DELIVERABLE D2.3.1: Pedagogical and Diagnostic Framework

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CONTENTS

1. 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 is focused on 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 foreseen weSPOT Toolkit gives smart support for personal scientific inquiry to address a lack of scientific inquiry skills in an age group of 12-25.

The current deliverable, D2.3.1, outlines the pedagogical framework for scientific inquiry. The framework is based on existing IBL models described in D2.1 state of the art, and on the notion that good IBL is closely related to good, well established, research. The crucial aim of weSPOT is to provide a 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 framework is aimed at supporting informal, self-regulated learning settings as well as the embedding in a formal learning context. 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). The difficult and ambitious aspiration is, to give as much freedom in inquiry based learning as appropriate for the individual and, at the same time, to provide as much guidance and orientation as needed, by smart agents. The pedagogical model is adapted to the above framework.

However, the weSPOT project will not only develop a smart and adaptive inquiry support and guidance environment, but also a diagnostic instrument which is able to measure the students' skills and competences related to a meaningful inquiry process. This diagnostic instrument has a threefold objective: first, to provide feedback to the student about his/her own progress in scientific reasoning, second, to provide feedback to the teacher or other learning guide, to be informed about additional support or input needed in different stages of the inquiry process, and third, for the weSPOT project, to provide on one hand a base line for the respective skills and competences present without weSPOT and, on the other hand, the improvement achieved when using the weSPOT approach.

This diagnostic instrument will look at the entire inquiry life cycle which may start with the formulation of a research question and may end with the valorisation of the results and it will cover the four different complexities of inquiry, from confirmation inquiry to open, self directed inquiry. The second part of the deliverable will focus on the diagnostic framework describing the adopted approach. The weSPOT diagnostic instrument for inquiry skills and competences will be used a) to establish a European baseline of the current level of inquiry skills in the target group and b) to demonstrate the potential of the weSPOT-technology for STEM-learning in general.

The work presented in this deliverable constitutes the main basis for informing the technical development of the technology that will assist learners and teachers in their inquiry journey.

2. 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. 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. 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.

2.1 The Structure of the Deliverable

The remainder of this deliverable is structured as follows: first, we review the different definitions of the terms “skills” and “competence”, explore the confusion in the use of the terms in the literature and provide the weSPOT adopted definitions. Next the pedagogical model is outlined and explained followed by examples. In the last section of this deliverable the diagnostic framework is introduced and outlined.

3. IBSC SKILLS AND COMPETENCE IN weSPOT

Inquiry skills and competences are needed to carry out scientific research. To give some examples: research 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. Therefore, defining the terms will allow the consortium to identify necessary skills and competences that suit the weSPOT approach.

This section reviews the different definitions regarding the terms “skills” and “competence”, explores the confusion in using the terms in the literature and suggests the most suitable definitions for the weSPOT consortium.

3.1 Skills

During the course of years’ different definitions of skills have been provided focusing on different aspects. One of the first attempts by Pear (1927) to define skills focused on manual motor activities, defining skill as being concerned with the quantity and quality of motor output, without any cognitive dimension. While, Hans Renold introduced a cognitive dimension defining skill as ‘any combination, useful to industry, of mental and physical qualities which require considerable training to acquire’ (More, 1980, p. 15).

Generally the term skill is used to refer to a level of performance, in the sense of accuracy and speed in performing particular tasks (skilled performance) (Winterton, Delamare - Le Deist, & Stringfellow, 2006).

Skilled performance has long been a subject of psychological research. Bryan and Harter (1897; 1899, in Healy & Weiner, 2007), demonstrated that skill acquisition involves a series of stages associated with reaching a stable level of performance and that improvements continue well beyond achieving an adequate level. Early research on motor skills placed its attention on motor skills and studied telegraphers (Swift, 1904; 1910), manual work (Cox, 1934). Motor skill acquisition has continued to occupy the attention of researchers; increasing understanding of the role of perception, feedback and other factors (Newell, 1991; Schmidt, 1975; 1988).

Welford (1968, p. 12-13), defined skill as a combination of factors resulting in 'competent, expert, rapid and accurate performance', and regarded this as equally applicable to manual operations and mental activities. His work showed how actions are selected and coordinated at different levels of skilled performance and the conditions of practice and training that promote the acquisition and transfer of skill.

More recently, research into skilled performance has increasingly taken into account broader cognitive skills such as problem solving and decision making. Evidence have shown that acquiring skill and demonstrating skilled performance involve a combination of underlying perceptual, cognitive and motor skills (Carlson & Yaure, 1990; Salthouse, 1986). Moreover, knowledge and working memory play a major role in acquiring skills (Chase & Ericsson, 1982) including procedural skills (Carlson, Sullivan and Schneider, 1989), problem-solving skills (Carlson et al., 1990) and complex cognitive skills (Logie et al., 1989; McKeithen et al., 1981).

Fitts and colleagues (Fitts et al., 1961; Fitts & Posner, 1967) developed a framework that describes skill acquisition and includes three phases: the cognitive phase, the associative phase and the autonomous phase. In the cognitive phase, understanding the nature of the task is very important and encompasses conscious cognitive processes. The associative phase refers to inputs linked more directly to appropriate actions and reduced interference from external inputs while the autonomous phase take place when actions become automatic requiring no conscious control (Winterton, Delamare-Le Deist & Stringfellow, 2006).

In the context of the European Qualifications Framework, skills are described as cognitive (involving the use of logical, intuitive and creative thinking) or practical (involving manual dexterity and the use of methods, materials, tools and instruments) (European Parliament, 2008, p. 4).

Proctor and Dutta (1995, p. 18) in their seminal work define skill as 'goal-directed, well-organised behaviour that is acquired through practice and performed with economy of effort'. All these elements are important for the development of skills. They (Proctor & Dutta, 1995) distinguished four different types of skills: perceptual skills, response selection skills, motor skills and problem-solving skills. Perceptual skills are concerned with the ability to make distinctions and judgements; response selection skills are concerned with selecting the appropriate response; motor skills refer the manual aspects of performance; and problem-solving skills are concerned with providing solutions to problems at hand and dependent upon intellect and mental models.

The definition of skill provided by Proctor and Dutta (1995) is the one adopted by the weSPOT consortium and sees skill as a goal oriented and well organised behaviour which is developed through practice and gradually becomes automated.

3.2 Competence

There is much confusion and debate about the concept of competence which makes it very difficult to provide a definition capable of accommodating all the different ways the term is used (Elleström, 1997; Robotham & Jubb, 1996). This terminological confusion often reflects on the use of the term in the literature and its interchangeable use with the term skill. A common confusion of competence is to link it exclusively to the performance of tasks. Another approach is to think of competence as the attribute that underlines performance. A preferred way might be to link these two approaches and to see competence in terms of knowledge, abilities, skills, and attitudes (Gonczi & Hager, 2010).

White (1959) is credited with having introduced the term competence to describe those personality characteristics associated with superior performance and high motivation. Postulating a relationship between cognitive competence and motivational action tendencies, White defined competence as an 'effective interaction (of the individual) with the environment' and arguing there is a competence motivation in addition to competence as achieved capacity.

There are two approaches when dealing with competencies, one seeing competency as a skill or ability, linked associated to behaviour efficiency (McClellan, 1996; Pearson, 1980; Spencer & Spencer, 1993; cited in Eraut et al., 1998), and another approach which views competence as strategic behaviour, linked to the possibility of adjusting performance to the demands from the context (Guasch, Alvarez & Espasa, 2010).

The latter approach seems better suited to weSPOT approach, since adjusting performance to the demands from the context is part of the educational process. Accepting the social nature of competencies implies that these are the actors – and their expectations – who determine and shape the content of the competencies required to succeed in specific professional contexts (Gonczi et al., 1993; cited in Eraut et al., 1998; Messick, 1984; Westera, 2001).

Some of the differences in the terminology can be attributable to different epistemological assumptions (Pate, Martin & Robertson, 2003) and the rationale for the use of competence often determines the definition (Hoffman, 1999). Furthermore, different cultural contexts often influence the understanding of the term competence (Cseh, 2003). For example, Boon and van der Klink (2002) in the US, and Eraut (1994) in the UK defined competence in terms of sociocultural practices.

Other researchers (Snyder & Ebeling, 1992) refer to competence in a functional sense, but the term in plural, 'competencies'. Others (Boam & Sparrow, 1992; Hendry, Arthur, & Jones, 1995; Mitrani, Dalziel & Fitt, 1992; Smith, 1993) use 'competency' when referring to occupational competence or treat the two as synonymous (Brown, 1993; 1994; McBeath, 1990).

Competence is the proven ability to select, combine and use the appropriate knowledge, skills and other acquisitions (values and attitudes) in order to successfully solve a particular category of work or learning situations and for professional or personal development in terms effectiveness and efficiency (Chiru, Tachiciu, & Ciuchete, 2012). In the context of the European Qualifications

Framework, competence is described in terms of responsibility and autonomy (European Parliament, 2008, p. 4). These three types of learning outcomes are interrelated and, at the same time, there is a certain hierarchy in the process to achieve these results: certain types of knowledge based skills and sets of knowledge and skills lead to the development of a certain competence (European Parliament, 2008, p. 5). Furthermore, competency is frequently associated with effectiveness, efficiency, proficiency and similar terms that suggest favourable outcomes for the individual (Weinert, 2001).

Dale and Iles (1992) distinguish occupational skills from psycho-social characteristics, but use competence and competency to describe both in discussing their role in assessing managerial skills. Hartle (1995, p. 107) argues that competency as 'a characteristic of an individual that has been shown to drive superior job performance includes both visible competencies of knowledge and skills and underlying elements of competencies, like traits and motives'. Elkin (1990) associates competences with micro-level job performance and competencies with higher management attributes and, in defining 'managerial competencies for the future', Cockerill (1989) combines output competences, like effective presentation skills, with input competencies such as self-confidence. It is clear that the multiple interpretations of the term do not only refer to its definition but even to its linguistic characteristics.

Mangham (1986) noted that competence may relate to personal models, outcome models or education and training models, as well as to the standards approach in which benchmarking criteria are used. Mansfield (2004, p. 304) similarly contrasts three different uses of competence: outcomes (vocational standards describing what people need to be able to do in employment); tasks that people do (describing what currently happens); and personal traits or characteristics (describing what people are like).

Weinert (1999, p. 7) lists nine different ways in which competence has been defined or interpreted: general cognitive ability; specialised cognitive skills; competence-performance model; modified competence-performance model; objective and subjective self concepts; motivated action tendencies; action competence; key competencies; meta-competencies.

Competency captures skills and dispositions beyond cognitive ability such as self-awareness, self-regulation and social skills; while some of these may also be found in personality taxonomies (Barrick & Mount, 1991) competencies are fundamentally behavioural and susceptible to learning (McClelland, 1998). At a European level the holistic approach to competence (Gonczi, 1994; Tovey, 1993), combining knowledge, skills and attitudes, is gaining ground over narrower approaches (Engle et al., 2001; Hager, 1994).

