DELIVERABLE D2.1: State of the art analysis

Project Acronym:	weSPOT
Project Name:	Working Environment with Social and Personal Open Tools for inquiry based learning
Call:	FP7-318499
Project Type:	Collaborative
Grant Agreement No.:	318499
Project Start Date:	1st October 2012
Project Duration:	36-Months
Due date of Deliverable:	Month 6
Actual Submission Date:	Month 7
Name of Lead Beneficiary for this Deliverable:	Friedrich-Alexander-University Erlangen-Nürnberg (FAU)
Report Author(s):	Aristidis Protopsaltis, Sonia Hetzner, Paul Seitlinger, Michael Bedek, Simone Ellen Rusman, Olga Firssova, Marcus Specht, Fotini Haimala, Kathy Kikis-Papadaki, Alexandra Okada, Alexander Mikroyannidis , Peter Scott
Reviewed by:	Pavel Boytchev, Jan van Bruggen
Revision:	v0.6
Dissemination Level:	RE

Document History

Version	Date	Comment	Modifications made by
0.1	28.03.2013	First Draft	Aristidis Protopsaltis FAU, Germany
0.2	09.04.2013	Second Draft	Aristidis Protopsaltis FAU, Germany
	22.04.2013	Review and addins	Sonia Hetzner FAU, Germany
0.3	17.04.2013	Third Draft	Aristidis Protopsaltis FAU, Germany Ellen Rusman, Olga Firssova, Marcus Specht OU, NL Alexandra Okada, Alexander Mikroyannidis, Peter Scott OU, UK
	19.04.2013	Examples of IBL and technology implementations	Ellen Rusman, Olga Firssova OU, NL Fotini Haimala FORTH, Greece
0.4	22.04.2013	Fourth Draft	Aristidis Protopsaltis, Sonia Hetzner FAU, Germany
0.5	23.04.2013	Fifth Draft	Aristidis Protopsaltis FAU, Germany
	23.04.2013	Review	Pavel Boytchev FMI, Bulgaria Ellen Rusman OU, NL Jan van Bruggen OU, NL
0.6	25.04.2013	Integration of review comments and suggestions	Aristidis Protopsaltis FAU, Germany

CONTENTS

EXECUTIVE SUMMARY

The weSPOT project aims at propagating scientific inquiry as the approach for science learning and teaching in combination with today's curricula and teaching practices. It lowers the threshold for linking everyday life with science teaching in schools by technology. weSPOT supports the meaningful contextualization of scientific concepts by relating them to personal curiosity, experiences, and reasoning. weSPOT addresses several challenges in the area of science learning and technology support for building personal conceptual knowledge. The project focuses on inquiry-based learning with a theoretically sound and technology supported personal inquiry approach.

The project foresees three main development aspects: (a) define a reference model for inquiry-based learning skills, (b) create a diagnostic instrument for measuring inquiry skills, and (c) implement a working environment that allows the easy linking of inquiry activities with school curricula and legacy systems.

The current deliverable, D2.1, falls within the development aspect a), and it compiles and describes the underlying theoretical models, like inquiry based and self regulated learning models, Piaget's theory on cognitive development, Vygotsky's social constructivism theory, and the relation of inquiry-based learning and technology. The deliverable will provide the basis for the development of the pedagogical framework, which the first version will be presented in the deliverable D2.3.1 and it will be continually updated throughout the project.

1. INTRODUCTION

WeSPOT is a project supported by the European Commission aiming at propagating scientific inquiry as the approach for science learning and teaching in combination with today's curricula and teaching practices. weSPOT conceptional and technological outcomes will lower the threshold for linking everyday life with science teaching in schools.

One of the advantages of the new online learning movement is the opportunity it presents to re-examine the ways in which some aspects of traditional instruction can be re-conceived to operate effectively in synchronous and asynchronous online learning environments. This technological shift—from knowledge being fixed to a certain time and place, to knowledge being accessible at anytime and at anyplace-creates the potential for a change in the way learning is transacted from those who provide information (i.e. teachers or facilitators) to those who receive it (i.e. students).

In the last ten years students have gained multiple ways to learn with digital and mobile media. Especially social and mobile media gained high popularity and are foreseen to be the most important media channels for the target group of learner between 12-25 years old today. Nevertheless the teaching approaches in primary, secondary and higher education have not taking full advantage of these technological advancements. The integration and connection between informal and formal methods of learning and instruction often have failed either due to lack of pedagogical innovation, technology usability, media literacy problems, the problem of recognizing informal learning activities in the curricular context or other. There is still a need for taking a better advantage of learning supported by technology and pedagogical innovation.

The promotion and innovation of Science education is the key focus of the weSPOT project. The project adopts innovative pedagogical concepts that illustrate and promote the nature of science and research. Inquiry-based learning (IBL) has been widely recognized in science learning as a successful and promising approach as for example in the report of the European Commission "Science Education Now: A renewed pedagogy for the Future of Europe" (European Commission, 2007). Increasingly the overall aim of Science Education in the digital age through inquiry based learning is to make all students scientific literate, able to apply science knowledge to improve their own lives, deal with an increasingly complex technological world and make science-related decisions as responsible citizens (American Association for the Advancement of Science, 1989).

Scientific inquiry in empirical sciences - the main focus of weSPOT - answers the question of how phenomena are related: why things do happen. It is about cause-consequence relations, which can principally be tested in experiments. It is not about believes but about empirical evidence. Inquiry based learning is learning, which starts from a project idea and follows the rules of scientific inquiry. It leads finally to structure knowledge about a domain and develops skills and competences about how to carry out research which is efficient, scientifically sound and which can be communicated.

Inquiry skills and competences are needed to carry out scientific research. To give some examples: It starts from clearly formulated research questions with clearly defined terms, it goes to structured observation under defined conditions and end with methodological competences which allow to process the collected data. Many more competences and skills are necessary to carry out meaningful inquiry.

weSPOT supports the meaningful contextualization of scientific concepts by relating them to personal curiosity, experiences, and reasoning. It addresses several challenges in the area of science learning and technology support for building personal conceptual knowledge. The project focuses on inquiry-based learning with a theoretically sound and technology supported personal inquiry approach. In inquiry based-learning learners take the role of an explorer and scientist and are motivated by their personal curiosity, guided by self-reflection, and develop knowledge personal and collaborative sense-making and reasoning. weSPOT will work on a meta-inquiry level in that it will (a) define a reference model for inquiry-based learning skills, (b) create a diagnostic instrument for measuring inquiry skills, and (c) implement a working environment that allows the easy linking of inquiry activities with school curricula and legacy systems.

1.1. The Goal of the Deliverable

The goal of the deliverable D 2.1 is to review the existing literature on IBL, IBL and technology and the existing models as a base line for the development of the weSPOT pedagogical model. The deliverable feeds into the deliverable D2.3.1 where the weSPOT IBL model will be outlined together with the weSPOT diagnostic framework.

1.2. The Structure of the Deliverable

The deliverable is structured in 8 sections. Following this introduction, section 2 discusses and defines Inquiry-based Learning (IBL), its origins, the Dewey's, Piaget's and Vygotsky's theories, key characteristics and its advantages and disadvantages. In section 3 the different levels of IBL in general and in science education are examined. Section 4 is dedicated to the different types of IBL, while section 5 presents and discusses the various IBL model in the field. Section 6 reviews IBL and its relation to technology and section 7 presents examples of successful implementation of IBL and technology. Section 8 presents a discussion on IBL and introduces the requirements for an IBL model that supports technology enhanced learning.

2. INQUIRY-BASED LEARNING (IBL)

Inquiry-based learning is a pedagogic and teaching approach based on the instructional method. It is grounded in the constructivist approach to learning, which advocates that each learner follows his own route to build and organizing personal knowledge, and that it is more important to know "how to learn" than the juxtaposition and memorizing of information. It is an active approach towards learning and teaching that places learners and students at the centre of the learning process and involves self-direction. Students develop knowledge and understanding of scientific ideas as well as an understanding of how scientists study the natural world (Anderson, 2002).

The nature of inquiry-based learning is contested and even the term itself is not in widespread use throughout the educational literature. Many terms are used for learning through inquiry, including ‘enquiry-based learning’, ‘guided-inquiry’, ‘problem-based learning’, ‘undergraduate research’ and ‘research-based teaching’ (Spronken-Smith & Walker, 2010).

2.1. The origins of inquiry-based learning

The basic elements of the inquiry-based approach have their origins in antiquity, and are apparent in the teaching of Confucius and Socrates (Spronken-Smith, 2007) where advocate the discovery of knowledge by learners rather than by the transmission of facts. It is the American educator and philosopher John Dewey (1859-1952), however, who was largely responsible for promoting ‘learning by doing’ (Dewey, 1933, 1938). This approach to learning was adopted by many school teachers in the 1970s and began to appear about the same time in tertiary institutions (Spronken-Smith, 2007). Despite a lengthy history, the literature base for IBL is at best patchy and diffuse, and although there are several recent volumes that describe the teaching approach and provide readers with a range of examples (e.g. see Alford, 1998; Bateman, 1990; Lee, 2004; and Weaver, 1989), most literature appears in pockets amidst educational and disciplinary journals.

In the 1960s Robert Karplus from the University of California Berkeley proposed and first used inquiry based learning as a model of science instruction based on the work of Piaget which eventually was called the Learning Cycle (Atkin & Karplus, 1962). This new science instruction method was advocating to the teachers to present science as inquiry and students work in the laboratory before being introduced to the formal explanation of scientific concepts and principals (NRC, 2000). This method was again formalized by Marshal Herron (1971), who developed the Herron scale to evaluate the amount of inquiry within a particular lab exercise. Today, the method is used in science lesson plans following Bybee's (1997) five steps of Engagement, Exploration, Explanation, Elaboration, and Evaluation.

Engagement is a time when the teacher is on centre stage describing the problem at hand, pre-assessing the students, helping the students to make connections, and informing providing directions. During exploration the students are at the centre of the action, collecting data to solve the problem. Students are active taking control of their learning and up to certain extend guiding their learning. At the explanation step, students use the data they have collected to solve the problem and report what they did and try to figure out the answer to the problem that was presented. At the elaboration phase, the teacher gives students new information that extends what they have been learning in the earlier parts of the learning cycle and they can be asked to apply the acquired knowledge to new problems. Evaluation is not the last step. Evaluation occurs in all four parts of the learning cycle. As in any cycle, there's really no end to the process. After elaboration ends, the engagement of the next learning cycle begins (Bybee, 1997).

2.2. Active Learning

Dewey, (1933, 1938) introduced the idea of active learning which influence the educational systems of the western society. He believed that learning ought to be active and that the current educational systems were unnecessarily long and restrictive. His idea was that children came to school to do things and live in a community which gave them real, guided experiences which fostered their capacity to contribute to society (Neill, 2005). For example, Dewey believed that students should be involved in real-life tasks and challenges:

- maths could be learnt via learning proportions in cooking or figuring out how long it would take to get from one place to another by mule
- history could be learnt by experiencing how people lived, geography, what the climate was like, and how plants and animals grew, were important subjects (Neill, 2005).

He argued that experience, and therefore knowledge, is based on two principles, continuity and interaction. Continuity refers to the experiences that people have and their influence in their development, while interaction refers to the situational influence on those experiences (Selby, 2010).

He also argued that in order for education to be most effective, content must be presented in a way that allows the student to relate the information to prior experiences, thus deepening the connection with this new knowledge. Furthermore, he argued that "if knowledge comes from the impressions made upon us by natural objects, it is impossible to procure knowledge without the use of objects which impress the mind" (Dewey, 1916/2009, p. 217-218).

Dewey was also a pioneer in the way he saw the teachers' role in the learning process. He saw the teacher not as the dominant figure standing at the front of the classroom delivering information to be absorbed passively by students, but instead, he perceived the teacher's role as facilitator and guide (Dewey, 1916/2009). The teacher's role is mostly to design an appropriate scenario, to arrange for the resources required to be available, and to act as a guide during the learning experience. Much of the control is left to the learners, who are expected to negotiate what they should learn, which strategy they would adopt to complete the task successfully. These ideas are central in constructivist learning approach and in inquiry-based learning.

Another influential idea provided by Dewey was the social aspect of learning. According to Dewey learning occurs within a social environment. Humans are social beings and exist in social environment and therefore knowledge is socially constructed (Grady, 2003).

Dewey's ideas influenced the development of the constructivist learning approach and other influential experiential models and advocates such as Piaget and Vygotsky. Problem-Based Learning (PBL) and Inquiry-Based Learning (IBL) for example, methods used widely in education today, incorporate Dewey's ideas pertaining to learning through active inquiry (Savery, 2006).

2.3. Piaget's Theory of Cognitive Development

Piaget (1936) theory of cognitive development explains the mechanisms and processes that infants and children develop their mental abilities and become able to use reason and hypotheses. According to Piaget, children construct an understanding of the world around them, making mistakes and learning from them and experience inconsistencies between what they already know and what they discover in their environment. Children store the acquired knowledge into structures called schemas (Piaget, 1936; 1973). When new information is attained, it can either be assimilated into existing schemas or accommodated through revising an existing schema or creating an entirely new schema, meaning a new category of information.

Schemas are central components of Piaget's theory and refer to the way learners organize and store information. It is one of the three main components that contribute to the cognitive development. Schemas allow elements of information and skills to be categorised and stored in long-term memory. When brought into working memory, a schema, no matter what its size, is treated as a single element (Protopsaltis, 2006). Schemas have been accepted as the main cognitive structure for storing information by cognitive scientists.

The other two components according to Piaget that contribute to the cognitive development are processes and stages. Piaget (1936, 1973) identifies four processes that contribute to the intellectual growth, assimilation, accommodation, equilibration, and disequilibrium.

