily recognize the content focus and purpose of the Educational Pathway.

Short description:

A description of no more than 30 words outlining the scope of the Educational pathway, descriptive enough to help the user in the first instance to estimate its possible relevance to her/his interests.

Keywords:

A limited number of words/short phases reflecting the topic and scope.

Target audience:

The intended end user: teacher with students, teacher, students, other…

Age range:

Up to 6, 6-9, 9-12, 12-15, 15-18…

Context:

The places that the Educational Pathway involves: school, University, farm, science museum/centre, independently on the web.

Time required:

The approximate time typically needed to realize the Educational pathway. This could be distinguished into the amount of time required for school-based work and science museum/centre-based work.

Technical requirements:

Description of any special technologies, infrastructure and/or technical expertise required for the realization of the Educational Pathway.

Author's background:

What was the main function of the person who prepared the Educational Pathway: school teacher; museum educator; parent; other.

Connection with the curriculum:

Reference to the items of the science learning vocabulary mainly covered by the Educational Pathway, and prerequisite knowledge

Learning objectives:

Short description of the objectives of the described science learning experience

Guidance for preparation:

Guidance provided by the creator of the Pathway about any necessary arrangements that will need to be made by the interested teacher before launching the activities described in the following sections.

B) Pre-visit

Teaching Phase 1: Question Eliciting Activities

- **Provoke curiosity:**
  Describe ways and materials *(resources already available in the Green Learning Network repository or other)* that the teacher will present to the students in the classroom to attract their attention to the targeted subject matter. Make sure they are easily available to the interested user in the Green Learning Network repository, and give directions for finding them. Possibly and if appropriate, integrate them into one practical resource in the appropriate format *(e.g. a slides presentation).*

  Define questions from current knowledge:
  Formulate the scientifically oriented questions that the teacher will present to the students to provoke their engagement in thinking about the target subject matter based on their existing knowledge. Make these questions digitally available and easily usable, e.g. by integrating them in the materials described in the previous step.

Teaching Phase 2: Active Investigation

Note: This is a transitional phase on the borderline between the Pre-visit and Visit sections of the Educational Pathway. 'Active Investigation', and in particular the step of 'Planning and conducting simple investigation' can take place either before or during the 'visit', or both, depending on whether the teacher decides to use Green Learning Network resources of an 'exhibit nature' (*exhibits, simulations, experiments, etc.)* at this stage *(on the web or during a physical visit to a science museum/centre*). However the use of physical observation is concentrated mainly in the next Teaching Phase, under the 'Visit' section of the Educational Pathway.

- **Propose preliminary explanations or hypotheses:**
  Describe ways in which the teacher can encourage students to propose possible explanations to the questions that emerged from the previous activity. The teacher should be guided here to identify possible misconceptions in students' thinking. If applicable, locate or make relevant assistance materials available in the Green Learning Network repository, and give directions for finding them. If appropriate, you may consider integrating them in the materials described in the previous steps *(e.g. a slides presentation).*

- **Plan and conduct simple investigation:**
  Describe ways and materials *(resources already available in the Green Learning Network repository or other)* that the teacher can use to facilitate the students to focus on evidence as a source of answers to scientific questions. This is the phase in which students are being prepared for the subsequent phase of evidence gathering during observa-

tion. Locate or make relevant assistance materials available in the Green Learning Network repository, and give directions for finding them. If appropriate and relevant, it is possible to guide the teacher to use Green Learning Network resources of an 'exhibit nature' *(exhibits, simulations, experiments, etc.)* at this stage – in which case this activity should be moved to the 'Visit' section of the Educational Pathway. However it should be noted that the use of physical observation is concentrated mainly in the next Teaching Phase of 'Creation', under the 'Visit' section of the Educational Pathway.

B) Visit

(Teaching Phase 2: Active Investigation)

Note: 'Active Investigation', and in particular the step of 'Planning and conducting simple investigation' can take place in either the Pre-Visit or the Visit phase of the experience, or in both, depending on whether the teacher decides to use Green Learning Network resources of an 'exhibit nature' *(exhibits, simulations, experiments, etc.)* at this stage (on the web or during a physical visit to a science museum/centre). However the use of observation for gathering evidence is concentrated mainly in the Teaching Phase of 'Creation' described below.