For our research within the weSPOT project the definitions by Eraut et al. (1998) and the Directorate for Education, Employment, Labour and Social Affairs Education Committee of the Organisation for Economic Co-operation and Development/DeSeCo (2005), which define competence as a system of complex actions including the knowledge, abilities and attitudes required for the successful completion of tasks seem more suitable. From an educational perspective operational competence is defined as the "ability to make satisfactory and effective decisions in a specific setting or situation" (Kirschner et al., 1997; Westera, 2001). Therefore, competence is interpreted as a function of knowledge, skill, situation, self-confidence and values (Kirschner et al., 1997; Stephenson & Weil, 1992) used to master complex situations.

Competence within the weSPOT project is defined as a set of observable performance dimensions, including individual knowledge, skills, attitudes, and behaviours, as well as collective team, process, and organizational capabilities, that are linked to high performance, and provide the individual with sustainable competitive advantage.

To sum up, in weSPOT **skill** is seen as a goal oriented and well organised behaviour which is developed through practice and gradually becomes automated. Skill is a much narrower term compared to competence and focuses on the ability to use the knowledge to accomplish a task.

Competence on the other hand is defined as a set of observable performance dimensions, including individual knowledge, skills, attitudes, and behaviours, as well as collective team, process, and organizational capabilities, that are linked to high performance.

3.3 weSPOT skills and competences

Inquiry skills help the learner to operate at higher levels in Bloom's (1956) Taxonomy of educational objectives. The lowest level skills are observation and measurement which gather space-time relationships (data). Organization of this data involves communication and classification. Explaining the data obtained uses the skills of making inferences and predictions. Generalizing the explanations makes hypothesis. Hypotheses are tested by experimenting using skills of problem solving, controlling variables, critical thinking, creative thinking, and interpreting data to make operational definitions.

3.3.1 Skills

Skills related to weSPOT project considered by the consortium to be the following. However, this list of skills is not exhausted and will be updated as the project evolves:

- Analytical skills to research a topic, develop a project plan and timeline, and draw conclusions from research results.
- Science skills to break down a complex scientific system into smaller parts, recognize cause and effect relationships, and defend opinions using facts.
- Literacy skills to read and understand non-technical and technical materials.
- Information foraging skills to be able to gather valuable pieces of information from different sources
- Experimentation skills to know the different methodologies and processes required.
- Problem solving skills to overcome obstacles and find solutions
- Mathematic skills for calculations and measurements.
- Attention to detail to follow a standard blueprint, record data accurately, or write instructions.
- Technical skills to troubleshoot the source of a problem repair a machine or debug an operating system, and computer capabilities to stay current on appropriate software and equipment.
- Presentation skills to effectively present information.
- Cooperation skills to listen to others needs or interact with project partners.
- Creative skills/abilities to solve problems and develop new ideas.
- Leadership skills to be able to lead a team.

- Organization skills to keep track of lots of different information.

3.3.2 Competences

Competences related to weSPOT can be the following but the list will be updated as the project develops:

Subject competence

Subject competence includes declarative and conceptual knowledge: a continuum of science knowledge and understanding throughout the various domains of science. When combined, depth and breadth provide an individual profile of science knowledge and understanding (Behrendt et al., 2001).

Research competence

To have research competence one should know how to conduct research with the appropriate methods and conduct it in an effective way (Murtonen, et al., 2008). Research competence requires the ability to apply a variety of analytical skills, mathematical and technical skills, information skills, experimentation skills and knowledge, sometimes to apply creative skills to obtain a solution, presentation skills, collaboration and communication skills especially if working within a team and so on.

Problem solving competence

Problem solving is a competence that requires several skills, knowledge and behaviours to be performed well. For example, to solve problems effectively one must have the skill to define the problem, have knowledge of all possible solutions, and exhibit behaviour that enables him or her to make a decision. Problem solving competence can be applied to technical as well to non technical tasks/areas (Mourtos, De Jong, & Rhee, 2004).

Communication competence

Communication is really a competency that relies on a combination of certain skills, behaviour and knowledge related to inquiry and science (Spektor-Levy, Eylon, & Scherz, 2008). To communicate effectively, for example, a person may need to have domain knowledge, understand cultural diversity, have advanced language skills, behave with patience, have technical skills regarding different presentation media etc.

Critical thinking competence

Critical thinking is purposeful, reasoned, and goal-directed competence. It is the kind of thinking required when solving problems, formulating inferences, calculating probabilities, and making decisions. Critical thinking also involves evaluating the thinking process (Halpern, 1998). Critical thinking competence involves higher order skills, which such as evaluation, analysis, and synthesis; and are not applied in a mechanical manner. Higher order thinking is thinking that is reflective, sensitive to the context, and self-monitored (Halpern, 1998).

3.4 weSPOT skills and competences examples

To elaborate the difference between skills and competence within the weSPOT project we will discuss the terms with a STEM related example.

To present effectively the results from a chemistry project based on IBL taught in the classroom one will need effective presentation skills without necessarily having communication competence, even though presentation skills can be part of the communication competence. When students go through the whole process of inquiry based learning and finish their work on a chemistry topic they will have to present their results to the classroom. To do so effectively they have to have certain presentation skills such as:

use power point, keep the text brief, include graphics, use different media if possible, stand upright in a confident manner, look at your audience, move around a bit, keep eye contact, do not read your presentation, keep your language simple, avoid jargon, prepare, plan, practice etc.

Presentation is a skill that can be obtained through practice, books, and classes. One can have very effective presentation skills without being communication competent. Communication competence requires additional skills and knowledge such as advanced language skills, deeper understanding of cultural diversities, technical skills about different presentation media, collaborative skills etc.

Another example that clarifies the difference between skill and competence in weSPOT can be seen in relation to research competence vs. analytical skills or experimental skills. The topic used here as an example comes from the WeSPOT consortium and is microclimate (Mikroyannidis, et. al., in press).

The aim of this inquiry scenario is to find the best place to have a bench at the school based on Microclimates study. The hypothesis is that the best place is the garden site nearest the school entrance because it is sheltered from the wind but south facing, so it is warm and not windy there. Other places to be considered are: Car park, Canteen, Games area and Reception.

The students need to go through 8 phases (Mikroyannidis, et. al., in press). Different phases require different skills by the learners. For example, at the phase 3, collect data, each team collects the data chosen to measure. To do these measurements, individuals need to have mathematical skills, for the calculations and technical skills for the use of the appropriate tools to make the measurements. By being able to complete this phase learners show that they have and apply the required skills. However, these skills do not imply that learners have research competence since to be research competent requires a much broader array of skills, knowledge and aptitudes such as the ones required for this phase but also analytical skills, experimentation skills, domain specific knowledge, collaboration skills, presentation skills, transfer of skills to different domains and so on.

Basic process skills: observation, classifying, measuring, communication, inferring, and predicting.

Integrated process skills: controlling variables, defining operationally, formulating hypotheses, collecting data, interpreting data, experimenting, and making models.

Inquiry requires a wide variety of processes, like: simplifying and structuring complex problems, observing systematically, measuring, classifying, creating definitions, quantifying, inferring, predicting, hypothesizing, controlling variables, experimenting, visualizing, discovering relationships and connections, and communicating.

From a science perspective, inquiry-oriented instruction engages students in the investigative nature of science. As Novak (1964) suggested "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).

The learning outcomes of inquiry-based learning typically include the development of skills in self-reflection, critical thinking, the ability to undertake independent inquiry, responsibility for own learning and intellectual growth and maturity (Lee, 2004).

4. weSPOT PEDAGOGICAL FRAMEWORK

Inquiry-based learning is a pedagogic and teaching approach based on the instructional method. It has to do with the constructive approach to teaching, 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).

4.1 The WeSPOT IBL approach

The crucial aim of weSPOT is to provide a 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 framework is aimed at supporting informal, self-regulated learning settings as well as the embedding in a formal learning context. 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). The difficult and ambitious aspiration is, to give as much freedom in inquiry based learning as appropriate for the individual and, at the same time, to provide as much guidance and orientation as needed, by smart agents. The pedagogical model is adapted to the above framework.

The call for inquiry learning is based on the certainty that science learning is not about memorisation of scientific facts and information, but rather is about understanding and applying scientific concepts and methods (Bell, Urhahne, Schanze, & Ploetzner, 2010). This emphasis on methods can be traced back up to the work of Dewey (1933, 1938) where he argued that scientific knowledge develops as a product of inquiry. 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”. Nevertheless inquiry “refers to the activities of students in which they develop knowledge and understandings of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 1996, p. 23). Like real scientists, students can study and investigate the natural world, make their own observations, collect and analyse their own data, and propose explanations based on the evidence of their own work.

Furthermore, national guidelines for science education in Europe (Rocard et al., 2007) and in the USA (National Research Council, 2000) underline the value of inquiry learning and place strong emphasis on activities that investigate and analyse science questions. In the same vein, national science education standards were introduced in four main competence areas: domain-specific knowledge, methodological knowledge, communication, and judgement (KMK, 2005). The area "methodological knowledge" includes many inquiry learning related activities and emphasises the importance of this educational dimension.

Since inquiry encompasses the application of scientific methods into studying and investigating problems, topics and areas of interest, an inquiry-based learning model must demonstrate that good scientific inquiry is based on good scientific research and therefore good scientific method.

"Scientific inquiry is more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of 'making a great many careful observations and then organizing them.' It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as 'the scientific method (AAAS, 2009).

The National Science Teachers Association (NSTA, 2004) defines scientific inquiry as "a powerful way of understanding science content. Students learn how to ask questions and use evidence to answer them. In the process of learning the strategies of scientific inquiry, students learn to conduct an investigation and collect evidence from a variety of sources, develop an explanation from the data, and communicate and defend their conclusions" (p. 1), in essence NSTA describes how to conduct scientific inquiry and outlines the basic procedure.

Formal scientific method has its roots at the seminal work of Karl Popper (2002) where he described the notion of falsifiability as an inherent testability of any scientific hypothesis. Falsifiability refers to a statement, a hypothesis or a theory that can be shown or proven false by means of observation or experimentation or both. Poppers approach in science lies in his view that science virtue lies not in caution of avoiding errors, but in ruthlessness in eliminating them (Lakatos & Musgrave, 1971) and adopting a well structured and thorough method does exactly that.