Assimilation refers to the process of incorporating new information into pre-existing categories of information, schema (Piaget, 1973). People have pre-existing knowledge and when they learn new information they integrate this information with the existing ones extending their knowledge and therefore their schema. However, if the existing schema does not fit the new information then learners need to construct a new schema and accommodate the new information. This process is called accommodation (Piaget, 1973) and is the second process that contributes to intellectual growth according to the theory of cognitive development (Piaget, 1973). Assimilation and accommodation are the two parts of adaptation, which is simply refers to adapting schemata to make an accurate (enough) model of the world. The third process called disequilibrium. Piaget (1973) suggested that humans naturally strive to achieve a cognitive balance; there must be a balance between applying prior knowledge (assimilation) and altering schemata to account for new information (accommodation). However, when a schema does not fit reality, there is confusion, dissonance, or discomfort in the mind. This state of mind is called disequilibrium. The ways to overcome this tension is by balancing the use of assimilation and accommodation, and thus proceed to higher levels of thought and learning, equilibration, which is the fourth process cognitive development. According to Piaget, adaptation is the most important principle of human functioning (Singer & Revenson, 1997).

In addition to the processes Piaget (1973) described four stages of cognitive development, sensorimotor, pre-operational, concrete operational and formal operational. The sensorimotor stage starts from birth until the second year and children can differentiate their selves from the objects, realise objects and its existence after they disappeared from his sensory senses. At the pre-operational stage (2-7 years), children learn the language and represent objects by words and their thinking is egocentric. The third stage, the concrete operational stage (7-11 years), refers to logical thinking about events and objects, use and understanding of numbers and classification of objects according to their features. None of these stages are relevant to the project since the target group is learners from 12-25 years old who lie in the fourth stage of Piagetian development, the formal operational stage (11 years and up). At this stage, people can think logically about abstract propositions and test hypothesis systematically, mentally manipulate ideas, become concerned with the hypothetical, the future and ideological problems. This is the stage that inquiry-based learning is applied in its different forms.

One of the major criticisms on Piaget's cognitive development theory has to do with the concrete stages of development and the omission of the effect the social environment may have on cognitive development and learning. An alternative theory was proposed by Vygotsky the so called Sociocultural Theory of Development and became a major influence in the field of psychology and education (Woolfolk, 2004).

2.4. Social Constructivism

Vygotsky is considered the "founding father" of social constructivism. His idea that social interaction was essential to the learning process along with critical thinking is at the centre of social constructivism. Social interaction or cooperative learning had a big impact on how students internalized what they learned. "Vygotsky stated that language enhances learning and that it precedes knowledge or thinking. [In order] to embrace diversity, students must interact socially [by using language]" (Powell & Kalina, 2009, p. 245).

Vygotsky also introduced another very influential concept, the concept of a zone of proximal development (ZPD) which he defined as "the intellectual potential of an individual when provided with assistance from a knowledgeable adult or more advanced peer" (Jones & Brader-Araje, 2002, p. 6). By assisting a learner, that learner continued to progress to the next level of understanding. Learners made sense of new information based on pre-existing understandings. Making sense of new information is an active process that requires learners to act upon (Jones & Brader-Araje, 2002). Inquiry-based learning or co-operative learning as Vygotsky called it "is an integral part of creating … a social constructivist classroom" (Powell & Kalina, 2009, p. 244).

Scaffolding is another Vygotskian principle for the sociocultural perspective. Scaffolding involves providing the learner with hints or clues for problem solving in order to allow the student to better approach the problem in the future (Woolfolk, A., 2004). While Piaget would assume the student does not yet have the mental structures to solve such a problem, Vygotsky would offer encouragement or strategies, in the form of scaffolding, in order for the student to attempt the problem.

The ideas of Vygotsky's cognitive development are very closely related to the IBL approach. Since IBL is influenced by the constructivist approach to learning seeing it as an active process, where the learners takes control of his learning and the teachers serves as a facilitator. Furthermore, the social factor in IBL is very important and it can even be enhanced with the use of technology. Finally, scaffolding plays a central role in IBL since different types and levels of IBL require different levels of scaffolding.

2.5. Key characteristics of inquiry-based learning

According to Conole, et al. (2008) there are four main characteristics of inquiry learning.

- **Questioning and hypothesis**: Learners are engaged by scientifically oriented questions (Grandy & Duschl, 2007). Learners asking questions about the world, collecting data, making discoveries and testing those discoveries (de Jong, 2006) or making hypothesis and predictions about natural phenomena (Osborne et al., 2005). The teacher does not begin with a statement, but with a question. This allows the students to search for information and learn on their own with the teacher's guidance.
- **Adopting an evidence-based approach:** Learners prioritise evidence collection that allows them to develop and evaluate explanations that address scientifically oriented questions (Grandy & Duschl, 2007).
- **Synthesis and metacognition:** Learners synthesising the obtained information, using metacognitive processes, to formulate explanations to address scientifically oriented questions (Grandy & Duschl, 2007). The result will be the development of an 'integrated' scientific understanding i.e. the combination of knowledge of scientific concepts, understanding of scientific tools and inquiry skills (Edelson, Gordin, & Pea, 1999).
- **The nature of Science:** Learners evaluate their explanations in light of alternative explanations particularly those reflecting scientific understanding (Grandy & Duschl, 2007) and the claims of others.

Specific learning processes that students engage in during inquiry-learning include:

- Creating their own questions
- Obtaining supporting evidence to answer the questions
- Explaining the collected evidence
- Connecting the explanations to the evidence
- Creating arguments and justifications.

2.3 Advantages of inquiry-based learning

The benefits of inquiry-based learning can be seen especially when activities are open-ended and learner-directed (Huber & Moore, 2001). It is important that learners choose their own questions to explore, and pursue their own course. This approach increases motivation; it is a more pragmatic form of inquiry, and it leads to a better understanding of the nature of science and scientific research (Huber & Moore, 2001). According to Huber and Moore (2001, p.33) when instructors employ methods with predetermined outcomes such as worksheets or textbook-based instruction in conjunction with inquiry, students do not develop an understanding of the nature of science: "the presentation of science as a process of following step-by-step instructions and filling in blanks on worksheets promotes erroneous and impoverished concepts regarding the nature of science".

Inquiry-based learning provides authentic activities in authentic contexts and these activities provide learners with the motivation to acquire new knowledge, to incorporate new knowledge into their existing knowledge, and an opportunity to apply their knowledge.

The first advantage of inquiry-based learning is related to the development of general inquiry abilities (Edelson, et al., 1999). Students learn to generate questions, understand scientific concepts and scientific tools. Furthermore, the use of inquiry-based learning offers to the students the chance to achieve two other interrelated learning objectives: the acquisition of specific investigation skills, and the understanding of science concepts and principles in realistic settings (Edelson, et al., 1999). While working within pragmatic context and investigating scientific principles learners apply real scientific methods, processes and tools and therefore develop authentic scientific skills and competencies and refine their pre-existing understanding of scientific principles in the answers that they construct.

General inquiry skills include posing and refining research questions, planning and managing an investigation, and analyzing and communicating results. Inquiry activities provide the opportunity to develop and exercise these general inquiry abilities. Furthermore, inquiry-based learning activities can give learners the opportunity to apply their scientific understanding in the pursuit of research questions. The need to apply scientific knowledge can require a learner to reorganize and re-index it in ways that will support its future use. The application of existing knowledge can also reinforce it and enrich its connections to other knowledge (Edelson, et al., 1999).

Additionally, inquiry-based learning can maintain children's and young adolescents initial curiosity about the world making them confident that they can use the methods of inquiry to find answers for their questions and their world. It teaches problem-solving, critical thinking skills, and disciplinary content. In addition, promotes the transfer of concepts to new problem questions, teaches students how to learn and builds self-directed and self-reflected learning skills.

IBL increases students' attainment in mathematics and science, with an even strong impact in students with lower levels of self confidence and those from disadvantaged backgrounds (Rocard et al., 2007). Furthermore, students will remember and understand scientific knowledge better (Walker, 2007).

Another advantage of inquiry-based learning is that it increases teachers' willingness and motivation to teach science (Rocard, et al., 2007). Besides inquiry-based learning techniques are efficient on groups of students for which traditional deductive methods are ineffective (students with lower levels of self-confidence and those from disadvantages backgrounds, girls studying science) and it can provide increased opportunities for cooperation between various actors in the formal and informal arena (it created opportunities to involve firms, researchers, universities. parents and other kinds of local resources) (Rocard et. al., 2007). Finally, students will learn how scientific knowledge is generated and how the current body of scientific knowledge was developed and produced (Walker, 2007) and as a result they will acquire a more balanced and pragmatic view about science and its nature.

2.4 Disadvantages of inquiry-based learning

Despite the advantages that inquiry-based learning has there also some disadvantages. Inquiry-based learning is time consuming; it demands lots of preparation time and considerable planning. Assessment can be difficult and it might needs novel methods to be measured. Also it requires more effort from students and demands them to be active learners, since they are taking control of their learning and they need to generate their own knowledge. This approach might not be suitable for all students and especially the novice ones.

Minimal guidance imposes greater cognitive load on learners and as a result hinders learning. Cognitive load theory suggests that the free exploration of a highly complex environment may generate a heavy working memory load that is detrimental to learning. This suggestion is particularly important in the case of novice learners, who lack proper schemas to integrate the new information with their prior knowledge (Kirschner, Sweller, & Clark, 2006). Furthermore, problem solving, which is a central aspect of inquiry-based learning, places a huge burden on working memory (Sweller, 1988).

Another disadvantage of inquiry-based learning might be that its focus moves away from the content of science to the processes. It is assumed that knowledge can best be acquired through experience based on the procedures of the discipline (i.e., seeing the pedagogic content of the learning experience as identical to the methods and processes (Kirschner, 1992). It may be a fundamental error to assume that the pedagogic content of the learning experience is equal to the methods and processes (i.e., the epistemology) of the discipline being studied and a mistake to assume that instruction should exclusively focus on methods and processes (Kirschner, Sweller, & Clark, 2006).

Finally there is a plethora of evidence that minimal guidance during instruction is significantly less effective and efficient than guidance specifically designed to support the cognitive processing necessary for learning (Mayer, 2004). Using minimal guidance or no guidance at all when using inquiry-based learning might actually obstruct learning, especially with novice learners.

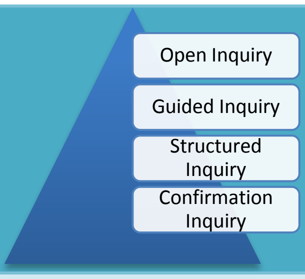
3. INQUIRY-BASED LEARNING LEVELS

Developing an understanding of science requires students to engage in practicing and using its discourse in a range of structured activities (Duschl & Osborne, 2002). Additionally, inquiry-based approaches require engaging in argumentation, construction of explanations and the evaluation of evidence (Osborne, Erduran, & Simon, 2004). By doing so learners are getting familiar with the nature of science and develop their understanding. For the domain of science learning, Quintana et al. (2004, p. 341) define “inquiry as the process of posing questions and investigating them with empirical data, either through direct manipulation of variables via experiments or by constructing comparisons using existing data sets”.

Schwab (1962) called for inquiry to be separated into four distinct levels. This was later formalized by Marshall Herron (1971), who developed the Herron Scale to evaluate the amount of inquiry within a particular lab exercise. The model classified inquiries on a scale of 0 Confirmation/Verification, 1 structured, 2 Guided and 3 Open Inquiry, depending on how much structure the teacher provides and whether there is an existing solution to the problem or question under consideration. Since then, there have been a number of revisions proposed, but the consensus in the science education community is that there is a spectrum of inquiry-based teaching methods available.

Tafoya Sunal, and Knecht (1980) suggested four kinds of inquiry-based learning based on different levels of student autonomy (Table 1). The first level is the confirmation inquiry in which students are provided with the question and procedure (method) as well as the results, which are known in advance. The second level is structured inquiry, where the learning goal is to introduce students to the experience of conducting investigations or practicing a specific inquiry skill, such as collecting and analysing data. The third level is the guided inquiry, where the question and procedure are still provided by the teacher. Students, however, generate an explanation supported by the evidence they have collected. The teacher provides students with only the research question, and students design the procedure (method) to test their question and the resulting explanations with guidance or mentoring support. The fourth and highest level of inquiry is open inquiry, where students have the opportunity to act like scientists, deriving questions, designing and carrying out investigations as well as communicating their results. This level requires experienced scientific reasoning and domain competences from students.

Table 1. Levels of inquiry according to (Tafoya et al., 1980)



	Main responsibility for:		
Level of inquiry	Problem	Procedure	Solution
Level 4 Open inquiry	Student	Student	Student
Level 3 Guided inquiry	(teacher)	Student	Student
Level 2 Structured inquiry	(teacher)	(teacher)	Student
Level 1 Confirmation/ verification	(teacher)	(teacher)	(teacher)

The inquiry skills described in table 2 show a detailed version of the five skill areas related to the each of four levels of inquiry. These twenty skills were adapted from the table inquiry grid for teaching towards student skills presented by Bodzin and Beerer (2003):

Table 2: Levels of inquiry skills (table adapted by Okada, 2008)

	INQUIRY SKILL AREA				
LEVEL OF INQUIRY	1.Scientifically orientated questions	2. Priority to evidence	3. Explanations from evidence	4. Explanation connected to knowledge	5. Communicate and justify
4 Open inquiry	Posing a scientific question	Determining what constitutes evidence, and collecting evidence	Formulating explanations after summarizing evidence	Examining independently other resources and forming the links to explanations	Forming reasonable and logical argument to communicate explanations
3 Guided inquiry	Selecting among given questions and posing new scientific	Collecting certain data with guided support for what	Formulating explanations from evidence with guided support	Linking areas and sources of scientific knowledge to clarify	Communicating explanations based on scientific reasoning with

	questions with guided support	constitutes evidence		explanations	guided support
2 Structured inquiry	Sharpening or clarifying question provided by teacher, materials, or other source	Analyzing given data to select evidence	Selecting possible ways to use evidence with directed support to formulate explanation	Selecting possible connections to clarify explanations	Selecting broad guidelines to use sharpen communication
1 Confirmation/ verification	Engaging in questioning provided by teacher, materials, or other source	Analyzing given data to select evidence with directed support	Applying provided evidence to formulate explanation with directed support	Selecting possible connections to clarify explanations with directed support	Applying given steps and procedures for scientific communication

Similarly to Tafoya and colleagues (1980), Banchi and Bell (2008) also suggest that there are four levels of inquiry-based learning, focusing however on science education. The four levels are the same as the ones suggested by Tafoya et al. (1980): confirmation inquiry, structured inquiry, guided inquiry and open inquiry. With confirmation inquiry, students are provided with the question and procedure (method), and the results are known in advance. Confirmation inquiry is useful when a teacher's goal is to reinforce a previously introduced idea; to introduce students to the experience of conducting investigations; or to have students practice a specific inquiry skill, such as collecting and recording data.