Teaching Phase 3: Creation

- **Gather evidence from observation:**
  This is the core element of the 'Visit' phase, and can be realized either in the school classroom/lab, by remotely using science learning resources made available by the science museums/centres on the web, or during a physical visit which will involve the use of digital resources. Locate the appropriate resource in the Green Learning Network repository. Explain its use to the teacher, and provide access to any accompanying user support materials. The selected resource *(e.g. a simulation, an experiment, an animation, a graph or other exhibit of similar nature)* must provide students with an opportunity to collect evidence addressing the scientific questions posed in the previous stages through direct or indirect observation phenomena of the natural world. Provide guidance to the teacher organize and manage the activity most effectively and efficiently. It is recommended to introduce at this stage group work. Guide the teacher to divide students in groups, each of which will be facilitated by the teacher to formulate and evaluate explanations to the scientific questions based on the collected evidence. If applicable, locate or make relevant assistance materials available in the Green Learning Network repository, and give directions for finding them.

Teaching Phase 4: Discussion

Note: This is a transitional phase on the borderline between the Visit and the Post-visit sections of the Educational Pathway. 'Discussion' can take place either during or after the 'visit', or both, depending on whether the teacher considers that the use of the digital 'exhibits' is necessary *(or feasible)* at this stage. Ideally, 'Discussion', and particularly the step of 'Explanation based on evidence', should take place in front of the 'exhibit', to reinforce the link between the physical experience of using the resource and the mental processing of the observed information by the students.

- **Explanation based on evidence:**
  Guide the teacher to provide the correct explanation for the researched topic. Describe ways and materials *(resources already available in the Green Learning Network repository, or other)* she/he can use to this end, and give directions for finding them. If appropriate, integrate them into one practical resource in the appropriate format *(e.g. a slides presentation).*

- **Consider other explanations:**
  Guide the teacher to facilitate the student groups to evaluate their own explanations in the light of alternative explanations, particularly those reflecting scientific understanding. Describe ways and materials *(resources already available in the Green Learning Network repository or other)* the teacher can use to this end, and give directions for finding them. If appropriate, integrate them into one practical resource in the appropriate format *(e.g. a slides presentation).*

C) Post-visit

(Teaching Phase 4: Discussion)

Note: This is a transitional phase on the borderline between the Visit and the Post-visit sections of the Educational Pathway. Ideally, 'Discussion' should take place in front of the 'exhibit', to reinforce the link between the physical experience of using the resource and the mental processing of the observed information by the students. However, if necessary or preferred, it can also be organized as a post-visit activity leading into the next phase of 'Reflection'.

Teaching Phase 5: Reflection

- **Communicate explanation:**
  Guide the teacher to facilitate each student group to reflect on the previous experiences and produce a report with its findings, presenting and justifying its proposed explanations to other groups and the teacher. Make available or direct to materials *(resources already available in the Green Learning Network repository or other)* which the teacher can use to help the students familiarize themselves with and become effective in scientific writing.

Follow-up activities and materials

Describe and direct the user to any follow-up activities or materials that can be used to 'wrap-up' the main 'visit' experience. These could include appropriate learning assessment and/or reminder materials *(e.g. quizzes, games, other user-friendly tests),* hints for further activities, suggestions for other relevant 'visits', etc.

Sustainable contact

Describe and direct the user to any existing possibilities for maintaining contact with the digital resource and its provider, or with other users of the same learning experience.

6.5

Educational Pathway Pattern for an Open Visit by Lifelong Learners

Introductory note

Among the possible Educational Pathway Patterns, the pattern for the description of open visits by independent informal learners can be seen as the simplest, least predefined learning experience examined in the Green Learning Network. In this case, the museum educator/science communication professional, or even an experienced, motivated end-user, selects digital learning objects and combines them to form a meaningful, self-contained, user-friendly informal learning experience. The integration of resources scattered in various science museums/centres into the same learning experience is a priority (rather than selecting resources from a single museum or science centre).

A considerable degree of variation in the 'degree of structure' of the open pathway is expected to arise during the use of the Green Learning Network platform in the field, reflecting the varying degrees of user freedom in the context of informal science learning. In its extreme un-structured form, the open pathway can merely relate to random browsing and/or exploring of a set of aggregated learning objects. In such a case, implying any form of prescribed linearity of the experience should be avoided. More generally, the debates within the Green Learning Network consortium clearly show a very strong culture among science museum and centre professionals which emphasise leaving the choice and order of activities or experiences totally open, with at least intervention as possible. This aspect of the 'open' visit should be deemed possible in the Green Learning Network platform, without being restrictive. It should be added that science museums and centres see the ways in which end users themselves will combine learning objects free of any interventions, as a valuable source of information about users' preferences and emerging understandings of the resources.