Another seminal work that changed inquiry research came from Kuhn (1970, 1996). He argued that science does not progress in a linear fashion, but undergoes periodic revolutions, also called "paradigm shifts", in which the nature of scientific inquiry within a particular field is suddenly transformed. He argued that science is broken up into three distinct stages. Prescience, which lacks a central paradigm, comes first. This is followed by "normal science", when scientists attempt to enlarge the central paradigm by "puzzle-solving" (Kuhn, 1970). As anomalous results build up, science reaches a crisis, at which point a new paradigm, which subsumes the old results along with the anomalous results into one framework, is accepted. This is termed revolutionary science (Kuhn, 1970).

Scientific inquiry is possible only in an environment in which certain attitudes are developed or tolerated. Successful scientific investigation requires from the investigator certain mental attitudes such as, curiosity, which makes people ask two questions: Why and How, scepticism, which makes people re-examine past explanations and re-evaluate past evidence, and objectivity, which enables them to seek impartially for the truth, to avoid personal preconceptions, prejudices, or influence the interpretation of those facts (Hunt & Colander, 2010).

Scientific investigation is seldom simple. Each field of knowledge has its special problems, and investigators must always adjust their methods to the peculiarities of the situation they are dealing with. The basic procedures of the scientific method are as important in social science as in physical science. Social scientists must observe carefully, classify and analyze their facts, make generalizations, and attempt to develop and test hypotheses to explain their generalizations (Hunt and Colander, 2010). Although there is no ideal structure, a realistic approach to approach a research question in social science is the following: observe, define the problem, review the literature, observe some more, develop a theoretical framework and formulate a hypothesis, choose the research design, collect the necessary data, analyze the results, and draw conclusions (Hunt & Colander, 2010).

These steps differ slightly from those used by a natural scientist, but only slightly—the primary difference comes in testing a hypothesis. In some natural sciences, it is possible to conduct controlled experiments in which the same experiment can be repeated again and again under highly regulated conditions. Nonetheless, the process of formulating hypotheses, testing and analyzing the results, and formulating new hypotheses, seems to be acceptable by the scientific community.

The steps of the scientific method have been reviewed and outlined by Crawford and Stucki (1990) and can be summarised as follows: define a question, gather information and resources (observe), form an explanatory hypothesis, test the hypothesis by performing an experiment and collecting data in a reproducible manner, analyze the data, interpret the data and draw conclusions that serve as a starting point for new hypothesis, publish results, and retest (frequently done by other scientists). Each element of the scientific method is subject to peer review for possible mistakes (Moulton & Schifferes, 1960).

The scientific method is a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge (Goldhaber & Nieto, 2010). To be termed scientific, a method of inquiry must be based on empirical and measurable evidence subject to specific principles of reasoning (Cohen & Whitman, 1999) and therefore an inquiry-based learning model ought to include such principles. 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 & Frederiksen 2005a; 2005b; White, Frederiksen, & Collins, 2009) but it does not offer the complete scientific inquiry process. Therefore another approach that places the scientific processes of inquiry at its centre is needed.

Levy (2009) described an inquiry-based learning framework that revealed two main conceptual frames through which students viewed their experiences, labelled the ‘information’ frame and the ‘discovery’ frame, distinguishing the experience that students have when doing inquiry. When viewed through the information frame, students experienced research and inquiry as the exploration and acquisition of existing disciplinary knowledge, while when viewed through the discovery frame, they experienced research and inquiry as participation in building on, and contesting, that knowledge.

Students' differing experiences are represented by the vertical axis of the matrix below (see Figure 1). The horizontal axis adds a further dimension, classifying students' experiences according to the extent to which their accounts emphasised student- or teacher-led processes. Levy (2009) used the term 'student-led' to refer principally to the framing of the inquiry question, and secondarily to the directing of the inquiry process, by the student. Similarly, 'teacher-led' refers principally to the framing of the inquiry question, and secondarily to the directing of the inquiry process, by the teacher; case scenarios or problems may be used to frame inquiries in more teacher-led contexts (Levy, 2009). The matrix differentiates accordingly between 'responsive' and 'active' modes of both information- and discovery-oriented inquiry, corresponding to four broadly differing modes of student inquiry that are characterised as: Identifying; Pursuing; Producing; Authoring. Depending on the nature and status of the inquiry methods used, in Producing and Authoring modes students may engage in forms of inquiry that count as 'real' research or scholarship in terms of rigour of practice and originality of contribution.

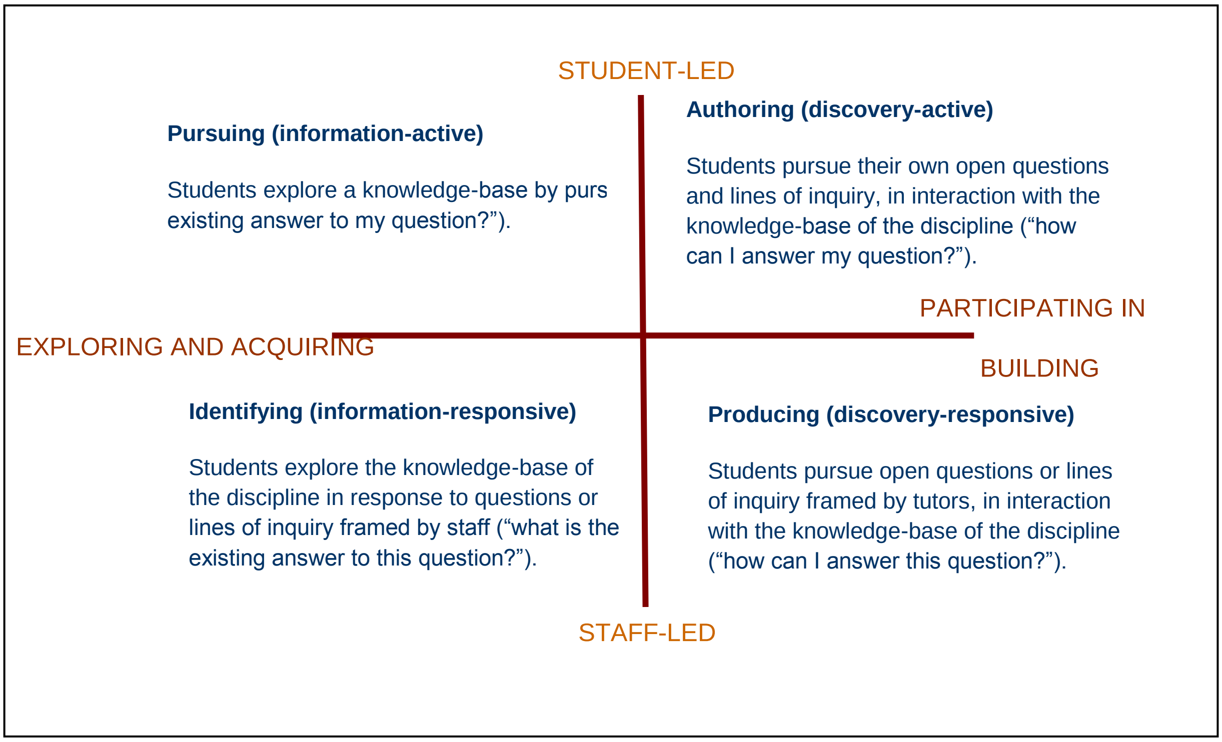


Figure 1: Inquiry-based Learning conceptual framework (Levy, 2009)

The weSPOT pedagogical approach focusing on both dimensions of IBL, teacher-lead and student-lead, but the model is closer to the form of inquiry that according to Levy (2009) count as 'real' research or scholarship in terms of rigour of practice and originality of contribution, which brings closer the student/learner to the real scientific approach.

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 follows the rules of scientific inquiry. It leads finally to structure knowledge about a domain and to more skills and competences about how to carry out research which is efficient and which can be communicated.

4.2 THE weSPOT IBL MODEL

The weSPOT model moves on from the simplistic cyclical models (see D2.1 State of the Art Analysis) because it aims to model the complete scientific inquiry process. The weSPOT model is based on the steps required for good research, steps described in scientific literature (Crawford & Stucki, 1990; Hunt & Colander, 2010) such as, data collection, data analysis, hypothesis forming, communication and dissemination of findings etc. and it is closely related to the inquiry model by Mulholland et al. (2012). It shares many of the phases that Mulholland et al. (2012) described in their model (see D2.1 State of the Art Analysis), such as create a question or a hypothesis, collect data, analyse data, share finding etc., but it is more elaborate regarding the sub-phases providing a detailed description of things that teachers and students should consider when doing inquiry.

The weSPOT inquiry-based learning model consists of the following phases:

Context

Question/hypothesis

- Embedding
- Existing knowledge
- Mental representation
- Language/definitions
- Field of research
- Ethics
- Empirical meaning
- Reflection

Operationalisation (realisation of idea with the aim to measure)

- Indicators
- Predictions
- Resources
- Methodology (of data collection and processing)
- Ethics (Ethical issues)
- Reflection

Data collection

- Information foraging
- Systematic observation
- Experimentation
- Tools
- Simulation

- Data storage
- Data security
- Documentation
- Reflection

Data Analysis (processing)

- Quantitative analysis (Statistical methods/analysis)
- Qualitative analysis
- Tools
- Visualisation
- Noise reduction (of data)
- Reflection

Interpretation/discussion

- Embedding (Embedding into existing theories/results/domain knowledge (classification))
- Confirmation/falsification (of the initial question/hypothesis)
- Significance (statistical)
- Relevance (of the results)
- Threshold
- Exhaustion
- Reflection

Communication

- Strategy
- Audience
- Tools
- Dissemination (Events/Presentation/Publication)
- Discussion
- Feedback (Receiving and reacting)
- Writing up
- Reflection

The weSPOT inquiry-based learning model presented in figure 2, consists of six phases, placed within the context, that mirror the phases that researchers need to go through in order to conduct their research, since inquiry is an integral feature of science. Each phase also consists of a number of activities ranging from five to nine. All the IBL model phases are placed in the context where the different aspects of inquiry can take place. The weSPOT inquiry-based learning model places reflection at the centre of each inquiry phase, see it as an integrated process throughout the inquiry activity and not as an independent phase that comes at the end of the process. The reason is that reflection is vital at every stage of the process even at the very beginning when students need to develop a question or a hypothesis. They need to reflect upon the question, and evaluate it before they decide to proceed. The evaluation can either be individual or collaborative. Additionally, there is bidirectional communication between the different inquiry phases, meaning that students and teachers can move from one phase to the next depending on their needs and their focus without needing to complete a phase.