In structured inquiry, the question and procedure are still provided by the teacher; however, students generate an explanation supported by the evidence they have collected. In guided inquiry, the teacher provides students with only the research question, and students design the procedure (method) to test their question and the resulting explanations. Because this kind of inquiry is more involved than structured inquiry, it is most successful when students have had numerous opportunities to learn and practice different ways to plan experiments and record data.

At the fourth and highest level of inquiry, open inquiry, students have the purest opportunities to act like scientists, deriving questions, designing and carrying out investigations, and communicating their results. This level requires the most scientific reasoning and greatest cognitive demand from students.

Edelson et al. (1999) on the other hand lists a range of inquiry-learning approaches such us discovery, controlled experimentation, modelling, synthesis of primary sources and exploration of quantitative data, and argues that each requires the development of a particular set of skills. Learners/students need to be able to communicate their findings and validate their explanations (Grandy & Duschl, 2007). They need to be able to handle and manipulate data, analyse and model methods, evidence and outcomes. They also need to be able to visualise data in a variety of different formats (as tables, as graphs, as equations, as diagrams, as 3D-models) and understanding what these different representations offer (Conole, et al., 2008).

4. TYPES OF INQUIRY-BASED LEARNING

Conole, et al. (2008) argued that based on the literature four distinct types of inquiry-based learning seem to exist. These different types are closely related to the key characteristics mentioned above, proposed by Grandy and Duschl (2007).

4.1. Peer, collaborative inquiry learning

The emphasis of the model is to facilitate and scaffold learners in dialogue and discussion around the inquiry process. Learners work in groups with peers and becoming acculturated into a scientific way of thinking. The model begins with a question or problem being set. The students then work individually and collaboratively to tackle the question, coming together to synthesise their findings and finally they collectively reflect on the process. The key pedagogies in this model are: orientate, discuss, interpret and reflect (Conole, et al., 2008). Discussion and collaboration tools could take a range of formats, both synchronous and asynchronous, but might include scaffolding and guidance to help the students develop their arguments and understanding.

4.2. Hypothesis-driven inquiry learning

The emphasis here lies on the inquiry process beginning with a hypothesis or question and designing or using existing methods to prove it right or wrong. The hypothesis model foregrounds the questioning and hypothesis characteristic of inquiry learning. The tools of importance in this model are concerned with supporting the learner in the development of their hypothesis, designing and conducting the investigation, and analysing the results. The hypothesis model emphasises six main pedagogical approaches: orientate, hypothesize, design, investigate, interpret and analyse (Conole, et al., 2008).

4.3. Multiple forms of representation

Here learners can see and present data in different formats, extracting information from different formats, understanding the relations between changes in representations and changes in actions or observations and helping them to understand the value of these different forms of representation. The use of technology here can have a predominant role. A fundamental aspect of scientific thinking is for students to be able to ‘see’, ‘interpret’ and ‘manipulate’ data and concepts in a variety of different formats and to develop an understanding of the purposes of each of these different forms of representation (Conole, et al., 2008). The tools are those which enable learners to explore different forms of representation of data and concepts. What’s more important than the tools is the ways in which they are used and the guidance to the students on how to use these tools and why they are using them.

4.4. Modelling

The emphasis in the modelling type is on adopting an evidence-based approach that enables the learner to use modelling as part of the process of investigation. Learners can use various tools that help them to model an approach and enable them to switch between more descriptive representations of a process to the more specific.

5. (Bruce & Bishop, 2002)MODELS OF INQUIRY-BASED LEARNING

There are a number of inquiry-based models such as the Cyclic Inquiry Model (CIM) and its variations, Knowledge-building community model (Scardamalia & Bereiter, 1994), Scaffolded Knowledge Integration (SKI) (Linn, 1995), Learning by Design (LBD) (Kolodner, Crismond, Gray, Holbrook & Puntembakar, 1998), the Stripling (2003) Model of Inquiry, Inquiry model (Alberta Education, 2004). The section below will describe the main attributes of these models.

5.1. The Inquiry Cycle

One of the first attempts to develop a model belongs to White and Frederiksen (1998) who created a model called the Inquiry Cycle and it was based on work previously undertaken by one of the authors (White, 1993; White & Horwitz, 1988). This work was based transforming the steps in the instructional cycle developed in prior research (White, 1993; White & Horwitz, 1988) into an Inquiry Cycle shown in figure 1 having 5 steps: question, predict, experiment, model, and apply.

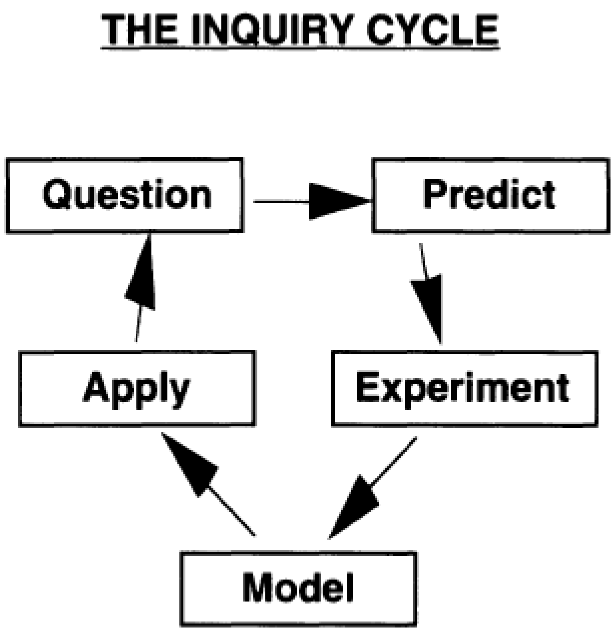


Figure 1: A model for the scientific inquiry process (White & Frederiksen, 1998)

The model provides a scaffold in a series of steps in a never-ending cyclical process of generating, testing and elaborating scientific models and principles, aiming in developing a useful, accurate, and comprehensive theory in a given domain (White, Frederiksen, & Collins, 2009). According to the authors admission (White & Frederiksen, 1998) the model is simple but general and tries to models the scientific inquiry and learning process but they (White, Frederiksen, & Collins, 2009) recognise that science does not proceed in this step-wise manner and for example the inquiry can start at anywhere in the sequence and not necessarily proceed through the steps in order. However, by offering a simple inquiry model in a cyclical fashion can be an effective initial model that enables students to develop the capabilities of inquiry and understand its basic processes (White & Frederiksen, 1998; White, 2005a; White, 2005b; White, Frederiksen, & Collins, 2009). Another limitation of the model can be identified on the luck of reflection which is essential in scientific enquiry.

White, Frederiksen, and Collins (2009) produced and updated version of their inquiry cycle model which includes a set of six steps, with metacognitive elements, representing abstract processes which derive their meaning from sets of related activities or subtasks. The steps include (see: Figure 2): question and theorise, hypothesize, investigate, analyse, synthesize, and extend.

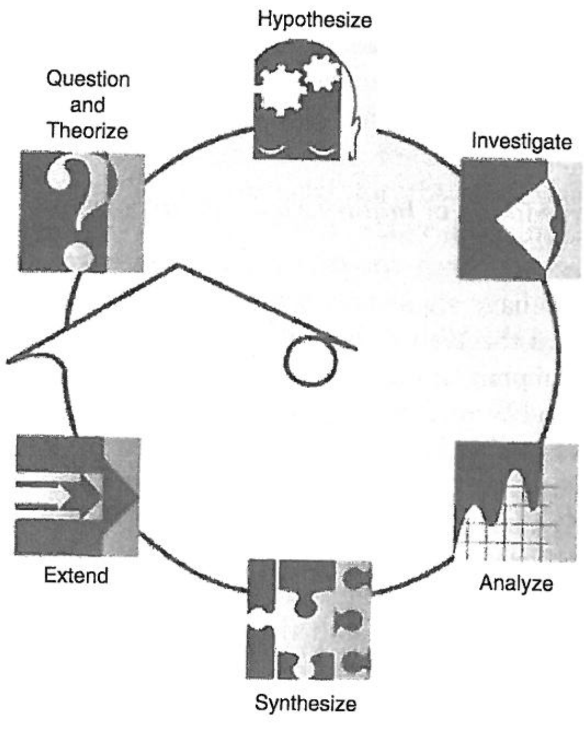


Figure 2: Inquiry cycle (White, Frederiksen, & Collins, 2009)

Each step constitutes from sub-tasks or activities important for the inquiry process. For example the “analyze” step includes three sub-tasks: a) organise data, summarise and create graphs, b) identify the patterns and consider their meaning and generality, and c) identify which hypotheses are supported and which are not. They use a software advisor for metacognitive scaffolding.

5.2. Cyclic Inquiry Model (CIM)

The UIUC inquiry model created by the University of Illinois at Urbana-Champaign (UIUC) (Bruce & Bishop, 2002). The main aim of the model is the creation of new ideas and concepts, and their spreading in the classroom. The Inquiry cycle is a process which engages students to ask and answer questions on the basis of collected information and which should lead to the creation of new ideas and concepts. The cycle of inquiry has 5 global steps: Ask, Investigate, Create, Discuss and Reflect.

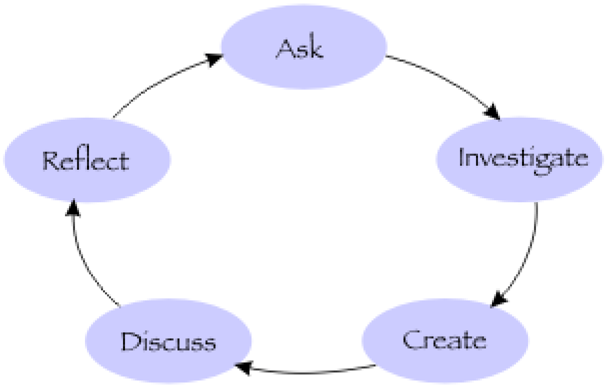


Figure 3: Cyclic inquiry model by Bruce & Bishop (2002)

During the preparation of the activity, teachers have to think about how many cycles to do, how to end the activity (at the *Ask* step): when/how to rephrase questions or answer them and express follow-up questions.

However, the UIUC model is also simple and general and does not take into consideration that science does not proceed in this step-wise manner and not necessarily proceed through the steps in order. On the plus side this model introduces a reflection step which essential in scientific enquiry process. However, reflection does not occur sequentially as separate step but rather is an integral activity throughout the whole enquiry process. Additionally, the cyclic model seems to be information-oriented, according to Levy’s (2009) different framing of inquiries, which makes it unsuitable for scientific inquiry, which is the focus of the weSPOT project and focusing on discovery of knowledge which represented by discovery-oriented IBL (Levy, 2009).

This approach has been proven very popular and formed the basis for a number of “improved” cyclic inquiry models which are presented below.

A slightly different approach proposed by Llewellyn (2005) is a 6-step inquiry cycle (Figure 2): generating a question; brainstorming; stating a hypothesis; choosing a course of action and carrying out the investigation; gathering data for appropriate conclusions; and communicating the findings.

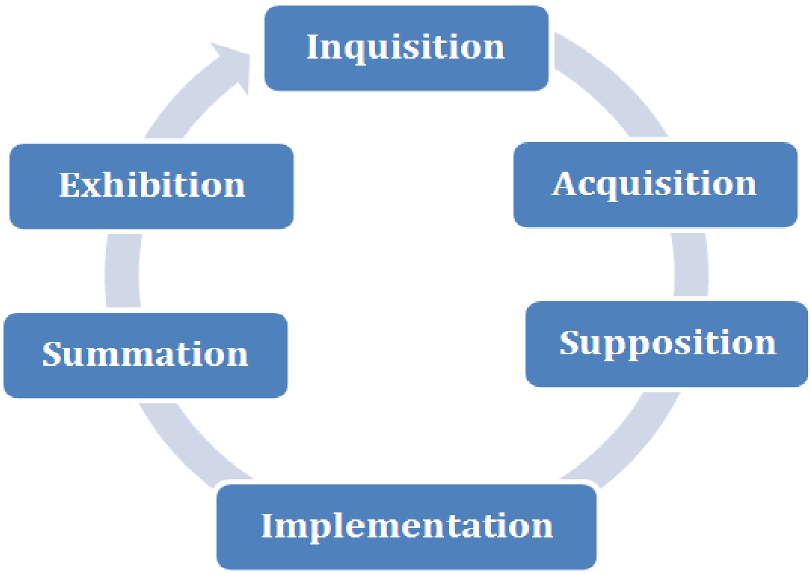


Figure 3: Six-step model by Llewellyn (2005)

Inquisition involves students' setting a question or problem that they want to solve. This phase initiates the inquiry process. In the acquisition step students use their prior knowledge to brainstorm solutions to the problem. Supposition is the next stage and involves students developing a hypothesis to test. Implementation follows when students design experiments or develop a plan of action. The Summation stage involves students experimenting, recording and analyzing their data and observations and they establish whether their hypothesis can be supported by their results. The Exhibition stage involves students communicating and explaining their results to others in a variety of methods and media. Students can enter and re-enter the cycle at various stages throughout their investigation as their inquiry process continues (Llewellyn, 2005).