In this context, the pathway pattern for an open visit proposed in the following sections should be seen as an initial proposition to be tested. It should be technically realised in the most flexible way to accommodate the widest possible variety of approaches across the spectrum of formal and informal learning experiences.

The underlying pedagogical approach for the open visit

Although the Inquiry-Based Learning approach adopted for the description of structured educational pathways may well be relevant to open visits, too, it is felt that its structured nature may not correspond well with many of the possible formats of an open visit. Therefore, in this case the much wider Resource-Based-Learning conceptual framework (see in the third section of this document) is applied as the basis for the conception of the open visit. To allow for the highest possible flexibility, the present Pattern makes minimal use of different sub-phases, retaining however the basic organization in a three-step scheme of activities before, during, and after the 'visit'. The core of the learning experience constitutes the 'visit' phase, with 'pre-visit' and 'post-visit' being left optional to the discretion of the designer of the pathway.

The Educational Pathway Pattern for an Open Visit by Lifelong Learners

A) Introductory section and preparatory phase

The following basic information about the intended learning experience is to be defined at the outset. This information should allow the user to assess the relevance of the resource to his/her learning needs, preferences and circumstances, and provide him with guidance for the preparation of the learning experience. Note that most of this information can be directly linked to specific elements of the Application Profile that will be used in the framework of the project. The formalisation proposed there for certain elements is to be applied accordingly in this introductory section too.

Title:

Give a title that helps easily recognize the content focus and purpose of the Educational Pathway.

Short description:

A description of no more than 30 words outlining the scope of the Educational Pathway, descriptive enough to help the user in the first instance to estimate its possible relevance to her/his interests.

Keywords:

A limited number of words/short phases reflecting the topic and scope.

Target audience:

The intended end user: independent informal learner, other...

Age range:

Up to 6, 6-9, 9-12, 12-15, 15-18, 18-25, 25+,...

Context:

The places that the Educational Pathway involves: science museum/centre, independently on the web.

Time required:

The approximate time typically needed to realize the Educational Pathway.

Technical requirements:

Description of any special technologies, infrastructure and/or technical expertise required for the realization of the

Educational Pathway.

Author's background:

What was the main function of the person who prepared the Educational Pathway: museum educator; parent; school teacher; other...

Science learning elements:

Reference to the items of the science learning vocabulary mainly covered by the Educational Pathway

Learning objectives:

Short description of the objectives of the described science learning experience

Guidance for preparation:

Guidance provided by the creator of the Pathway about any necessary arrangements that will need to be made by the interested user before launching the activities described in the following sections.

B) Pre-visit (optional)

Orientation information

Describe and direct the user to any information available on the context and elements of the learning activity, which may prepare and orient the use before the 'visit'. Such information may typically be available on the web (e.g. on the museum's website), but in cases it may also relate to other media, such as TV programmes, printed materials (e.g. museum leaflets) etc.

Building pre-experiences

Describe and direct the user to any information or activities that might exist and which would be a useful pre-experience preceding the main intended 'visit'. Such content may for example refer to other learning objects on the web, or, in the case of an open pathway addressing children and families, elements of the school curriculum which children should have some knowledge of.

Support or guidance available before the visit

Describe and direct the user to any support or guidance mechanism or contact that may exist for the preparation of the 'visit'.

B) Visit (the minimal core of the learning experience)

Provoke curiosity: questions to ask, things to observe (optional)

Describe in simple terms the questions that the user could ask, or the observation or information he/she could concentrate on, during the 'visit' to get the most of the learning potential offered by the experience. Direct the user to any relevant digital resources.

The core experience

Direct the user to the digital resources constituting the core of the 'visit' and describe in detail the way in which the 'visit' should be conducted, focusing on information that will help the user's orientation through the resources involved. If appropriate, explain the rationale behind the proposed ordering of the activities, or state and explain the freedom in which the learning experience can be shaped by the user.

Support or guidance available during the visit (optional)

Describe and direct the user to any support or guidance mechanism or contact that may exist to support the 'visit' in real time.

Any other relevant information (optional)

Provide any other information that does not fall under the previous categories but is necessary or useful for the effective / efficient realisation of the 'visit'.

C) Post-visit (optional)

Follow-up activities and materials

Describe and direct the user to any follow-up activities or materials that can be used to 'wrap-up' the main 'visit' experience. These could include appropriate learning assessment and/or reminder materials (e.g. quizzes, games, other user-friendly tests), hints for further activities, suggestions for other relevant 'visits', etc.

Sustainable contact

Describe and direct the user to any existing possibilities for maintaining contact with the digital resource and its provider, or with other users of the same learning experience.

7

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