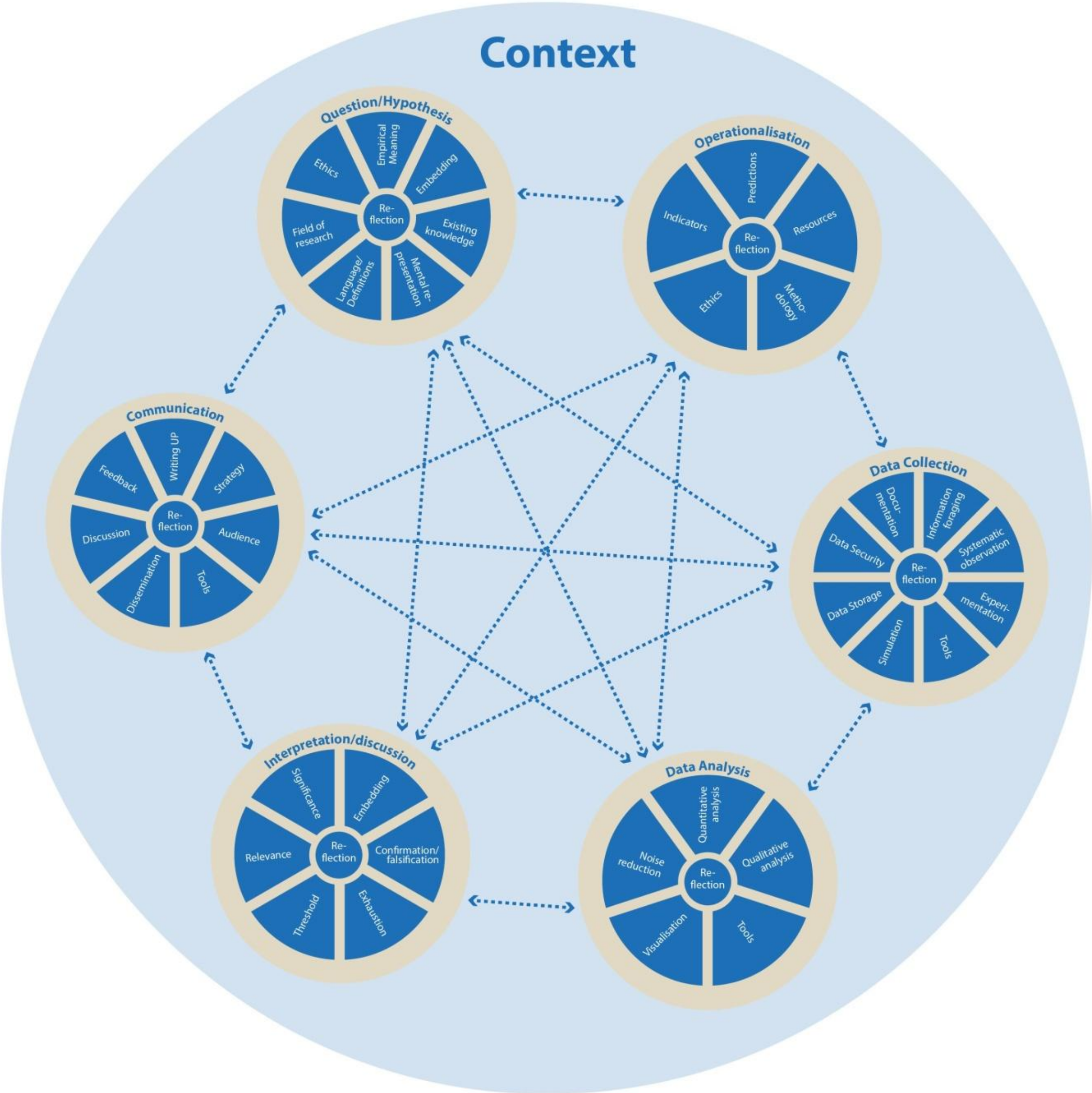


Figure 2: weSPOT inquiry based learning model

4.2.1 Context

Context refers to the physical or theoretical settings of the whole inquiry process, from the formation question or hypothesis, to the settings of the data collection and analysis, to the dissemination of the findings. The question under consideration can come from direct observation from the natural environment or from theoretical discussion/sources during the learning process. Very often science begins with observation. Science is about the real world, and the best way to start getting to know about the real world is to observe it. Context includes all the phases, emphasising the background that the inquiry will take place. Context can also be very important during the phases of data collection and data analysis, and influence the overall inquiry and affect the result of empirical studies.

Dewey (1989) also pointed out in his work of "Context and Thought" the importance of context in conducting empirical work. Being members of a specific culture, researchers are placed within the contexts of their time, their societies, and their individual relationships. He argues that it is never only the close and direct research field which is concerned in scientific examinations, but also the context it is placed in.

4.2.2 Question/hypothesis

The first phase of the weSPOT inquiry-based model consists of the "question/hypothesis". Students/learners decide on a topic or area of interest and try to formulate the questions or hypotheses that would like to pursue. The topic/area under consideration can either come from students direct natural observations or from have a theoretical foundation.

The question can refer to the explanation of a specific observation in nature, as in "Why is the sea blue?", but can also be open-ended, as in "Does light travel faster in air than in water?" This stage also involves reading, reviewing and evaluating previous evidence from other scientists, including experience. If the answer is already known, a different question that builds on the previous evidence can be created. When applying the scientific method to scientific research, determining a good question can be very difficult and affects the final outcome of the investigation (Schuster & Powers (2005).

A hypothesis is an assumption, based on the knowledge obtained while formulating the question, which may explain the observed behaviour of a part of our world or our universe. The hypothesis might be very specific, or it might be broad and it can be related to a population. A scientific hypothesis must be falsifiable, meaning that one can identify a possible outcome of an experiment that conflicts with predictions deduced from the hypothesis; otherwise, it cannot be meaningfully tested (Miller, 1985).

The "question/hypothesis" phase consists of 7 sub-phases or tasks, empirical meaning, embedding, existing knowledge, mental representation, language/definition, field of research and reflection.

Empirical meaning

At this sub-phase the students need to think about the empirical meaning of their question or hypothesis. Can empirical evidence be obtained to prove or reject the question or hypothesis chosen to pursue inquiry? Is the question or hypothesis under consideration verifiable or provable by means of observation or experiment?

Embedding

This stage also involves looking up and evaluating previous evidence from other scientists, including experience, conducting a literature review. Knowledge of the relevant literature is essential because it provides background, suggests approaches, indicates what has already been covered and what hasn't, and saves you from redoing what has already been done. If the answer is already known, a different question that builds on the previous evidence can be posed.

Existing knowledge

Students draw on their existing knowledge and with support (Dialog process, scaffolding) start thinking on the direction and methods of their enquiry.

Mental representation

Mental representations (or mental imagery) enable representing things that have never been experienced as well as things that do not exist (Sternberg, 2009). At this phase students are asked to create a clear idea of the topic or task under consideration.

Language/definition

In science language play a vital role and students need to be able to know the relevant definitions and use the appropriate language depending on the field of research they are working on.

Field of research

Field of research refers to area or topic that the research will focus on. It is a branch of knowledge that is taught and/or researched at a particular educational level. Fields of research or study usually have several sub-disciplines or branches (Abbot, 2001).

Ethics

Ethics in science refer to the application of ethical principles in scientific research. Ethics are usually focus on the design and implementation of research involving human participants, animals, but also various aspects of scientific misconduct (such as fraud, fabrication of data and plagiarism), regulation of research, etc.

Reflection

Reflection requires metacognitive skills. This means that learners are aware of their own learning and can asses, analyze and modify it when necessary (Corno, 1986; Corno & Rohrkemper, 1985). Specifically, students must be able to recognize when their understanding conflicts with evidence, identify possible gaps and make decisions on how to proceed. They must be able to identify what type of evidence they need in order to test their ideas and how to modify their beliefs in a manner consistent with that evidence.

Metacognition refers to learners' automatic awareness of their own knowledge and their ability to understand, control, and manipulate their own cognitive processes and include self-regulation and metacomprehension.

Self-Regulation refers to the learners' ability to make adjustments in their own learning processes in response to their perception of feedback regarding their current status of learning. Its focus is on the ability of the learners themselves to monitor their own learning (without external stimuli or persuasion) and to maintain the attitudes necessary to invoke and employ these strategies on their own. To learn most effectively, students should not only understand what strategies are available and the purposes these strategies, but also become capable of adequately selecting, employing, monitoring, and evaluating their use of these strategies (Graham, Reid, & Harris, 1992; Reid & Harris, 1993).

Metacomprehension refers to the learners' ability to monitor the degree to which they understand information being communicated to them, to recognize failures to comprehend, and to employ repair strategies when failures are identified (Gale, 2007).

4.2.3 Operationalisation

The next phase of the weSPOT inquiry model is operationalisation. Operationalisation is the process of defining an unclear concept so as to make the concept clearly distinguishable or measurable and to understand it in terms of empirical observations. It attempts to define concepts in terms of specified operations or procedures of observation and measurement (Britannica, 2013).

For example, a researcher may wish to measure the concept "happiness." Its presence, and the depth of the emotion, cannot be directly measured by an outside observer because happiness is intangible. Rather, other measures are used by outside observers, such as facial expression, choice of vocabulary, loudness and tone of voice etc.

Operationalisation is an integral part of the empirical research process. When there is a large empirical research question or purpose the conceptual framework that organizes the response to the question must be operationalised before the data collection can begin. If a scholar constructs a questionnaire based on a conceptual framework, they have operationalised the framework. Most serious empirical research should involve operationalisation that is transparent and linked to a conceptual framework (Shields & Tajalli, 2006).

The phase of the operationalisation consists of 6 different sub-phases, indicators, predictions, resources, methodology, ethics and reflection.

Indicators

Indicators assist for the transition from theory to specific measures. They specify the measurable aspects of the research and identify what is going to be measured and how. A measurable quantity which 'stands in' or substitutes, in some sense, for something less readily measurable. In this sense thermometer readings would be indicators of temperature, because what is actually measured is the height of, say, mercury in a tube; inferring temperature from this requires knowledge of physics (Sapsford, 2006).

Predictions

This step involves determining the logical consequences of the hypothesis. A statement about what will be observed before the actual event (Colombo, 2006). One or more predictions are then selected for further testing. Prediction specifies how one can demonstrate that a hypothesis is true. The prediction should be distinguished from the hypothesis. Different hypotheses can have the same prediction.

The ability to make accurate predictions hinges on the seven steps of the Scientific Method. Scientists generate a prediction using deductive reasoning (Colombo, 2006). Here students state their null hypothesis and the alternative hypothesis. A null hypothesis is the assumption that the hypothesis is false. The alternative hypothesis is the desired outcome.

Resources

The means available to conduct the research, such as library, textbooks, technology, tools etc.

Methodology
A set or system of methods, principles, and rules for regulating a given disciplines in sciences. It is considered as a guideline system for solving a problem, with specific components such as phases, tasks, methods, techniques and tools (Irny & Rose, 2005).

Ethics
Ethics in science refer to the application of ethical principles in scientific research. Ethics are usually focus on the design and implementation of research involving human participants, animals, but also various aspects of scientific misconduct (such as fraud, fabrication of data and plagiarism), regulation of research, etc.