There are also a significant number of approaches originating from a variety of learning contexts, such as collaborative or individual inquiry; real or simulated environment; curriculum guided or not. Murdoch (2007) proposes 7 steps of social inquiry for implementation in groups and integration of investigation to the curriculum (Figure 4).

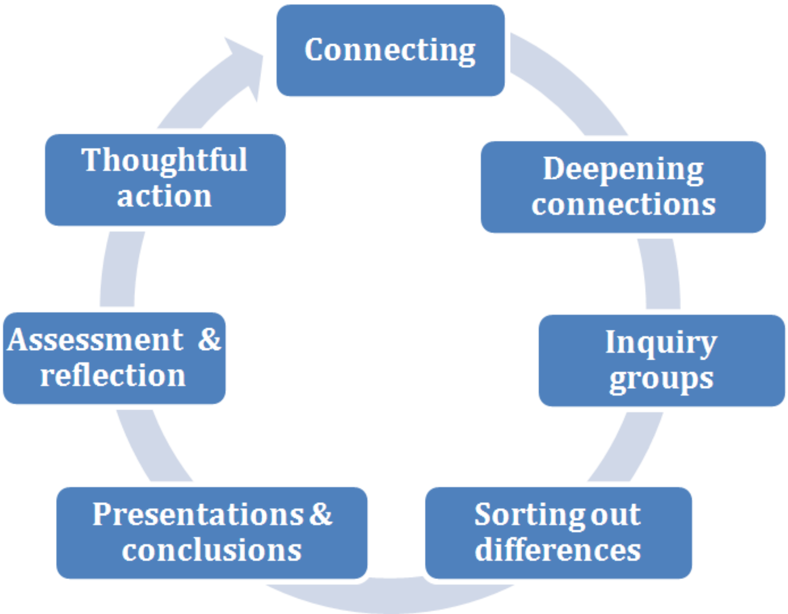


Figure 4: Seven-step inquiry cycle by Murdoch (2007)

Mulholland et al. (2012) highlight the inquiry cycle based on an 8-phase model, comprised by initial topic selection, question or hypothesis, method, data collection, data analysis, conclusions, communication of findings and reflection upon the method of inquiry (Figure 5). This model was based on the cyclic, octagonal representation of the inquiry process developed in the Personal Inquiry (PI) project (Scanlon, Anastopoulou, Kerawalla, & Mulholland, 2011).

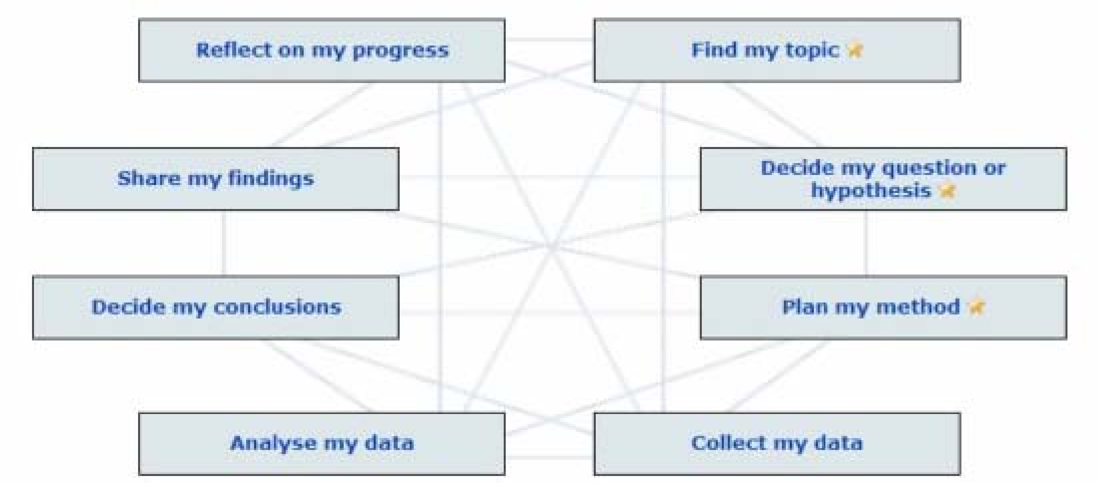


Figure 5: Eight-phase inquiry model by Mulholland et al (2012)

The find my topic stage requires from learners to define the topic of their investigation. This may be a free choice or may be from a domain selected by the teacher. The next phase, decide my inquiry question or hypothesis is where learners formulate their hypothesis or key question. Then the model includes the plan my methods stage. Here learners are required to choose the equipment, methods, and actions that they will need to undertake in order to respond to their research question or hypothesis. Following learners need to collect evidence using the methods and equipment decided upon in the previous phase. The fifth stage called analyse my data. In this stage, the learner analyses their data using various tools and represents their data using different forms of representation, graphs, tables, maps, or diagrams etc. The next stage is called decide my conclusions. Here learners' address their original research question or hypothesis, and conclude whether it is supported by the collected data. The following stage is named share my findings. Here the learner communicates their finding to others. The final stage of the model is named reflect on my progress. In this phase, the learner reflects in a variety of ways with the aim of evaluating their progress and understanding. They may reflect on the success of their methods, the relevance of their research question or hypothesis, or the suitability of their chosen data representations (Scanlon, Anastopoulou, Kerawalla, & Mulholland, 2011).

The eight phase model (Scanlon et al. 2011; Mulholland et al., 2012) implies access to the phases at any point and it is used with nQuiry software. It replicates the scientific process very closely and allows learners to proceed not necessarily through the steps in order. However, includes reflection as a separate phase rather than as an integrated process in each phase.

5.3. Knowledge-building community model

Knowledge-building community model is based on the socio-constructivist approach. The model (Scardamalia & Bereiter, 1994) suggests a way to organize instruction so that student initiated contributions to the collective knowledge and peer evaluation of knowledge produced is possible. Knowledge forum is their technological response to the needs of building a Knowledge Building (KB) community through "knowledge-building discourse". The model focuses on the collaborative aspects of IBL, building communities that support the IBL process, but it does not outline any steps for applying IBL.

5.4. The Inquiry Model

The Inquiry Model was first presented in the nineties (Alberta Education, 1990) and it has been updated since (Alberta Education, 2004).

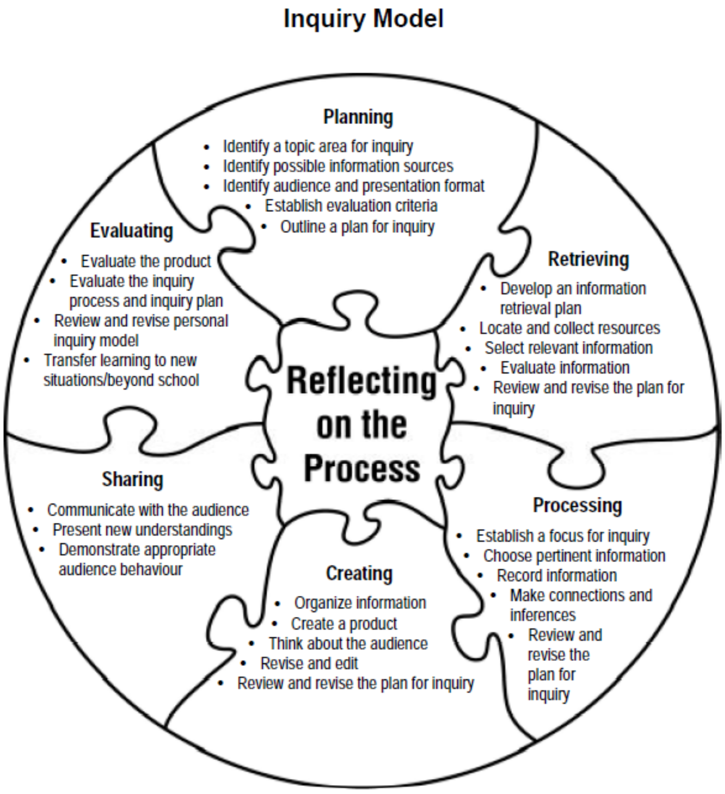


Figure 6: Inquiry Model (Alberta Education, 2004)

The Alberta inquiry model places reflection at the centre of the enquiry process and it consists of seven phases. It sees reflecting on the process as an integral to all phases in the Inquiry. Planning, Retrieving, Processing, Creating, Sharing and Evaluating include both the affective and cognitive domains associated with metacognition (Alberta Education, 2004). At the planning phase students need to find a topic or an area that they are interested in and understand that the underlying purpose of inquiry-based learning. At the next phase students should think about the information they have and the information they need to find. The next phase is the processing phase. Here students required to find a “focus” on the topic or scientific area that would like to investigate. They need to narrow down the topic and create hypothesis. Then they move on to the creating phase. Here learners need to organize the information, rephrase them and create a presentation format. After the creating phase they proceed to the sharing phase. In this phase students required to communicate their work to a wider audience. The final phase of the Alberta Education inquiry model consists of the evaluating phase. At this phase students required to reflect on the evaluation of their product and their inquiry process. They need to understand and question the evaluation criteria, to identify the steps in their inquiry process, and to share their feelings about the process (Alberta Education, 2004).

The Alberta model follows the cyclistic approach but it places reflection at the centre of the inquiry process which is an essential aspect of scientific inquiry. However, it seems that the model deals with the theoretical aspects of the enquiry process, focusing mainly on identifying and discovering relevant information, synthesise, present and communicate them, rather than on real scientific inquiry which embraces scientific methods, data collection and experimentation and sees them as the foundation of the scientific enquiry, which is the focus of the weSPOT project.

5.5. Stripling Model of Inquiry

The Stripling (2003) Model of Inquiry follows a process that progresses through phases, but is recursive and reflective throughout. The model constitutes from 6 distinctive phases (see Figure 7): connect, wonder, investigate, construct, express, and reflect. In the connect phase students are introduced to the possibility of interpreting and questioning an information source. At the wonder phase they will develop focus questions to guide their investigation. Following at the investigate phase learners will use a combination of primary and secondary sources to pursue their questions in depth. The next phase, the construct phase, requires from students to organize and draw conclusions from the information they have found, to confront conflicting ideas and form their own evidence-based opinions, and to be ready to take a stand and defend it. The Express phase is requires from students to demonstrate their learning and communicate their results in various forms and formats. At the end of the model a reflect phase is envisage. Reflection is embedded throughout the inquiry process, but it is especially important at the end of a learning experience for students to think about what they have learned about the topic or idea and about inquiry itself.

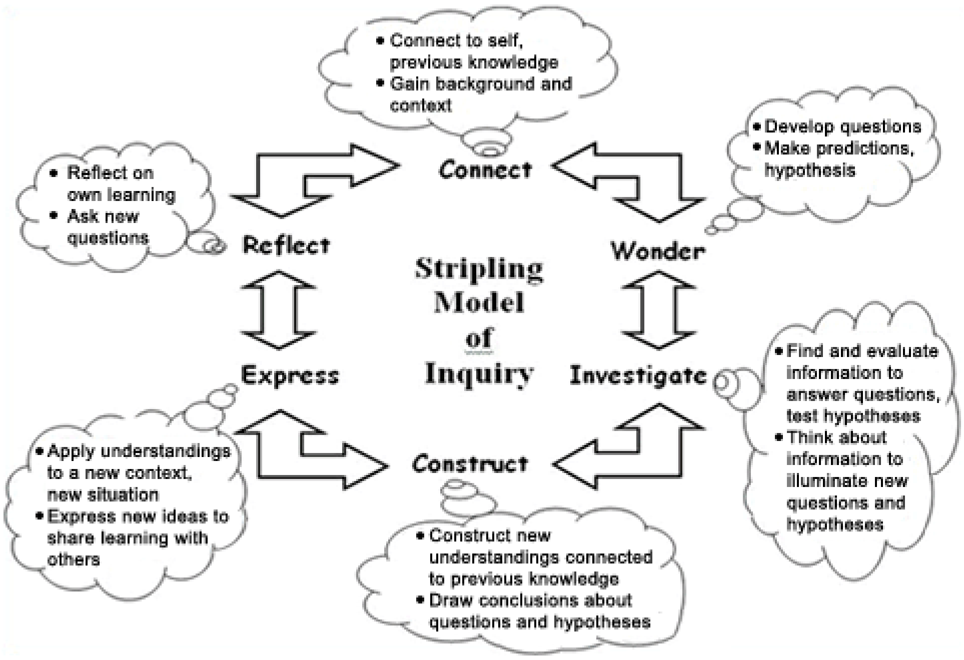


Figure 7: The Stripling Model of Inquiry (Stripling, 2003)

The stripling model follows the cyclistic approach and even though supports reflection throughout the inquiry process it also sees it as a distinct phase at the end of the enquiry process, which might produce the false impression since reflection is integral in every inquiry phase. Furthermore, it focuses on theoretical aspects of the enquiry process, mainly on information rather than an active enquiry that embraces discovery of knowledge via experimentation and it sees it as an integral part of scientific enquiry, which is the view of the weSPOT approach.

5.6. Scaffolded Knowledge Integration (SKI)

In the SKI framework, learners are viewed as adding to their repertoire of ideas and reorganising their knowledge web about science. Students organise and reorganise their ideas with the help of instruction, experience, observation, and reflection (Linn & Hsi, 2000). The framework is organised around four principles: (a) making science accessible for students, (b) making thinking visible for students, (c) providing social supports for students, and (d) promoting lifelong science learning (Williams & Linn, 2002, p. 416). The SKI framework provides a theoretical background for applying inquiry rather than a model that outlines the main scientific processes.