Reflection
Reflection at this face is the same as described above. However, reflection at the phase is primarily concerned with the sub-phases included in this face, without excluding the evaluation of the previous phase, since the phases are not considered in isolation and there are interconnected. By reflecting, learners will evaluate their predictions and indicators, identify and scrutinise the methodology and consider any ethical implications that might arise.

4.2.4 Data collection

The next phase of the weSPOT inquiry methods is data collection. Data collection refers to testing a hypothesis and see whether the real world behaves as predicted by the hypothesis. Scientists test hypotheses by conducting experiments. The purpose of an experiment is to determine whether observations of the real world agree with or conflict with the predictions derived from a hypothesis. If they agree, confidence in the hypothesis increases; otherwise, it decreases.

At this phase researchers are deciding on the research design. Select a means of gathering data—a survey, an experiment, an observational study, use of existing sources, or a combination etc. The research conclusions will be only as good as the gathered data, so collecting should be done in a very rigours manner and recording the data is essential. If a researcher cannot document what he/she has done, is like he/she has not done it.

The phase of testing contains 9 sub-phases, information foraging, systematic observation, experimentation, tools, simulation, data storage, data security, documentation, and reflection.

Information foraging
Information foraging refers to theories on optimizing peoples' information search, processing and digestion in complex, information rich situations (Pirolli & Card, 1999). It aims to describe knowledge workers (such as students who are engaged in the data collection phase of the inquiry workflow) strategies to seek, gather and “consume” information. Human search behaviour is assumed to be adaptive to the information forager’s environment. The main focus is on the question of how people gain and extract information from external sources, such as papers, books or on-line documents (such as blogs or internet forums).

Systematic observation
Systematic observation is setting up a study to eliminate or reduce bias. It involves carefully observing and measuring behaviour as it occurs and it can be applied to both participants and natural

elements. Systematic observation may take place in any setting and its aim is to obtain an accurate measure of behaviour, performance and/or activities. Very often the starting point for any science is systematic observation. As we accumulate knowledge and propose explanations, the observations become more detailed, we look for things that we did not know to look for before, and we pay more attention to the conditions or context in which the observations occur (Shadish, Cook & Campbell, 2002).

Experimentation

Experimentation is a systematic procedure carried out with the goal of verifying, falsifying, or establishing the validity of a hypothesis. Different research methods can be explored and used depending on the problem at hand. The methods can either be qualitative or quantitative or both (Shadish, Cook, & Campbell, 2002).

Tools

At this sub-phase students need to think about the tools needed for the testing, and data collection.

Simulation

Simulation can be one of the methods use to perform the testing of the hypothesis. Simulations can include mathematical simulations, statistical simulations, computer simulations, and so on.

Data storage

Data storage refers to storing and retrieving data from any medium and it does not necessarily focus only to digital storage. When testing occurs, large amount of data maybe created and students need to think about storing and retrieving this data. Data storage is equally important for digital and non-digital data.

Data Security

Another important aspect is data security. Students need to think at this phase about how to keep the data safe and secure. Data security refers to both digital and non-digital data.

Documentation

It is important for students to learn about the importance of documentation in science. Keeping a record and documenting all the scientific process adds validity into research, allows for independent researchers to validate and replicate the conducted research.

Reflection

Reflection at this face is the same as described above with the same characteristics, evaluating primarily the sub-phases of the current phase, without excluding the evaluation of the previous phases, since the phases are not considered in isolation and there are interconnected.

4.2.5 Data Analysis

Analysis of data is a process of inspecting, cleaning, transforming, and modelling data with the goal of highlighting useful information, suggesting conclusions, and supporting decision making. Data analysis has multiple facets and approaches, encompassing diverse techniques under a variety of names, in different business, science, and social science domains.

The predictions of the hypothesis are compared to those of the null hypothesis, to determine which is better able to explain the data. In cases where an experiment has been performed, a statistical analysis is required.

The phase of analysis consists of 6 sub-phases, qualitative analysis, quantitative analysis, tools, visualisation, noise reduction and reflection.

Qualitative analysis

Qualitative research has its own data analysis techniques. Students use the appropriate techniques to analyse the obtained data.

Quantitative analysis

Quantitative analysis can include mathematical or statistical analysis of the obtained data.

Tools

This sub-phase focuses on the tools need to perfume the analysis on the data. Tools can include mathematical or statistical tools, computerised or non-computerised.

Visualisation

The visualisation sub-phase refers to the representation of the data by visual means.

Noise reduction

Noise reduction refers to the unexplained variation or randomness that is found within a given data sample or formula. There are two primary forms of statistical noise: errors and residuals. A statistical error is simply the portion of the final amount that differs from the expected value that was assumed to be the correct answer. A residual is the result of a more casual estimate of the anticipated outcome. The general notion behind statistical noise is that a particular set of data is not necessarily precise and might not be able to be duplicated if the same information was collected or calculated again.

Reflection

Reflection at this face is the same as described above with the same characteristics, evaluating primarily the sub-phases of the current phase without excluding the evaluation of the previous phases, since the phases are not considered in isolation and there are interconnected.

4.2.6 Interpretation/discussion

The next phase of the weSPOT inquiry model focuses on the discussion and interpretation of the results. Data interpretation and discussion is a very important part of a research inquiry as it describes the relevance of the results in relation to the question or hypothesis.

Summarizing the steps one has followed and discussing the finding takes place at this stage. The discussion should relate the obtained conclusions to the existing body of research, suggest where current assumptions may be modified because of new evidence, and possibly identify unanswered questions for further study.

The phase consists of 7 sub-phases, embedding, confirmation/falsification, exhaustion, threshold, relevance, significance and reflection.

Embedding
This stage is similar to the one described in the “question/hypothesis” phase but it now focuses on the finding of the inquiry. It involves looking up and evaluating previous evidence from other scientists, and comparing them with the results at hand.

Confirmation/falsification
The aim of a research inquiry is to confirm or very often to falsify the hypotheses under investigation.

Exhaustion
Exhaustion of the hypothesis refers to how complete the obtained results are and if the question or hypothesis has been answered completely or there is still room for more research/inquiry. At this sub-phase the researcher identify problems and shortcomings with the conducted research and provides alternatives in order to improve it. Additionally, the consequences for the theory/hypothesis/question are identified and recommendations are made.

Threshold
Threshold is a statistical concept and it refers to the change in a stimulus that is detectably different 50% of the time. Identifies the accepted values.

Relevance
Relevance refers to the importance of the analysed data in relation to the existing theories and research.

Significance
Statistical significance is a statistical assessment of whether observations reflect a pattern rather than just chance and the significance that the obtained results might have on existing theories and/or research fields.

Reflection
Reflection at this face is the same as described above with the same characteristics, evaluating primarily the sub-phases of the current phase, without excluding the evaluation of the previous phases, since the phases are not considered in isolation and there are interconnected.

4.2.7 Communication

Research is not complete until it is written up and its results shared, not only with other scientists or fellow inquiry participants who may build upon it to further advance the science, but also with those who may benefit from it, who may use it, and who have a stake in it.

Scientific communication takes place in many ways, including archival publication in scholarly journals and informal communication among groups of scientists, conferences etc.

The communication phase consists of 7 sub-phases, strategy, audience, tools, dissemination, discussion, feedback and reflection.

Strategy
The strategy helps to set a clear direction for communication, identify the right audience, tools, and events and meeting to communicate the results.

Audience
Students and researchers need to think about their audience. Different audience have different needs, different backgrounds and different expertise and therefore when communicating the inquiry results the approach needs to be adopted to take into account these differences.

Tools
What tools can be used to aid the communication of the results.

Dissemination
Dissemination is only one part of communication. It refers to publicising the inquiry results without expecting and receiving any feedback.

Discussion
This sub-phase refers to the discussion of the results with peers either in the class or with the team if it is a collaborative inquiry.

Feedback
Feedback can be obtained by fellow students, teachers, experts and so on.

Writing up
This sub-phase refers to the completion of the research and the switch to writing-up mode in order to write up their thesis. This entails developing a good, effective and concise report. Students might need to write multiple reports that present the results at different levels of detail for different audiences.

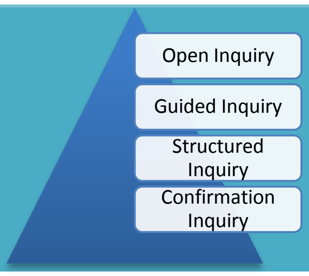
Reflection
Reflection at this face is the same as described above with the same characteristics, evaluating primarily the sub-phases of the current phase. However, as this is the last phase, it is envisage that students will also review the whole process of inquiry and evaluate their learning.

The different phases of the weSPOT IBL model are interconnected. This means that students/learners and/or teachers can start their scientific inquiry at any phase depending of the focus of the curriculum and the lesson and can even focus on one aspect of the inquiry if needed or even different aspects of inquiry for different learners or teams depending on their expertise. For example, if the focus of the subject at hand is the data analysis, the teacher can provide the students with the data set and request from the students to proceed with the analysis identifying and using the appropriate methods and tools. The inquiry process then will only deal with the sub-phases of the data analysis phase without expanding to the other phases. Thus the weSPOT model offers the flexibility for tailored and adapted scientific inquiry depending on the needs of the curriculum and the expertise and knowledge of the learners.

4.3 weSPOT IBL model and different levels of inquiry

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 weSPOT IBL model is compatible with the above categorisation. In an open inquiry the student has to make all the decisions throughout the process, from selecting the field of research, embedding it to existing theories, to making predictions, collecting and analysing the data using the right methods and tools, to discussing and presenting the results.

In a guided inquiry, the teacher is in charge of the first phase by deciding on the topic and creating the hypotheses and the students is taking control of all the other phases. However, the teacher can offer his/hers guidance throughout the process when necessary by assisting the students either on a phase level or on a sub-phase level.

In a structured inquiry the teacher has a greater degree of control by supporting and directing the students during the phases of the inquiry. These phases are: Question/hypotheses, Operationalisation, and partly on Data collection. The students then need to perform the rest of the phases, data collection, interpretation and communication. However, in the structured inquiry teachers guidance can be spread in most of the other phases by assisting students in certain sub-tasks. For example, students will perform the data analysis but the teacher might explain to them the appropriate method and tools.

In confirmation inquiry the teacher has the absolute control over every phase, making all the decisions and the students execute. For example, the teacher decides on the topic, creates the hypotheses, makes predictions, decides upon the research and analysis method and tools, guides the discussion and decides on the presentation strategy, audience, format and so on. The students perform the activities.

4.4 weSPOT IBL model example

4.4.1 The Microclimates Scenario

The first scenario is used to show case the weSPOT IBL model is a scenario within a secondary education context, about microclimates (Mikroyannidis et al., in press). Microclimates are areas where the normal temperature and conditions are slightly different from the surrounding areas. The aim of this scenario is to find the best place to have a bench at the school. The initial hypothesis is that the best place is the garden site nearest the school entrance because it is sheltered from the wind but south facing, so it is warm and not windy there. Other places to be considered are the car park, the canteen, the games area and the reception.