5.7. Learning by Design (LBD)

Learning by Design involves students in a design challenge that students need to solve by using their prior knowledge either individually or in groups. The teacher acts as a facilitator and helps students to compare and contrast their ideas, identify what they need to learn to move forward in addressing the design challenge, choose a learning issue to focus on, and design and/or run a laboratory activity to examine that issue (Kolodner, et al., 1998). The discussion provides an opportunity for the teacher to identify gaps in the learning process and begin scaffolding.

The LBD model has two major connected components a design/redesign cycle and an investigation cycle. The cycles constitute of exploratory and experimental work, followed by reflection stage, application of what was learned, evaluation of that application, and generation of additional learning issues.

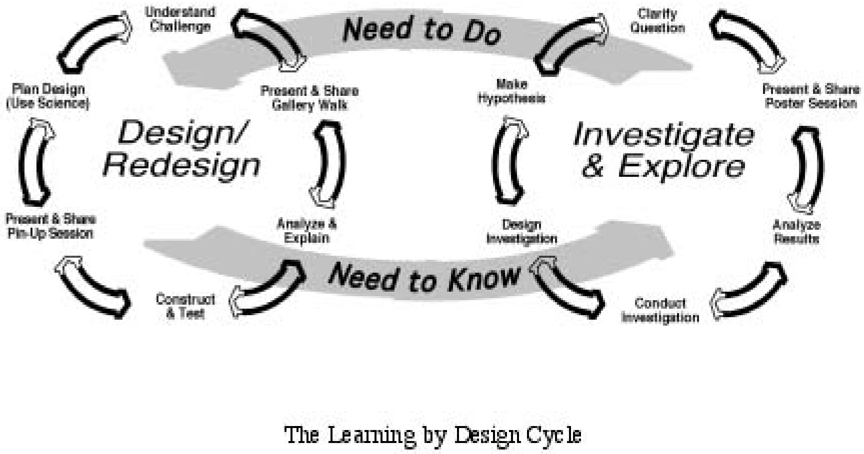


Figure 8: Learning by Design model (Kolodner, et al., 1998)

The model consists of two cycles of exploratory and experimental work, followed by reflection on what has been learned, application of what was learned to achieving the design challenge, evaluation of that application, and generation of additional learning issues (Kolodner, et al., 1998). Potential solutions to the design challenge are attempted in each cycle and evaluated by building and testing a model or actual device; comparing different design alternatives based on qualitative and/or quantitative understandings; or analyzing using established design guidelines or the ratings of experts (Kolodner, et al., 1998, p. 18). Within the cycle students have several opportunities to share their work with others and hear their feedback and ideas.

The LBD model focuses more on the design of a product or an application rather than on scientific inquiry. Construction and trial of real devices would give students the opportunity to experience uses of science, test their conceptions and discover the gaps in their knowledge but it won't show them the enquiry processes. Furthermore, the model is using the practices of problem-based learning (PBL) (Kolodner, et al., 1998) which are only part of inquiry-based learning.

5.8.Dialogic inquiry

Wells (2001) has developed a framework for dialogic inquiry (Figure 9) and divides the process of inquiry into three stages ('research', 'interpret' and 'present'). Each stage has stated aims and activities, along with the types of dialogue that could be used to achieve these. The model therefore uses collaboration as an important driver for supporting the inquiry learning process.

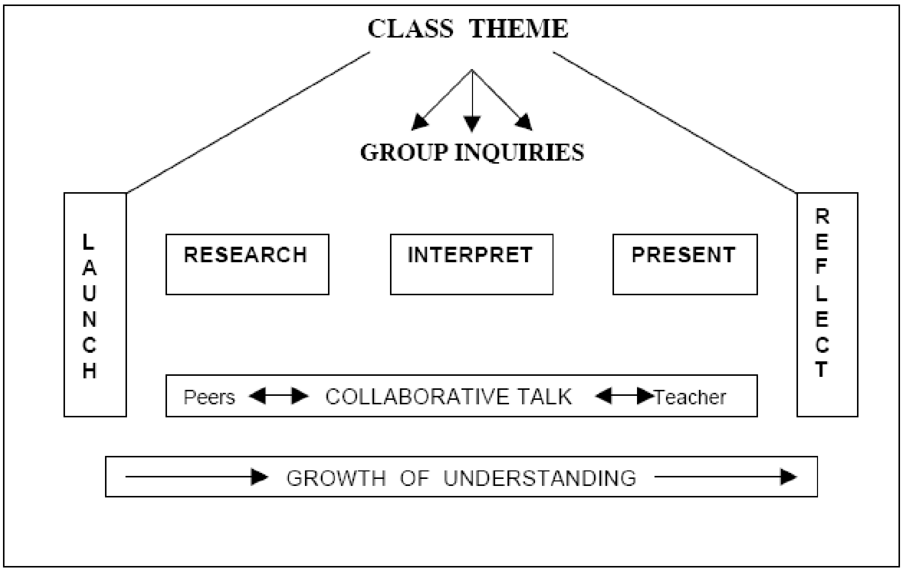


Figure 9: Dialogic inquiry model

"Dialogic inquiry" is an educational approach that acknowledges the dialectic relationship between the individual and the society, and an attitude for acquiring knowledge through communicative interactions. Wells (1999) points out that the predisposition for dialogic inquiry depends on the characteristics of the learning environments, and that is why it is important to reorganize them into contexts for collaborative action and interaction.

6. INQUIRY-BASED LEARNING AND TECHNOLOGY

Inquiry-based learning can occur with or without technology. But technology can play a special role in supporting inquiry-based learning and in transforming the learning process. To better understand the context in which technology can support inquiry-based learning, two important distinctions should be noted: technology can be viewed as the subject of instruction or as a tool for instruction, and can serve as an amplifier of traditional practice or as a transforming agent.

ICT technologies are creating new opportunities for students to engage in serious inquiry (Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000), to undertake aspects of inquiry that it would be impossible to do otherwise (Novak & Gleason, 2001) and transform the labs from passive teaching areas of science to a dynamic and hands-on, authentic areas of investigation and discovery (Barstow, 2001). The interactive nature of computer technology can support students in carrying out inquiry-based activities, using topics, questions, and even theories that they themselves define and develop. Also offers to the teachers the right equipment to act as facilitators, allowing the student to be engaged in a more realistic scientific inquiry experience (Kubicek, 2005).

Computer-supported learning environments make it easier for students to propose their own research topics or areas, produce their own data, produce new questions and alternative explanations and thus replicate scientific processes and methods in more realistic environments. It can support teacher on guide and sustain the scientific process and demonstrate its validity to everyday life.

New technologies like the World Wide Web change the impression that science consists of unchanged facts and theories, impression that traditional textbooks might have created. The Web much more effectively represents the fluid character of science by its ability to revise information continuously and to provide access to multiple sources sometimes contradictory. It can provide access to older scientific work in form of reports, data, presentations and articles together with the most recent ones on the same topic, offering the opportunity to explore how scientific data, models and theories are created, modified and refined over time. Demonstrating that science is ever changing, old theories and models can be updated, modified or ever become obsolete (Kubicek, 2005). The Web also provides access to resources from a wide variety of perspectives, demonstrating how social and cultural factors might influence science and how multiple inferences can be drawn from the same set of observations.

Computer technology can facilitate the collection of data and manipulation of variables in experiments and models. Learners can predict, observe, and explore the effects of experimental parameters on dependent variables in more complex experiments than could ordinarily be replicated in the classroom and perform much more complex analysis (Kubicek, 2005).

Simulation are also another technology depended tool that can support science and its teaching. When used can allow teachers to demonstrate the impacts of the choice of variables used in an experiment. Since simulations are used by scientists themselves, an understanding of their strengths and their limitations is also useful to developing a more informed perspective on an important method of science investigation. Simulations can also be used to further an understanding of the nature of science by facilitating the use of different methods to investigate the same issue (Chinn & Malhotra, 2002). The use of simulations can assist the teacher in shifting the emphasis to "thinking, conjecture and talk about scientific method, about the reasons, limitations and benefits of carrying out controlled experimentation, and about qualitative interpretation of evidence" (Miller, 2001, p. 194). However, simulations should not be used to replace real experiences, but rather to supplement them.

Models are another important tool used in science to communicate and understand scientific processes and construct knowledge and often used in conjunction of simulations. Research shows that models are important in the development of science concepts (Raghavan & Glaser, 1995; Driver et al., 1996; Gilbert et al., 1998) and the understanding of scientific processes (Thomas, 2001). Computers enable learners/students to develop scientific models with multiple variables, test them by running through simulations, refine them and therefore become informed of how scientific inquiry proceeds via experimentation works (Thomas, 2001). Research suggests that when using computer simulations and modelling, students tend to develop new strategies for solving problems, complete tasks of greater cognitive complexity, test personal hypotheses by making predictions, develop higher-order thinking skills, and engage in complex causal reasoning (Cox, 2000).

Social media and other communication tools such as wikis, blogs, emails etc. can facilitate synchronous and asynchronous communication between learners, teachers and scientists, give access and create communities of practice, which in turn creates added potential to enrich discussions on science and its subjectivity, its social/cultural embeddedness, methods, observations and inferences. Students can interact with other students, teachers, and scientists, thus increasing the array and diversity of approaches brought into the classroom, and providing access to expert advice, diverse knowledge sources, and multiple representations (Feldman, et al., 2000; Breuleux, 2001). The communication of students with scientist can results in more effective integration of the nature of science into learning programmes (Barab & Hay, 2001; Cohen, 1997; Evans et al., 1999; Moss et al., 1998; Moss, 2003). Furthermore, it can facilitate interactions with students in other schools can enhance opportunities for collaboration which is a fundamental feature of scientific work. Collaborative electronic learning environments can provide students with experiences of "co-construction of shared understanding" (Thomas, 2001, p.33), can support a shift in focus from whole-group to small-group interaction, and can encourage teamwork and collaborative inquiry (Levin & Thurston, 1996). Such interactions should be designed to integrate with pedagogical objectives, and can complement open-ended inquiry activities (Kubicek, 2005). Interactions with practicing scientists can provide an added source of expert information, open a window on examples of real science, and even help to break down certain myths and misconceptions about the discipline or the topic under consideration. Scientists often use different methods, have different views and approaches on science, and interactions with them can also support a better understanding of the nature of science (NOS).

Technology can contribute to a better understanding of abstract concepts, such as atoms or genes, which are difficult to understand because they are unobservable. Such concepts are theoretical constructs based on experimentation, and technology can facilitate their observation and provide the means for experimentation. This is useful in because it increases the cognitive connections between data and the real world (Kubicek, 2005). Other phenomena which are also unobservable in the classroom due to scale or accessibility can equally benefit by the use of technology.

Electronic databases, permit students to gather second-hand data quickly and independently, thus allowing them to spend more of their time analyzing, interpreting and predicting than on mechanical tasks of data collection. Databases which are designed to allow student to insert their own data and keep their own records, record the intermediate products of their investigations, as well as their plans, hypotheses, and observations (Edelson, 2001) can save time and facilitate reflection and discussion.

Simulated experiments and virtual labs can save time for both teacher and students normally spent on setups, cleanups and other tedious procedures of lab work (Kubicek, 2005). Tools such as sensors, mobiles and portable devises, previously only available to scientists, permit students to directly interact with the environment and collect new first-hand data within a practical time- frame. Such experiences are very valuable and have the potential to transform the way science is taught in the classroom since it offers the opportunity to the students to engage into real scientific processes and collect real data, something that a few years ago was only available to few or even only scientists due to high cost and availability of such devices. Mobile devices and technology has made such tolls widely available and, if used within the right context and with the right pedagogical approaches can provide a truly realistic scientific experience. For example, students can use such tools to visit a local area and collect measurements, analyze, compare and discuss the results. They also can record images, video, sound, take notes, use GPS technology and mapping software to record information and use them latter in the class.

Immersive technologies such as Augmented Reality (AR) are often used to enrich the experience and display otherwise hidden phenomena. It allows the interaction between the real and the virtual world, enhancing a person's perception of the surrounding world and is able to display relevant information at the appropriate time and location. By interacting with the virtual objects learners can not only visualize invisible physical quantities but can also control the conditions that need to be met in order for a phenomenon to occur (e.g. learners by rotating a miniature wing at different angles can see through the airflow augmentation on the wing, why planes fly) (Lazoudis & Panagea, 2011). AR allows students and teachers to interact and do doing things that are not possible. It allows for potential learning opportunities that cannot possibly exist without the assistance of technology. For example students can view and manipulate the structure of a hemoglobin molecule. Such and interaction would not normally be possible without the use of such technology.

However, the answer to the question, "Can technology has significant effect on learning?" is yes as long as one determines the models of teaching and learning that underlie the instruction in the classroom. Pedagogy is the key element in applying the use of technology effectively. Looking at the interaction between pedagogy and technology so far, one can conclude that traditional pedagogy has not improved much by the addition of technology. Good pedagogy, on the other hand, can be made significantly more effective by appropriate uses of technology.

When technology and learning are combined using inquiry-based learning, the following guidelines can be very effective:

- Technology is considered a tool, much like pen and paper, but considerably more powerful, flexible and adaptable.
- The use of the technology is usually taught using solving problems approach.
- Students assist one another with the mechanics of the technology and they might be the experts.
- Talk about technology is as important as the technology itself.
- Talk about how to find information using technology is as important as the information itself.
- Technology is used to assist communication either within the classroom or by expanding audience.

If technology is used in balance with real experience, though, and is placed in its proper context, it can enrich the classroom by providing new and contrasting contexts in which to understand experiences (Feldman, Konold, & Coulter, 2000).

7. EXEMPARY CASES OF IBL AND IBT IMPLEMENTATIONS

Technology has played a major part in realising learning environments based on advanced approaches to learning and instruction, modelling based on simulated experiments (as in Co-Lab) or hypermedia environments (as in WISE), in collaborative scientific inquiry (as in LET'S GO) contextual learning with mobile devices such as PDAs, GPS receivers, digital cameras, and mobile subnetbooks (as in the PI project), Emerging Learning Objects, ELOs (as in SCY) etc. This section describes exemplary examples of IBL instantiations and/or tools and digital environments for IBL is based on accounts of implementations of IBL as given in research publications.

7.1.PI-project

Description and (learning) activities

In the PI-project (http://www.pi-project.ac.uk/) the nQuire technology toolkit is used to support personal inquiries (PIs) that students (aged 11-14) themselves develop in a semi-formal (outside school/class) context, but that are supported by teachers and researchers. Personal Inquiry is interpreted as giving learners opportunities to design inquiries that are meaningful to them. The project involves tracking and supporting students' inquiries across different contexts (school, home, field trips etc.): starting an inquiry, gathering and assessing evidence, conducting experiments and engaging in informed debate. Concrete learning activities that were supported in the described scenario's (partly scripted in the tool and partly face-to-face): make predictions, plan an inquiry (including constraints), operationalize variables, reflect, select and collect data, represent data and analyze data (Sharples & Scanlon, 2010).

Learning objectives and targeted (IBL-)skills

The following objectives and/or skills are mentioned in the literature:

- Re-visualising everyday things as the object of scientific inquiry
- Be able to deal with challenging problems and competing sources of evidence
- Being able to engage in critical activities (e.g. assessing and collecting evidence)
- Reason about and make sense of the complex world
- Ability to think and act in ways associated with inquiry: asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analysing alternative explanations, communicating scientific arguments (Jones & Brader-Arje, 2002, p. 195).

Tools

nQuire: software tool that enables students guided by teachers to design and run science inquiries at school, at home, or outdoors on mobile devices. Students are guided through the inquiry process. Teachers can choose from a set of ready-made inquiries for their students, modifying them as they need, or creating their own new inquiries. They can also monitor their students' progress through inquiries, and give them access to new parts as they complete each stage. Developers can create new inquiries for students and teachers to use, and extend and develop the open source nQuire system to achieve their own goals (Mikroyannidis et al., in press).

7.2. LET’s GO

Description and (learning) activities

The aims of the LET’s GO-project (Maldonado & Pea, 2010) are to provide a learning environment and tools for secondary school students to participate in collaborative scientific inquiry (formulate questions and hypotheses, collect, analyse, discuss, reflect upon and compare data) while studying problem topics in environmental and ecological sciences and to support teachers in designing such environments.

Learning objectives and targeted (IBL-) skills

To design learning activities by using a co-design methodology with different stake-holders involved in the whole process (Pea, et al., 2012).

- “Foregrounding the social nature of inquiry” and the “social construction of identity for participants as inquiring learners in science” (p. 106)
- “Enhanced opportunities for scientific inquiries, systems thinking and conceptual change” (p. 107)

Tools, instruments and methods

- Sensors for real-time data capture and display (http://research.cens.ucla.edu/research/)
- Information visualization techniques for data analysis and sense-making
- Low-cost mobile computers and smart-phones for field-based science
- Geo-tagged digital photos and videos for documenting field settings for research.
- Interactive/collaborative analysis of data (p. 109)

7.3. Co-lab

Description and (learning) activities

Co-lab is a Web-based environment for collaborative inquiry based learning in several natural science domains (water management, greenhouse effect, mechanics and electricity). This environment was implemented at secondary schools (upper level) and was used in a number of research experiments (Manlove, Lazonder, & de Jong, 2007; 2009).

The Co-lab environment includes a sequence of 10-30 hour courses designed for studying in this environment, some of the courses comprising several modules of different complexity levels. The environment includes mechanisms for student support and guidance as collaboration prompts that help participants to explain their thoughts, make reasoning explicit.

Co-lab supports collaboration in working on scientific problems together independent of time and place (from working with peers in the same class, school to distributing activities between school, home, etc. Collaborative learning between different schools, towns, regions and countries is also facilitated. Co-Lab environment also contains tools for supporting reflection and self-regulation, including collaboration prompts that help students explain their thoughts, make the reasoning more precise and uncover misconceptions.

As reported in a number of publications (Manlove, Lazonder, & de Jong, 2007; 2009) students worked on science related inquiry learning tasks collaborating with peers, sharing acquired understanding and solutions. Students started their inquiries by selecting a goal and sub-goals and proceeded through the inquiry process guided by prompts and cues.

Learning objectives and targeted (IBL-)skills

Go through the inquiry process in a simulated environment; develop knowledge of selected science domains; develop self-regulation skills and collaborative learning skills.

Tools and instruments

The CoLab environment is an integrated tool suite for inquiry learning and data collection as tools for simulation, modelling, visualisation and presentation of graphical information. It also includes tools for collaboration as a whiteboard collaboration tool, a chat tool and a control tool to keep track of actions of different learners. Furthermore it includes tools for information gathering and writing (Report Tool). The Co-Lab supports regulative activities, planning, monitoring and evaluation.

7.4. Learning with SCY (Science created by you) environment

Description and (learning) activities

The core idea of the project is that learners develop domain knowledge, inquiry skills and deep insights in the domain and underlying learning science models by designing learning objects that represent their advancing knowledge, and by reflecting on what they produce and what is produced by others (Wasson, Vold, & de Jong, 2012).

Inquiry forms the starting point in the learning and design process in the course of which learners construct series of (learning) products (the so called Emerging Learning Objects, ELOs, as concept maps, tables with data etc.) and a final product, an artefact.

For this purpose learners go through the inquiry cycle phases of formulating questions and hypotheses, gathering and processing information, designing and conducting experiments, interpreting results and communicating conclusions.

The start of a project is presentation of a challenge or a SCY-Mission such as Create a Healthy Pizza of *Design a CO2-friendly house* (Wasson, Vold, & de Jong, 2012). To perform the task learners navigate in the SCY learning environment moving from one task to another designing ELOs until they reach the target by designing the target product. For different tasks they get support in the environment (either background information or task descriptions and prompts, feedback, tagging ELOs etc.). When a learner invites other learners to collaborate, additional support and communication tools become visible (chat window). Learners share access to all artefacts, which they discuss, on which give each other feedback thus engaging in collaborative learning and using special feedback and both peer- and self-assessment tools.

Learning objectives and targeted (IBL-)skills:
Scientific skills: formulate a hypothesis, design an experiment, collect data, interpret data, and communicate the results. Meta-cognitive skills: reflection, self-assessment, planning.

Tools and instruments
SCYSIM – a variant of the SimQuest simulation tool designed to run and display simulation models, on which learners can perform experiments by modifying model variables and observing the results.

SCY-Map – a concept mapping tool for collaborative concept mapping. This tool aids elaboration and communication and comparison of knowledge between group members who construct a concept map together.

Data processing and visualisation tool – a tool that enables students to process and visualise numerical data sets by producing scatter plots, charts, etc. The tool also enables learners to compile descriptive statistics.

Further the environment includes communication tools (SCY-chat) and assessment tools (Scy portfolio).

7.5. Stanford Mobile Inquiry-based Learning Environment (SMILE)

Description and (learning) activities
Stanford Mobile Inquiry-based Learning Environment (SMILE) (Seol, Sharp, & Kim, 2011a; 2011b) enables students to generate, share, and evaluate multimedia-rich inquiries. It consists of an assessment/inquiry maker which allows students to create their own inquiries or homework items based on their own learning. All student-created multimedia inquiry items can be tagged by the generator and can be rated by peers to indicate how relevant or useful the item is to their own learning.

The student-generated questions are collected, passed out to the whole class and all students take a quiz created by all students and also give rating to each question based on standard rule made by local level. After students' answers are submitted, they can review their results immediately.

Through creating their own questions and sharing them with peers, students are able to check their understanding of what they learned for the day and compensate their lack of learning from peers' questions. After the activity, the teacher can give more additional information and detailed explanations to the class which helps them improve their understanding. The application also permits teachers/facilitators to review the student-generated homework items from the homework pool, weed out the ones that may not be relevant and leave only the ones that are highly useful or ones with highest student ratings (Seol, Sharp, & Kim, 2011a; 2011b).

Learning objectives and targeted (IBL-) skills:

SMILE mainly aims at engaging students in critical reasoning and problem solving by enabling them to generate, share, and evaluate multimedia-rich inquiries. Through the learning activities and especially by generating and exploring their own scientific questions, students engage in scientific reasoning, evaluate their peers feedback, develop collaborative learning skills and in this way deepen their understanding on scientific issues.

Tools and instruments

SMILE consists of two elements: a mobile-based application for the students called Junction Quiz and an activity management application for the teacher called the Junction Quiz controller. All components of this system are connected to an ad-hoc network, which introduces a temporary local connection supported by a wireless network router. This type of network is rapidly deployable, self-configuring, and does not require any existing network infrastructure. Open-source Apache software is used for the application server (Seol, Sharp, & Kim, 2011a; 2011b).

Through Junction Quiz students can write their own questions, with four possible solutions. When all students finish writing their questions and their newly-created questions are sent to the server. Students then solve questions and rate them. Once all students have completed this, students can view a summary of their results and see which questions they answered correctly or incorrectly. They can also view detailed information about individual questions including how many students answered each correctly and average ratings. Students can also view who answered the most questions correctly and whose question received the highest ratings.

The Junction Quiz Controller, on the other hand, serves to manage and save data from the activity via an ad-hoc network. It is a Graphic User Interface-based application that can be launched on and operated from any desktop, laptop, or notebook on which Java is installed. The application basically allows the teacher to control and monitor all of the students' activity in real time. It also allows the teacher to save the data from a given activity for later access.

7.6. Web-based Inquiry Science Environment (WISE)

Description and (learning) activities

Web-based Inquiry Science Environment (WISE) is an online platform for designing, developing, and implementing science inquiry activities by the University of Berkeley (http://wise.berkeley.edu/webapp/index.html). WISE provides a simple user interface, cognitive hints, embedded reflection notes and assessments, and online discussions, as well as software tools for activities such as drawing, concept mapping, diagramming, and graphing. WISE can also incorporate interactive simulations and models built in a variety of modern web technologies.

Learning objectives and targeted (IBL-) skills:
WISE projects promote student self-monitoring through collaborative reflection activities and teacher feedback. Some of its features are the following:

-Predict, Observe, Explain and Reflect: Students write and justify predictions, describe observations of data collected, and use evidence to explain changes to their predictions.

-Critique and Feedback: Students develop criteria to evaluate divergent claims in terms style, purpose, and sources of evidence. Based on these criteria, they write critical responses to the work of their peers.

-Science Narratives: Students write coherent narratives that require them to select key events, and to attend to their order and coherence.

-Challenge Questions: Students evaluate the quality of different scientific explanations and are automatically redirected to relevant activities to improve their understanding.

Tools and instruments
1. Argument Organizers & Explanation Generation Tools:

-Idea Manager: A graphic organizer that guides evaluation of evidence in terms of content, source, and connection to claims. The Idea Basket provides a persistent space for students to collect and sort multimedia information. The Explanation Builder provides an organizing space that scaffolds argument formulation using evidence in their Idea Basket.

-WISE Draw and Flipbook Animator: Students create drawings, take snapshots to create animation frames, and play back their flipbook-style animations. In doing so, students are guided to translate their arguments into different representational forms.

-MySystem: A diagramming tool to visualize sequences of events, and guide the writing of verbal narratives. Translating between different representational forms helps students recognize both the abstract structure of narrative, as well as the key content details.

-Inquiry and Role-Play: WISE projects investigate personally meaningful driving questions. Students take on roles of scientists to investigate compelling phenomena, helping students to view science as accessible, which can enhance their motivation to achieve.

-Peer Critique and Feedback: Students are anonymously assigned work from their peers to analyze and critique. Practice generating criteria and giving feedback on other's work helps develop critical evaluation skills, as well as collaborative knowledge building.

-Debate, Brainstorm and Discussion: Students share written explanations and feedback with their peers. They are encouraged to elaborate and build upon one another's ideas.

2. Rich Media & Interactive Simulations

- Virtual Experiments: Similar to the activities of professional scientists, students plan and conduct experiments and gather data to support their claims. Prompts and graphic organizers scaffold students' interactions with rich simulations and models of complex scientific phenomena.

-Multimedia Texts: Curriculum designers can customize and embed media-rich artefacts relevant to the target content in each project (e.g. animations, images, diagrams, graphs, videos, external web pages, and narrative text). Supported by scaffolding tools, students gain fluency in abstracting information from various representational forms.

8. DISCUSSION OF INQUIRY-BASED LEARNING

The crucial aim of weSPOT is to provide learning and research framework for "young researchers" which allows them to explore "scientifically" specific aspects of their physical environment, in the mood of inquiry based learning within a networked and mobile world. The scientific exploration process can take place independently, or in collaboration with others. It can be self directed or guided by others (e.g. teachers, instructors etc.).

Two main trends exist in higher education according to Spronken-Smith and Walker (2010), the first is a move towards more student-centred learning (Biggs, 2003; Ramsden, 2003), while the second is a call for stronger links between teaching and disciplinary research (e.g. Badley, 2002; Boyer Commission, 1999; Brew, 2003, 2006; Jenkins, Healey & Zetter, 2007; Healey & Jenkins, 2009; Rowland, 1996).

Inquiry-based learning has been promoted as a student-centred pedagogy which can both enhance student learning outcomes, particularly the development of higher order skills (Justice, Rice, & Warry, 2009; Prince & Felder, 2006; Spronken-Smith et al., 2008a, b), as well as strengthen the teaching–research connection (e.g. Healey, 2005; Healey & Jenkins, 2009; Jenkins et al., 2003). The approach of the weSPORT consortium is ambitious to enhance both, student-centered learning and teaching-research connection by focusing on the scientific aspects and processes of IBL and bringing the students closer to the scientific process

From a science perspective, inquiry-oriented instruction engages students in the investigative nature of science. As Novak suggested some time ago (1964), "Inquiry is the [set] of behaviors involved in the struggle of human beings for reasonable explanations of phenomena about which they are curious." So, inquiry involves activity and skills, but the focus is on the active search for knowledge or understanding to satisfy a curiosity (Haury, 1993). 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).