The scientific questions proposed by the teacher are:

- *Where is the windiest part of the school grounds?*
- *Where is the sunniest part of the school? This is likely to be the warmest.*
- *Where will we find the warmest part of the school grounds?* (Mikroyannidis et al., in press).

Therefore, the inquiry is based on four measurements: speed of wind, sunny periods, temperature and humidity.

Below are the phases of the WeSPOT IBL model in relation to the microclimate example.

Phase 1 - Question or hypothesis. Students discuss the main questions and define more specific questions to be answered in advance in order to define their hypothesis. The field of research in this example has been decided by the teacher who he/she will make the connection with existing research and theories so students have a complete idea of the research area. That can be done either before the inquiry starts or in previous learning sessions. Some example specific questions can be the following:

- *What are the energy sources in the classroom?*
- *What quantity of energy do they consume?*
- *Is there a relation between external climate and energy consumption?*
- *How long is the air-conditioner working during the day and at what temperature?*
- *What measures could be taken to minimize the energy consumption (e.g. do not open windows, do not leave the door open during breaks, do not switch the light on during the day, etc.)* (Mikroyannidis et al., in press).

After that students prioritize these questions and define their hypothesis. These hypotheses are formulated by different teams in each class and further investigated. The students think about the questions either individually or collectively and therefore reflect upon them. The reflection can either be self-reflection or group reflection.

Phase 2 - Operationalisation. Here students plan their method, discuss what information they need, how they can collect it and what needs to be measured, how it will be measured, decide on specific indicators and make prediction. Some of the activities can be the following:

- *To measure the temperature inside and outside three times a day (morning, midday and evening).*
- *To compare the temperature in the classroom and outside the building.*
- *To check during the measurement if the window or the door are open.*
- *To watch external climate conditions (sunny, windy, rainy etc.)*
- *To check when the air-conditioner is on and off.*
- *To calculate the energy consumption of the air-conditioner.*
- *To search the web for the most efficient way of use of the air-conditioner they have in the classroom.*
- *To check how often the lights are on and off.*
- *To calculate the energy consumption of the lights.*
- *To check how long the sunlight is enough during the day.*
- *To make informal questionnaires with their parents and relatives about how they save energy* (Mikroyannidis et al., in press).

Depending on the type of inquiry, guided, structured, confirmatory, or open the teacher provides guidance and makes decisions. For example, if the inquiry is confirmatory, the teacher will make all the decisions about what needs to be measured, how, where and when and make specific predictions. However, if the inquiry is open, the students will take control of everything and will make the decisions about each specific sub-phase of the model, if needed. Some of the subtasks maybe excluded from the processes because they do not fit the scope of the specific topic, for example in the microclimate example the teacher or students can decide that at the operationalisation stage the ethical aspects are not important and therefore do not take them into consideration. The students think about every step of the process either individually or collectively and therefore reflect upon them. The reflection can also either be self-reflection or group reflection depending on the type of inquiry.

Phase 3 – Data collection. Each student or team collects the data it has chosen to measure by using the appropriate method and the appropriate tools. Then they have to document their activities by for example taking pictures or recording the measurements and store their data in a secure and safe way. While doing so they are reflecting on the process and the suitability of the chosen method, tools and so on in order to make the best choices. However, if the inquiry is guided or confirmatory, reflection might be reduced since most of the decisions are made by the teacher.

Phase 4 – Data analysis. Students or teams analyse the collected data by using the appropriate method and tools. They prepare diagrams and graphics, and identify relations between different factors related to energy consumption (human behaviour, climate, conditions in rooms, etc.), and exclude the invalid data to reduce the noise of the data. Reflection at this step is very similar to the reflection described in the phase above.

Phase 5 – Interpretation/Discussion. Students, individually or in teams make conclusions related to their hypothesis and discuss different decisions and results. They decide on the relevance of their results, their significance, and they place them within the appropriate research field, microclimate.

Each team has to defend their conclusions and provide the needed arguments and reflect upon. Each student has to make her/his own decision. On the basis of final decisions the class prepares a list with suggestions to the school management. Some possible suggestions:

- *How long to have the lights on and when to switch them on and off depending on different conditions.*
- *How long to have the air-conditioner on and when to switch it on and off depending on different conditions.*
- *What type of woodwork to use.*
- *What type of doors to use and of what material.*
- *What additional energy sources to be used* (Mikroyannidis et al., in press).

Phase 6 – Communication. Each team or student prepares its presentation, conclusions and recommendations, and gives arguments (data, tables, diagrams, pictures), decides on how to disseminate the results. The need to think about their audience is it going to be their fellow students' teachers, parents etc. Different audiences may require different types of communication. They decide on the tools they need to use and how can incorporate the feedback they might got from the fellow students or peers. Throughout this phase reflection is at the centre scrutinising every single step or decision the students have made. Each team or student then makes its presentation in front of the audience and receive feedback.

4.5 weSPOT model phases and its relation to skills, activities and technologies

This section presents the relation of the weSPOT IBL model with its sub-phase and the correspondence of skills, activities and technologies.

Table 2: WeSPOT model phases, skills, and activities

IBL Model Phases and Tasks	Skills	Activities
Question/hypothesis	**Subject competence**	
• Embedding	Critical thinking Comprehension skills Domain knowledge	Connect it to existing theories List/name existing theories Paraphrase/explain/describe/relate
• Context	Observation skills	Identify/name/select/record
• Existing knowledge	Learning skills (Knowledge)	Connect it to existing knowledge
• Mental representation	Comprehension skills Metacognitive skills	Create a mental model
• Language/definitions	Learning skills (Knowledge) Language skills Comprehension skills	Use the appropriate definitions/language State/select/name/write
• Field of research	Learning skills (Knowledge)	Place it into the appropriate field of

	Analytical skills Language skills Comprehension skills	research
• Empirical meaning	Critical thinking Analytical skills	Identify/state the empirical meaning
• Reflection	Metacognitive skills	Rethink all the steps or the phase Evaluate process
Operationalisation (realisation of idea with the aim to measure)	**Analytical competence**	
• Indicators	Learning skills (Knowledge/remembering/recalling)	Identify indicators to be measured
• predictions	Critical thinking analytical skills inferring skills	Make predictions
• Resources	Learning skills (Remembering) search skills	Identify/think about the different resources needed
• Methodology (of data collection and processing)	Learning skills (Knowledge) Critical thinking skills	Identify the appropriate methodology
• Ethics (Ethical issues)	Learning skills (Knowledge/recalling/remembering)	Think/consider/identify/list/name possible ethical issues
• Reflection	Metacognitive skills Evaluation skills Critical thinking skills	Rethink all the steps or the phase
Data collection	**Experimental competence**	
• Information foraging	Research skills Learning skills computer literacy skills or technical skills	Identify the relevant information
• Systematic observation	Observation skills Experimentation skills	Perform systematic observation
• Experimentation	Problem solving skills Experimentation skills	Perform experiment
• Tools	Technical skills	Use the appropriate tools
• Simulation	Technical skills	Create simulation
• Data storage	Technical skills	Store data
• Data security	Technical skills	Secure data
• Documentation	Technical skills Writing skills language skills	Document process and results
• Classification	Critical thinking Analytical skills	Classify data
• Reflection	Metacognitive skills Evaluation skills Critical thinking skills	Rethink all the steps or the phase Evaluate process
Data Analysis (processing)	**Data Analysis competence**	

• Quantitative analysis (Statistical methods/analysis)	Quantitative analysis skills statistical skills mathematical skills	Perform quantitative analysis
• Qualitative analysis	Qualitative analysis skills statistical skills mathematical skills	Perform qualitative analysis
• Tools	Technical skills	Use the appropriate tools
• Visualisation	Technical skills Comprehension skills	Visualise the results
• Noise reduction (of data)	Analytical skills Evaluation skills	Evaluate the results
• Reflection	Metacognitive skills Evaluation skills Critical thinking skills	Rethink all the steps or the phase Evaluate process
Interpretation/discussion	**Synthesis competence**	
• Embedding (Embedding into existing theories/results/domain knowledge (classification))	Existing knowledge Classification skills Learning skills Inferring skills Comprehension skills	Embed the results into existing theories Describe the results Relate the results with existing theories
• Confirmation/falsification (of the initial question/hypothesis)	Experimentation skills Statistical skills Mathematical skills Evaluation skills	Falsify or confirm the results
• Significance (statistical)	Analytical skills Statistical skills mathematical skills	Identify the significance of the results
• Relevance (of the results)	Critical thinking skills Analytical skills	Identify the relevance of the results
• Threshold	Analytical skills Statistical skills Mathematical skills	Identify the threshold
• Exhaustion	Analytical skills Critical thinking skills Evaluation skills	Evaluate the results
• Reflection	Metacognitive skills Evaluation skills Critical thinking skills	Rethink all the steps or the phase Evaluate process
Communication	**Communication competence**	
• Writing up	Language skills/writing skills	Write the results
• Strategy	• Planning kills • organisation skills	Plan and organise the dissemination
• Audience	Planning skills organisation skills Analytical skills	Identify your audience
• Tools	Technical skills	Use the appropriate tools
• Dissemination (Events/Presentation/Publication)	Presentation skills/communication skills/language skills/writing skills	Present the results

• Discussion	Communication skills	Discuss/explain/describe/relate/paraphrase
• Feedback (Receiving and reacting)	Communication skills Interpersonal skills	Evaluate feedback
• reflection	Metacognitive skills Evaluation skills Critical thinking skills	Rethink all the steps or the phase Evaluate process

5. weSPOT DIAGNOSTIC FRAMEWORK

1.1 General Approach

The theoretical framework for the pedagogical diagnosis will be tailored to the ambitious aim of inferring students' inquiry and meta-cognitive skills as well as domain-specific knowledge from observational data tracked within the weSPOT environment.

In recent years, several research groups, both in the field of computer science (e.g. Duval, 2011; Dychkoff et al., 2012; Lockyer & Dawson, 2011) and cognitive science (e.g. Anderson et al., 2010; Augustin, Hockemeyer, Kickmeier-Rust, & Albert, 2011; Heller et al., 2007; Lindstaedt et al., 2009), have made progress in developing approaches towards the automatic measurement of latent constructs based on user-interaction data.

Usually, empirical research (mainly in social science) makes use of person factors (e.g. motives, level of inquiry skills, etc.) as independent variables in order to predict behavior, the dependent variable, such as task performance or communication/collaboration. Referring to Schönbrodt and Asendorpf (2011), behavior can be the independent variable just as well that "refers to internal states or traits of individuals" (Schönbrodt & Asendorpf, 2011, p. 8). Within the context of weSPOT this interexchange of independent and dependent variables will take place, resulting in the general goal of deriving latent constructs (e.g. inquiry skills) from manifest, user-interaction data (see Figure 3). To put it in other words, the general research question to be addressed is "*What tells us the behavior in* [virtual environments] *about psychological constructs*..." (Schönbrodt & Asendorpf, 2011, p. 8).

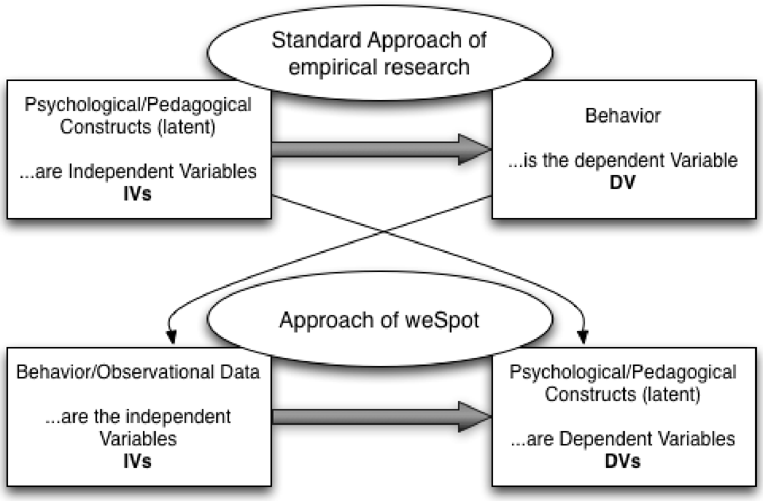


Figure 3. General measurement approach to be applied in weSPOT to measure latent constructs

By successfully addressing this general research question a huge potential for pedagogical and psychological research can be expected. First, while the observation of human behavior is usually the most time-consuming and expensive part of empirical studies, within a learning environment, such as weSPOT, gathering a huge amount of empirical data can be realized automatically. Second, the application and evaluation of measurement algorithms that are built upon formal psychological models allow for testing the external validity of these models in a natural setting. Therefore, weSPOT can be regarded as a behavior research tool to examine social but also cognitive processes, as well as to examine relationships between psychological constructs and observational data.

1.2 Defining the relationship between latent constructs (inquiry skills) and manifest user-interaction data

1.2.1 Top-Down Approach: Applying the Formal Concept Analysis

The first step in our endeavor of realizing a non-invasive measurement of skills will be to address the question: *How do inquiry skills relate to observable learning activities carried out by the students within the learning environment?*

An appropriate methodology to answer this question is the Formal Concept Analysis (FCA, e.g. Ganter, Stumme, & Wille, 2005), a mathematical framework developed by philosophers and mathematicians to formally define concepts as well as their interrelations in a formal way, and thus, more precisely: A concept "*is constituted by its extension, comprising all objects which belong to the concept, and its intension, including all attributes (properties, meanings) which apply to all objects of the extension*" (Wille, 2005, p.2). For a brief introduction into FCA see Wolff (1994). To describe the general principles and procedure of conducting an FCA,

Table 3 provides a short and simple example within the domain of animals. The starting point of the procedure is a cross-table, in which objects are represented in rows and attributes are represented in columns. Such cross-tables are given to domain experts (e.g. biologists) who are asked to set a cross in a particular cell whenever they feel that the corresponding attribute (e.g. preying) belongs to the given object (e.g. Eagle). In this way a mathematical structure of the domain emerges, which is called *formal context*. Within this context a formal concept can be defined, which can easily be described by firstly looking at the object "Finch" in Table 3. When searching for another object that shares all the Finch's attributes we get the object "Eagle", resulting in the set *A* (a set of objects) encompassing "Eagle" and "Finch". Associated with *A* is the set *B*, the set of attributes that are true for both objects, i.e. "flying" and "bird". Finally, the pair (*A*,*B*) is called *formal concept*, where *A* is the concept's extension and *B* is the concept's intension. From a formal context *sub-supraconcept* relations can be derived. In this example, *preying flying birds* describe a subconcept of flying birds. Generally, a concept c is a subconcept of concept d if the extension of *c* is a subset of the extension of d (or dually, if the intension of *c* is a superset of *d*'s intension, (Wolff, 1994)). In other words: A subconcept is more specific (it has *more attributes* assigned to it, i.e. it´s *intension is larger*); a supraconcept is more generic (it encompasses *more objects*, i.e. it´s *extension is larger*).

Table 3. Formal Context of concepts within the domain of Animals

	Attributes			
Objects	preying	flying	bird	mammal
Lion	x			x
Finch		x	x	
Eagle	x	x	x	
Hare				x
Ostrich			x	

In a next step, these hierarchical relations between formal concepts can be visualized in form of a specific line diagram that helps making sense of the formal context. Such a line diagram, called *concept lattice*, based on the formal context above is shown in Figure 4. This concept lattice has been created by applying the "Concept Explorer"(ConExp) tool[1] (Yevtushenko, 2000). When looking at such a diagram the following reading rule has to be applied: an object g is associated with an attribute m if and only if the circle named g is connected to the circle named m by means of an upwards leading path. By following this simple rule we can easily learn a concept's intension and extension from the diagram by collecting all objects below and above the concept's circle, respectively: The *extension* of a particular formal concept is constituted by the objects which can be reached by downwards leading paths from that circle. The *intension* is represented by all attributes which can be reached by upwards leading paths from that circle. For instance, when looking at the circle named "finch" it becomes clear that the concept's intension is "flying" and "bird" and its extension is "finch" and "eagle".

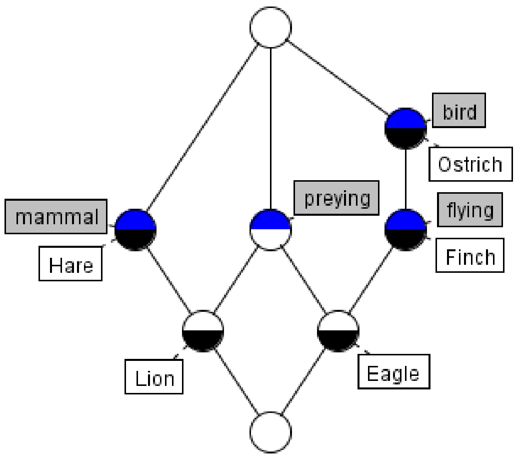


Figure 4. Line Diagram visualizing concept relations within the formal context of Table 3 (a blue filled upper semicircle means that there is an attribute attached to this concept and a black filled lower semicircle means that there is an object attached to this concept)

To sum up, this short and simple example should illustrate that the FCA provides a practical framework to reveal connections between concepts, as well as between objects and attributes.

[1] http://conexp.sourceforge.net/

The main reason for applying the FCA in the context of weSPOT is to guide the process of defining a formal context of inquiry concepts as well as relations between inquiry skills and tasks carried out by the students during their (observable) learning tasks. To this end, we regard tasks as objects and inquiry skills as attributes. Up to now, we have derived 25 skills (to be represented in the columns) and 46 tasks (to be represented in the rows) from a working document created in the course of the consortium meeting in Leuven (April 8-9 2013; https://basecamp.com/1774169/projects/877175-project-wespot/messages/9603557-deliverable-2-1). In Table 5, including the main part of this working document, the columns 1 and 2 list all tasks and skills, respectively, developed during the meeting. Note that the table is an intermediate result that will be refined and extended during the next six months. Based on these assignments (of tasks to skills) we have created a cross-table, i.e., a formal context of IBL, in which the grey-filled cells indicate, which tasks are predictive for a particular set of skills (see Table 6). In a last step, we have processed this cross-table by the ConExp tool[2] (Yevtushenko, 2000) to extract supra- and sub-concept relations between inquiry skills (see Figure 6, Figure 7, and Figure 8). FCA algorithms are described by Kuznetsov and Obiedkov (2001).Before we will describe the result of this analysis, Figure 55 schematically summarizes the whole procedure and additionally, gives an outlook of how the formal context of IBL should support a non-invasive assessment.

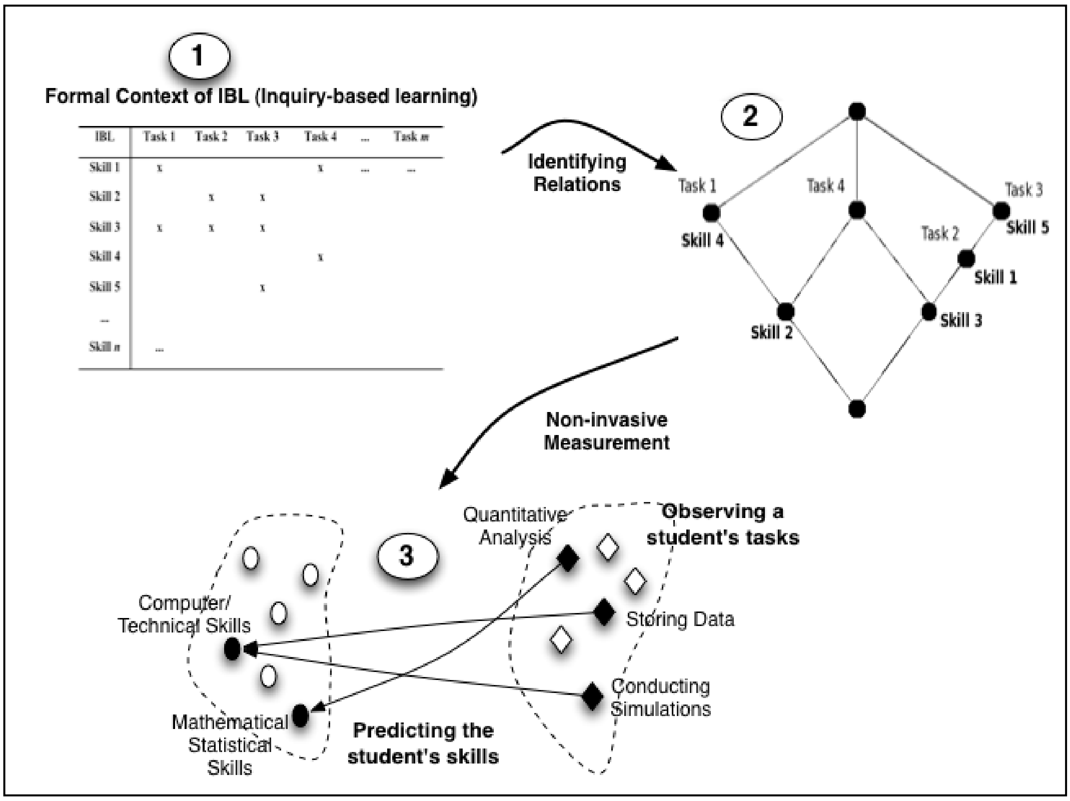


Figure 5. Procedure of applying FCA in weSPOT

As already described, the procedure has started by modeling the domain of IBL, i.e., by creating a formal context of IBL-skills in form of a skill by task cross-table (number 1 in Figure 5). After gathering experts' assignments of tasks to skills (during the meeting in Leuven), we have been able to apply FCA-algorithms to get a clearer picture of relations and interdependencies between skills as well as

[2] http://conexp.sourceforge.net/

between skills and tasks (number 2). Finally, the identified mapping of tasks on skills will be one way of conducting a non-invasive measurement within the weSPOT environment (number 3): In case of valid and reliable mappings (that will be checked in the course of evaluation studies), observing a student's tasks (e.g. "Data storage", "(conducting) Simulations") should be sufficient to get a first impression of her or his skills (e.g. " Computer Literacy / Technical Skills").