Using the stages and levels of inquiry sequences, teachers can implement inquiry practices in the science classroom. Teachers thereby help students learn inquiry skills by modelling successively more sophisticated forms of inquiry. Students develop increased understanding by moving through progressively more sophisticated levels of inquiry and carrying out various stages of inquiry repeatedly. As the level of intellectual sophistication required to conduct the various levels of inquiry grows, the locus of control shifts from teacher to student (Wenning, 2007).

Inquiry-based programs at the middle-school grades have been found to generally enhance student performance, particularly as it relates to laboratory skills and skills of graphing and interpreting data (Mattheis & Nakayama, 1988). Evidence has also been reported that shows inquiry-related teaching effective in fostering scientific literacy and understanding of science processes (Lindberg, 1990), vocabulary knowledge and conceptual understanding (Lloyd & Contreras, 1985, 1987), critical thinking (Narode et al., 1987), positive attitudes toward science (Kyle et al., 1985; Rakow, 1986), higher achievement on tests of procedural knowledge (Glasson, 1989), and construction of logico-mathematical knowledge (Staver, 1986).

Justice et al. (2007) commented that inquiry-based learning refers to both a process of seeking knowledge and new understanding, as well as a method of teaching. Thus, they saw inquiry-based learning as similar to research, and as a way to integrate research and teaching where both students and teachers are 'compatriots in the search for knowledge' (p. 202).

Healey (2005) argued for greater use of research-based teaching using inquiry-based learning. He argued that higher education should place more emphasis on pedagogies that are either research tutored or research-based (including learning through inquiry) – since these models have the most benefit for student learning.

The weSPOT approach adopts a similar view and it aims to connect real research and learning by providing an IBL model based on the processes of the well established scientific research method. The weSPOT IBL model will be presented in the deliverable D2.3.1.

8.1. REQUIREMENTS ON A IBL MODEL FOR SUPPORTING TECHNOLOGY-ENHANCED LEARNING

weSPOT addresses the meaning of inquiry-based learning through the research process, it aims at promoting IBL and Science Education by taking advantages of technology-based learning approaches and needs to assist towards the effort of connecting students with the communities of inquiry (experts, students, peers). Therefore and despite the large number of very valuable and validated IBL Models, the weSPOT project needs to develop a conceptual and pedagogical model to a) assist the development of effective technologies for supporting the scientific process and b) and support to overcome some pedagogical weaknesses IBL education can have.

Requirements on the model for supporting the conceptualization and development of technology for supporting the inquiry-based learning (RT).

RT1: The model should support the development process in a bi-directional modus, i.e. the technology supports the operationalisation of the model in real teaching situations and the model supports the design and testing of innovative technology (obviously following a pedagogical justification).

RT2: The model has a high level of details, supporting its translation to technical specification and the conceptualisation of system components for supporting the different aspects of the IBL process.

RT3: The model supports the development of a highly adaptive IBL environments, i.e. is adaptable according to the pedagogical setting (target, age groups involved, IBL experience of the learners, duration of the activity, nature of the discipline, etc.).

Pedagogical requirements on the model for supporting novel inquiry-based learning enhanced by technology and overcoming IBL pedagogy weaknesses (RP).

RP1: The model supports effectively the planning of teaching and learning activities.

RP2: The model supports a pedagogically adequate activation of the learners.

RP3: The model supports different levels of inquiry (from guided to open).

RP4: The model supports the development of a technology system assisting memorization (by annotation) and categorization of complex processes for avoiding cognitive overload.

RP5: The model supports the integration of new knowledge with existing one. Especially important for students with a low level of knowledge or expertise in a certain domain.

RP6: The model supports the debriefing o an experiment by linking domain knowledge and experiment.

RP7: The model supports and promotes collaboration and cooperation in the learning process.

9. REFERENCES

American Association for the Advancement of Science. (1989). *Science for all Americans.* New York: Oxford University Press.

Alberta Education. (1990). *Focus on research: A guide to developing students' research skills.* Edmonton, AB: Alberta Education. http://www.library.ualberta.ca/documents/focusonresearch.pdf (accessed 15/12/12).

Alberta Learning. (2004). *Focus on inquiry: A Teacher's Guide to Implementing Inquiry-based Learning.* Edmonton, AB: Alberta Education. http://education.alberta.ca/media/313361/focusoninquiry.pdf (accessed 03/02/13).

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry? Journal of Science Teacher Education, 13(1), 1-12.

Alford, R. (1998). *The Craft of Inquiry: Theories, Methods and Evidence.* New York: Oxford University Press.

Atkin, J. M., & Karplus, R. (1962). Discovery or invention? Science Teacher, *29*(5), 45-51.

Badley, G. (2002). A really useful link between teaching and research. *Teaching in Higher Education 7*(4), 443–55.

Banchi, H. & Bell, R. (2008). The Many Levels of Inquiry. *Science and Children, 46*(2), 26-29.

Bateman, W. (1990). *Open to Question: The Art of Teaching and Learning by Inquiry.* San Francisco: Jossey-Bass.

Barab, S. A., & Hay, K. E. (2001). Doing science at the elbows of experts: Issues related to the science apprenticeship camp. *Journal of Research in Science Teaching, 38*(1), 70–102.

Barstow, D. (Ed.). (2001). *Blueprint for change: Report from the national conference on the revolution in earth and space science education.* Cambridge, MA: TERC.

Berlyne, D. E. (1966). Curiosity and exploration. *Science. 153*, 25-33.

Biggs, J. (2003). Teaching for quality learning at university. Maidenhead: Open University Press.

Bodzin, A., & Beerer, K. (2003): Promoting inquiry-based science instruction (STIR). *Journal of elementary science, 15*(2), 39-49.

Boyer Commission. (1999). *Reinventing undergraduate education: A blueprint for America's research universities.* Stony Brook, NY: Carnegie Foundation for the Advancement of Teaching.

Breuleux, A. (2001). Imagining the present, interpreting the possible, cultivating the future: technology and the renewal of teaching and learning. *Education Canada, 41*(3), 1-8.

Brew, A. (2003). Teaching and research: New relationships and their implications for inquiry based teaching and learning in higher education. *Higher Education Research and Development, 22*(1), 3–18.

Brew, A. (2006). *Research and teaching: beyond the divide.* London: Palgrave Macmillan.

Bruce, B. C., & Bishop, A. P. (2002). Using the Web to Support Inquiry-based Literacy Development. *Journal of Adolescent and Adult Literacy, 45*(8), 706–714.

Bybee, R. (1997). *Achieving Scientific Literacy: From Purposes to Practices*. Portsmouth, NH: Heinemann Educational Books.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: a theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175-218.

Cohen, K.C. (Ed.) (1997). *Internet links for science education: Student–scientist partnerships*. New York: Plenum.

Conole, G., Scanlon, E., Kerawalla, L., Mulholland, P., Anastopoulou, S., & Blake, C. (2008). Inquiry learning models. *World Conference on Educational Multimedia, Hypermedia and Telecommunications 2008* (pp. 2065–2074). Chesapeake, VA: AACE.

Cox, M. (2000). Information and communications technologies: their role and value for science education. In M. Monk & and J. Osborne, (Eds). *Good practice in science teaching – what research has to say.* Buckingham, England: Open University Press.

Dewey, J. (1933). *How We Think: A Restatement of the Relation of Reflective Thinking to the Educative Process*. Boston, MA: Heath.

Dewey, J. (1938). Logic: The theory of inquiry. New York: Holt, Rinehart and Winston.

Dewey, J. (1916/2009). *Democracy and education: An introduction to the philosophy of education.* New York: WLC Books. (Original work published 1916)

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science.* Bristol, PA: Open University Press.

Duschl, A. R., & Osborne, J. (2002). Supporting and Promoting Argumentation Discourse in Science Education. *Studies in Science Education, 38*(1), 39-72.

de Jong, T. (2006). Computer simulations - Technological advances in inquiry learning. *Science, 312*(5773), 532-533.

Edelson, D. C. (2001). Learning-for-use: a framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching, 38*(3), 355-385.

Edelson, D., Gordin, D., & Pea, R. (1999). Addressing the challenge of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences, 8*(3/4), 391-450.

Evans, C. A., Abrams, E. D., Rock, B. N., & Spencer, S. L. (1999). *Student/Scientist Partnerships: A Teacher's Guide to Evaluating the Critical Components.* Unpublished manuscript of the University of New Hampshire, Durham, NH.

Feldman, A., Konold, C., & Coulter, B. (2000). *Network science, a decade later – the Internet and classroom learning.* Mahwah, New Jersey: Lawrence Erlbaum Associates.

Furth, H. G. (1969). *Piaget and knowledge; theoretical foundations.* Englewood Cliffs: Prentice-Hall.

Gilbert, J. K., Boulter, C., & Rutherford, M. (1998). Models in explanations, Part 1: Horses for courses? *International Journal of Science Education, 20*, 187–203.

Glasson, G. E. (1989). The effects of hands-on and teacher demonstration laboratory methods on science achievement in relation to reasoning ability and prior knowledge. *Journal of Research in Science Teaching, 26*(2), 121-131.

Grady, T. R. (2003). *An Interpretation of Dewey's Experiential Learning Theory*. ED481922. http://www.eric.ed.gov/PDFS/ED481922.pdf (accessed 22/03/13).

Grandy, R., & Duschl, R. (2007). Reconsidering the Character and Role of Inquiry in School Science: Analysis of a Conference. *Science & Education, 16*(2), 141–166.

Haury, D. L. (1993). *Teaching Science through Inquiry.* ERIC/CSMEE Digest. http://www.uhu.es/gaia-inm/invest_escolar/httpdocs/biblioteca_pdf/14_HAURY[1].1993%20TEACHING%20SCIENCE%20THROUGH%20INQUIRY.pdf (accessed 07/04/13).

Healey, M. (2005). Linking research and teaching to benefit student learning. *Journal of Geography in Higher Education, 29*(2), 183–201.

Healey, M., & Jenkins, A. (2009). *Developing undergraduate research and inquiry. Research Report to the Higher Education Academy*. York: Higher Education Academy. http://www.heacademy.ac.uk/assets/York/documents/resources/publications/DevelopingUndergraduate_Final.pdf (accessed 15/04/13).

Herron, M.D. (1971). The nature of scientific enquiry. *School Review, 79*(2), 171- 212.

Hiebert, J., Carpenter, T. P., Fennema, E., Fuson, K., Human, P., Murray, H., Olivier, A., & Wearne, D. (1996). Problem solving as a basis for reform in curriculum and instruction: The case of mathematics. *Educational Researcher, 25*(4), 12-21.

Huber, R. A., & Moore, C. (2001). A model for extending hands-on science to be inquiry-based. *School Science and Mathematics, 101*(1), 32-42.

Jones, A., Blake, C., & Petrou, M. (2012). Inquiry learning in semi-formal contexts. In Littleton, K., Scanlon, E., & Sharples, M. (Eds). *Orchestrating inquiry learning.* (pp. 193-213). London: Routledge.

Jones, M. G., & Brader-Araje, L. (2002). The impact of constructivism on education: Language, discourse and meaning. *American Communication Journal, 5(*3), 1-9.

Justice, C., Rice, J., & Warry, W. (2009). Academic skill development – Inquiry seminars can make a difference: Evidence from a quasi-experimental study. *International Journal of Scholarship of Teaching and Learning, 3*(1), 1–23.

Jenkins, A., Breen, R., Lindsay, R., & Brew, A. (2003). *Re-shaping higher education: Linking teaching and research.* London: RoutledgeFalmer.

Jenkins, A., Healey, M., & Zetter, R. (2007). *Linking teaching and research in disciplines and departments*. York: The Higher Education Academy.

Kirschner, P. A. (1992). Epistemology, practical work and academic skills in science education. *Science & Education, 1*(3), 273–299.

Kirschner, A.P., Sweller, J., & Clark, E.R. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist, 41*(2), 75-86.

Kolodner, J. L., Crismond, D., Gray, J., Holbrook, J., & Puntembekar, S. (1998). Learning by Design from Theory to Practice. Proceedings *International Conference of the Learning Sciences* (pp. 223-229).

Krajcik, J., Marx, R. W., Blumenfeld, P., Soloway, E., & Fishman, B. (2000). Inquiry based science supported by technology: Achievement among urban middle school students. Paper presented at the *American Educational Research Association*, Ann Arbor, Michigan.

Kubicek, P. J. (2005). Inquiry-based learning, the nature of science, and computer technology: New possibilities in science education. *Canadian Journal of Learning and Technology, 31*(1). http://cjlt.csj.ualberta.ca/index.php/cjlt/article/view/149/142 (accessed 03/02/13).

Kyle, W. C., Jr., Bonnstetter, R. J., McCloskey, J., & Fults, B. A. (1985). What research says: Science through discovery: students love it. *Science and Children, 23*(2), 39-41.

Lazoudis, A., & Panagea, D. (2011). The “Science Center To Go” project. *EDEN - 2011 Open Classroom Conference*, October 27 – 29, Athens, Greece, 7-12.

Lee, V. S., (Ed.) (2004). *Teaching and Learning through Inquiry: A Guidebook for Institutions and Instructors.* Sterling, Virginia: Stylus.

Lee, V.S., Greene, B. D., Odom, J., Schechter, E., & Slatta, W. R. (2004). What is inquiry guided learning? In V.S. Lee (Ed.), *Teaching and learning through inquiry: A guidebook for institutions and instructors*, (pp. 3–16). Sterling, VA: Stylus.

Levin, J. A., & Thurston, C. (1996). Research summary - educational electronic networks. *Educational Leadership, 54*(3), 46-50.

Levy, P. (2009). *Inquiry-based learning: A conceptual framework. Centre for Inquiry-Based Learning in the Arts and Social Sciences*. University of Sheffield. http://www.sheffield.ac.uk/content/1/c6/09/37/83/CILASS%20IBL%20Framework%20%28Version%204%29.doc (accessed 10/04/2013).

Lindberg, D. H. (1990). What goes 'round comes 'round doing science. *Childhood Education, 67*(2), 79-81.

Linn, M. C. (1995). Designing computer learning environments for engineering and computer science: The scaffolded knowledge integration framework. *Journal of Science Education and Technology, 4*(2), 103-126.

Linn, M. C., & Hsi, S. (2000). *Computers, Teachers, Peers.* Mahwah, NJ: Erlbaum.

Llewellyn, D. (2005). *Teaching High School Science through Inquiry, A Case Study Approach.* Thousand Oaks, Ca: Corwin Press.

Lloyd, C. V., & Contreras, N. J. (1985). The role of experiences in learning science vocabulary. Paper presented at the *Annual Meeting of the National Reading Conference.* San Diego, CA, ED 281 189.

Lloyd, C. V., & Contreras, N. J. (1987). What research says: Science inside-out. *Science and Children, 25*(2), 30-31.

Maldonado, H., & Pea, R. (2010). LET'S GO! to the creek: Co-design of water quality inquiry using mobile science collaboratories. http://www.stanford.edu/~kiky/WMUTE2010-MaldonadoPea.pdf (accessed 19/04/13).

Manlove, A., Lazonder, A.W., & de Jong, T. (2007). Software scaffolds to promote regulation during scientific inquiry learning. *Metacognition Learning, 2*(2-3)*,* 141-155.

Manlove, S., Lazonder, A. W., & de Jong, T. (2009). Trends and issues of regulative support use during inquiry learning: Patterns from three studies. *Computers in Human Behavior, 25*(4), 795-803.

Mattheis, F. E., & Nakayama, G. (1988). *Effects of a laboratory centered inquiry program on laboratory skills, science process skills, and understanding of science knowledge in middle grades student.* (ED 307 148).

Mayer, R. (2004). Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. *American Psychologist, 59*(1), 14–19.

McLeod, S. A. (2009). *Jean Piaget | Cognitive Theory*. http://www.simplypsychology.org/piaget.html (accessed 28/03/13).

Mikroyannidis, A., Okada, A., Scott, P., Rusman, E., Specht, M., Stefanov, K., Protopsaltis, A., Held, P., & Hetzner, S. (2013, in press). weSPOT: A Personal and Social Approach to Inquiry-Based Learning, *Journal of Universal Computer Science Special Issue on Cloud Education Environments.*

Miller, K. (2001). ICT and science education. – New spaces for gender. In A. Loveless & V. Ellis (Eds.), *ICT, pedagogy and the curriculum.* London: Routledge Falmer.

Moss, D. M. (2003). A window on science: exploring the JASON Project and student conceptions of science. *Journal of Science Education and Technology, 12*(1), 21-30.

Moss, D. M., Abrams, E. D., & Robb-Kull, J. (1998). Can we be scientists too? Secondary students' perceptions of scientific research from a project-based classroom. *Journal of Science Education and Technology*, *7*(2), 149–161.

Mulholland, P., Anastopoulou, S., Collins, T., Feisst, M., Gaved, M., Kerawalla, L., Paxton, M., Scanlon, E., Sharples, M., & Wright, M. (2012). nQuire: technological support for personal inquiry learning. *IEEE Transactions on Learning Technologies, 5*(2), 157–169.

Murdoch, K. (2007*). A basic overview of the Integrated Inquiry planning model.* http://www.inquiryschools.net/page10/files/Kath%20Inquiry.pdf (accessed 31/01/2013).

Narode, R., Heiman, M., Lochhead, J., & Slomianko, J. (1987). *Teaching thinking skills: Science.* Washington, DC: National Education Association. (ED 320 755).

National Science Board. (1991). *Science & engineering indicators-1991*. Washington, DC: U.S. Government Printing Office. (NSB 91-1).

National Research Council. (1996). *National science education standards*. Washington, DC: National Academic Press.

National Research Council (2000). *Inquiry and the National Science Education Standards: A guide for teaching and learning.* Washington, DC: National Academies Press.

Neill, J. (2005). *500 word summary of Dewey's "Experience & Education."* http://wilderdom.com/experiential/SummaryJohnDeweyExperienceEducation.html (accessed 25/04/13)

Novak, A. (1964). Scientific inquiry. *Bioscience, 14*, 25-28.

Novak, A. M., & Gleason, C. I. (2001). Incorporating portable technology to enhance an inquiry, project-based middle school science classroom. In R.F. Tinker & J.S. Krajcik (Eds), *Portable technologies – Science learning in context.* New York, N.Y: Kluwer Academic/Plenum Publishers.

Okada, A. (2008). Scaffolding School Pupils' Scientific Argumentation with Evidence-Based Dialogue Maps. In: Okada, A., Buckingham, S. S. & Sherborne, T. (Eds.). *Knowledge Cartography: software tools and mapping techniques*, London: Springer.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argument in school science. *Journal of Research in Science Teaching, 41*(10), 994-1020.

Osborne, J., Simon, S. A., & Monk, M. (2005). *Enhancing the Quality of Argument in Science Lessons*. Final report to ESRC (R000237915).

Pea, R., Milrad, M., Maldonado, H., Vogel, B., Kurti, A., & Spikol, D. (2012). Learning and technological designs for mobile science inquiry collaboratories. In Littleton, K., Scanlon, E., Sharples, M. (Eds). *Orchestrating inquiry learning* (pp. 105-127). London: Routledge.

Piaget, J. (1936). *Origins of intelligence in the child.* London: Routledge & Kegan Paul.

Piaget, J. (1973). *Main Trends in Psychology*. London: George Allen & Unwin.

Powell, K. C., & Kalina, C. J. (2009). Cognitive and Social Constructivism: Developing Tools for an Effective Classroom*. Education, 130*(2), 241-250.

Prince, M.J., & Felder, M. R. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education, 95*(2), 123–138.

Protopsaltis, A. (2006*). Reading in Web-based Hypertexts: cognitive processes, strategies and reading goals.* PhD thesis, University of Westminster, School of Electronics and Computer Science. http://westminsterresearch.wmin.ac.uk/9362/

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J. S., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D., & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences, 13*(3), 337–386.

Raghavan, K. & Glaser, R. (1995). Model-based analysis and reasoning in science: the MARS curriculum. *Science Education, 79*(1), 37–61.

Rakow, S. J. (1986). *Teaching science as inquiry. Fastback 246.* Bloomington, IN: Phi Delta Kappa Educational Foundation, ED 275 506.

Ramsden, P. (2003). Learning to teach in higher education. London: RoutledgeFalmer.

Rocard,M., Csermely,P., Jorde,D., Lenzen,D., Walwerg-Heriksson,H., & Hemmo,V. (2007). Science education now: a renewed pedagogy for the future of Europe. *European Commission: Directorate-General for Research, Science, Economy and Society.* Brussels.

Rowland, S. (1996). Relationships between teaching and research. *Teaching in Higher Education, 1*(1), 7–20.

Savery, J. R. (2006). Overview of Problem-based Learning: Definitions and Distinctions. *Journal of Problem-based Learning, 1*(1). Available at: http://dx.doi.org/10.7771/1541-5015.1002

Scanlon, E., Anastopoulou, S., Kerawalla, L., & Mulholland, P. (2011). How technology resources can be used to represent personal inquiry and support students' understanding of it across contexts. *Journal of Computer Assisted Learning, 27*(6), 516-529.

Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. *The Journal of the Learning Sciences, 3*(3), 265-283.

Schank, R. C. (1999). Dynamic memory revisited. New York: Cambridge University Press.

Schwab, J. J. (1962). The teaching of science as enquiry. In J.J.Schwab & P.F. Brandwein (Eds.). *The teaching of science* (pp. 3-103). Cambridge: Harvard University Press.

Selby, R. (2010). *Experiential Management Learning*. Unpublished Doctoral Thesis. http://www.blisty.cz/files/2012/05/25/selby-richard-2010.pdf (accessed 24/04/2013).

Seol, S., Sharp, A., & Kim, P. (2011a). Stanford Mobile Inquiry-based Learning Environment (SMILE): using mobile phones to promote student inquires in the elementary classroom. *2011 International Conference on Frontiers in Education: Computer Science & Computer Engineering, FECS 2011.*

Seol, S., Sharp, A., & Kim, P. (2011b). Stanford Mobile Inquiry-based Learning Environment (SMILE): using mobile phones to promote student inquires in the elementary classroom. Proceedings of *WORLDCOMP'11: The 2011 World Congress in Computer Science, Computer Engineering, and Applied Computing.* http://gse-it.stanford.edu/research/project/smile (accessed 19/04/13).

Sharples, M., & Scanlon, E. (2010). *Final Report Personal Inquiry (PI): Designing for Evidence-based Inquiry Learning across Formal and Informal Settings*. http://www.psychology.nottingham.ac.uk/staff/Claire.O'Malley/Claire_OMalley/Personal_Inquiry_files/Personal%20Inquiry%20-%20Final%20Report%20now%20available.pdf (accessed 20/04/13)

Singer, D. G., & Revenson, T. A. (1997). *A Piaget Primer: How a Child Thinks* (Revised Edition). Madison, Connecticut: International Universities Press Inc.

Spronken-Smith, R. (2007). *Inquiry-based Learning: Meaning, Theoretical Basis and Use in Higher Education* (pp. 1–17). Wellington.

Spronken-Smith, R., Bullard, J., Ray, W., Roberts, C., & Keiffer, A. (2008a). Where might sand dunes be on Mars? Engaging students through inquiry-based learning in geography. *Journal of Geography in Higher Education, 32*(1), 71–86.

Spronken-Smith, R.A., Walker, R., Batchelor, J., O'Steen, B., Angelo, T., & Matthews, H. (2008b). *Inquiry-based learning*. Prepared for the New Zealand Ministry of Education. http://akoaotearoa.ac.nz/projects/inquiry-based-learning (accessed 16/04/13).

Spronken-Smith, R., & Walker, R. (2010). Can inquiry-based learning strengthen the links between teaching and disciplinary research? *Studies in Higher Education, 35*(6), 723-740.

Staver, J. R. (1986). The constructivist epistemology of Jean Piaget: Its philosophical roots and relevance to science teaching and learning. Paper presented at the United States-*Japan Seminar on Science Education,* Honolulu, HI, ED 278 563.

Stripling, B. K. (2003). "Inquiry-Based Learning." In B. K. Stripling & S. Hughes-Hassell (Eds.). *Curriculum Connections through the Library* (pp. 3-39). Westport, CT: Libraries Unlimited.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive Science, 12, 257–285.

Tafoya, E., Sunal, D., & Knecht, P. (1980). Assessing Inquiry Potential: A Tool for Curriculum Decision Makers. *School Science and Mathematics, 80*(1) 43-48.

Thomas, G.P. (2001). Toward effective computer use in high school science education: Where to from here? *Education and Information Technologies, 6*(1), 29-41.

Walker, M. (2007). *Teaching inquiry based science*. LaVergne, TN: Lightning Source.

Wasson, B., Vold.V, & de Jong, T. (2012). Orchestration of assessment: assessing emerging learning objects. In Littleton, K., Scanlon, E., Sharples, M. (Eds). *Orchestrating inquiry learning* (pp.175-192). London: Routledge.

Wells, G. (2001). *Action, Talk and Text: Learning and Teaching Through Inquiry*, Teachers College Press. http://people.ucsc.edu/~gwells/Files/Papers_Folder/ATT.theory.pdf (accessed 18/03/13)

Wells, G. (1999). *Dialogic inquiry: Towards a sociocultural practice and theory of education.* New York: Cambridge University Press.

Weaver, F. S., Ed. (1989). *Promoting Inquiry in Undergraduate Learning*. New Directions for Teaching and Learning. San Francisco: Jossey-Bass Inc.

Wenning, J. C. (2007). Assessing inquiry skills as a component of scientific literacy. *Journal of Physics Teacher Education Online, 4*(2), 21-24.

White, B. (1993). ThinkerTools: Causal models, conceptual change, and science education. *Cognition and Instruction, 10*, 1-100.

White, B. Y., Frederiksen, J. R., & Collins, A. (2009). The interplay of scientific inquiry and metacognition: More than a marriage of convenience. In D. Hacker, J. Dunlosky, and A. Graesser (Eds.) *Handbook of metacognition in education* (pp. 175-205). New York: Routledge.

White, B., & Frederiksen, J. (1998). Inquiry, Modeling, and Metacognition: Making Science Accessible to All Students. *Cognition and Instruction, 16*(1), 3-118.

White, B. Y. and Frederiksen, J. R. (2005a). *Modeling, developing, and assessing scientific inquiry skills using a computer-based inquiry support environment*. Final report to the National Science Foundation.

White, B. Y., & Frederiksen, J. R. (2005b). A theoretical framework and approach for fostering metacognitive development. Educational Psychologist, *40*(4), 211-223.

White, B., & Horwitz, P. (1988). Computer microworlds and conceptual change: A new approach to science education. In P. Ramsden (Ed.), *Improving learning: New perspectives* (pp. 69-80). London: Kogan Page.

Williams, M., & Linn, M. C. (2002). WISE Inquiry in Fifth Grade Biology. *Research in Science Education, 32*(4), 415-436.

Woolfolk, A. (2004). *Educational Psychology* (9th Ed). Boston: Allyn and Bacon.