As mentioned above, the assignment of tasks and IBL-skills during the consortium meeting in Leuven (summarized in Table 2) has been transferred into a formal context (see Table 5), with the tasks in the rows, the skills in the columns and the assignments between those two sets by grey-highlighted cells.

By applying the ConExp tool (Yevtushenko, 2000), line diagrams (concept lattices) indicating sub-supra concept relations have been created. Figure 6 includes labels for both sets, i.e. the set of skills (grey boxes) and the set of tasks (white boxes), in order to enable for identifying the intension and the extension for each and every formal concept. Figure 6 focuses solely on the skills.

Table 5. Formal Context: Tasks X Skills

IBL Phases	IBL Tasks	Critical thinking skills	Comprehension skills	Observation skills	Learning skills	Metacognitive skills	Language skills	Analytical skills	Inferring skills	Search skills	Evaluation Skills	Computer / Technical Skills	Research Skills	Experimentation Skills	Problem Solving Skills	Writing Skills	Quantitative analysis skills	Statistics Skills	Mathematical Skills	Qualitative analysis skills	Existing Knowledge	Classification	Planning Skills	Organisation Skills	Presentation Skills	Communication Skills
Question/Hypothesis	Embedding	■	■																							
	Context			■																						
	Existing knowledge				■																					
	Mental representation		■			■																				
	Language/definitions		■		■		■																			
	Field of research		■		■		■	■																		
	Empirical meaning	■						■																		
	Reflection (Question)					■																				
Operationalisation	Indicators				■																					
	Predictions	■						■	■																	
	Resources				■					■																
	Methodology	■			■																					
	Ethics				■																					
	Reflection (Operationalization)	■				■					■															
Data collection	Information foraging				■							■	■													
	Systematic observation			■										■												
	Experimentation													■	■											
	Tools (Data Collection)											■														
	Simulation											■														
	Data storage											■														
	Data security											■														
	Documentation						■					■				■										
	Classification	■						■																		
	Reflection (Data Collection)	■				■					■															
Data Analysis	Quantitative analysis																■	■	■							
	Qualitative analysis																	■	■	■						
	Tools (Data Analysis)											■														
	Visualisation		■									■														
	Noise reduction							■			■															
	Reflection (Data Analysis)	■				■					■															
Interpretation	Embedding		■		■				■												■	■				
	Confirmation/falsification										■			■				■	■							
	Significance							■										■	■							
	Relevance	■						■																		
	Threshold							■										■	■							
	Exhaustion	■						■			■															
	Reflection (Interpretation)	■				■					■															
Communication	Writing up						■									■										
	Strategy																						■	■		
	Audience							■															■	■		
	Tools (Communication)											■														
	Dissemination						■									■									■	■
	Discussion																									■
	Feedback (Receiving and Reacting)																									■
	Reflection (Communication)	■				■					■															

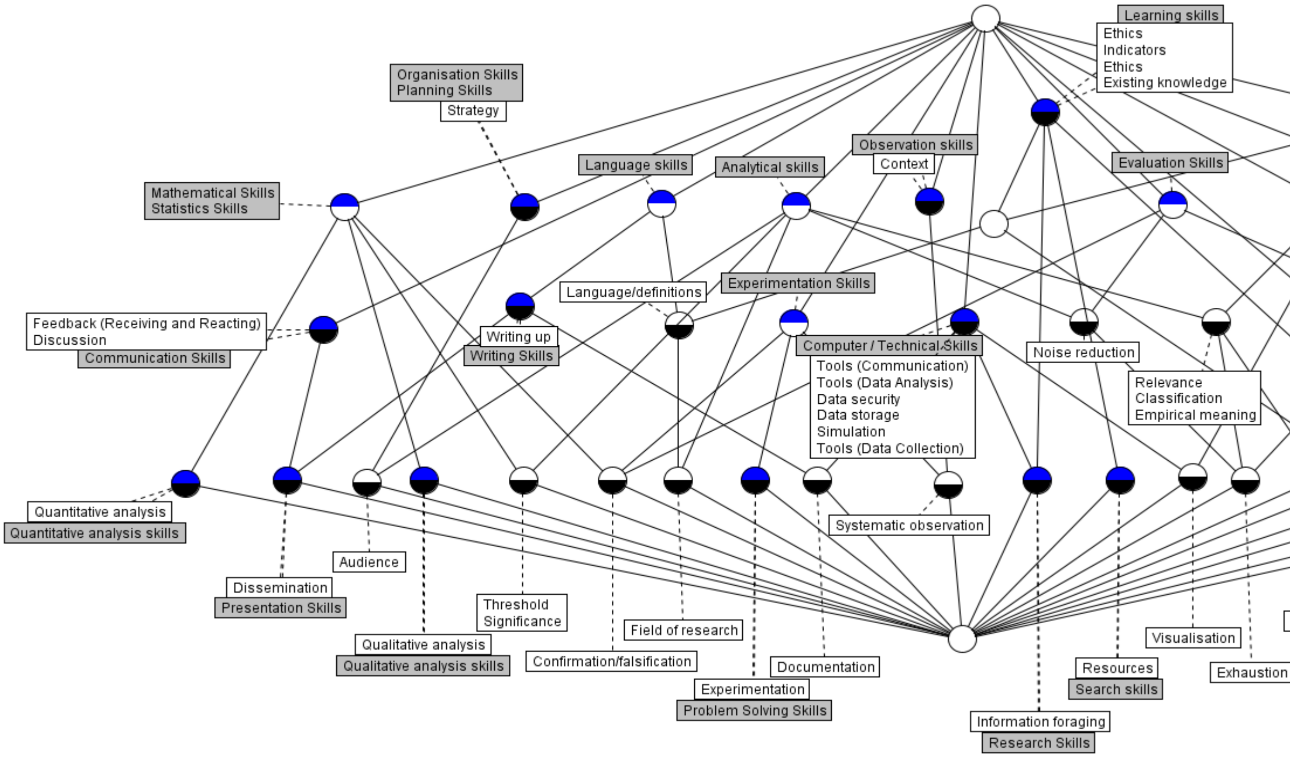


Figure 6. Concept Lattice of Skills (grey boxes) and Tasks (white boxes)

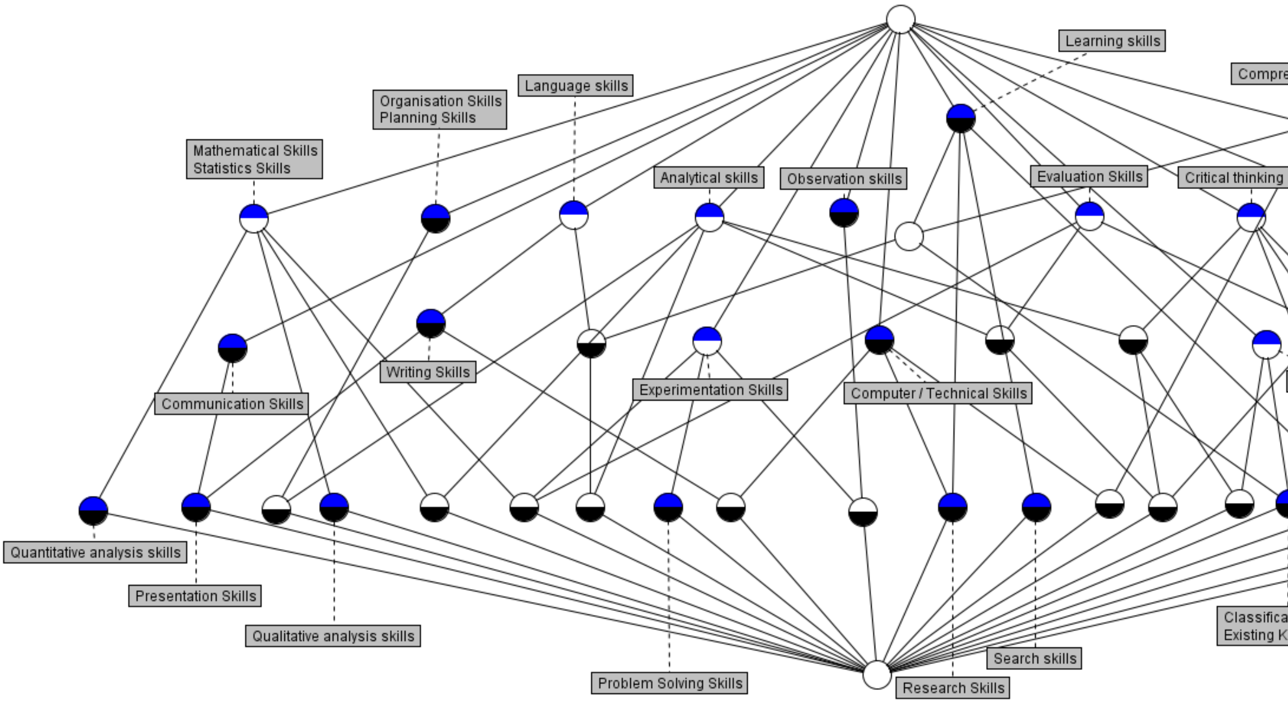


Figure7. Concept Lattice of Skills

Finally, we extracted the "quintessence" of the concept lattice shown in Figure 7 by structuring only those formal concepts with a minimal intension in which a particular skill occurs (indicated by the blue filled upper semicircles). This structure (see Figure 8) reveals two interesting insights which aren´t that obvious when looking at the formal context in Table 6: First, there are some skills which have been exactly assigned to the same set of tasks: Statistical Skills and Mathematical Skills, Planning Skills and Organization Skills and finally, Classification and Existing Knowledge. These "pairs" of skills are from an FCA point of view "conceptually the same" (or "synonyms") because there are no tasks included in the formal context which distinguishes between them. In consequence, future work on IBL skills and tasks in weSPOT will either aim to i) add new tasks or ii) to merge these "conceptually same" skills under a new label.

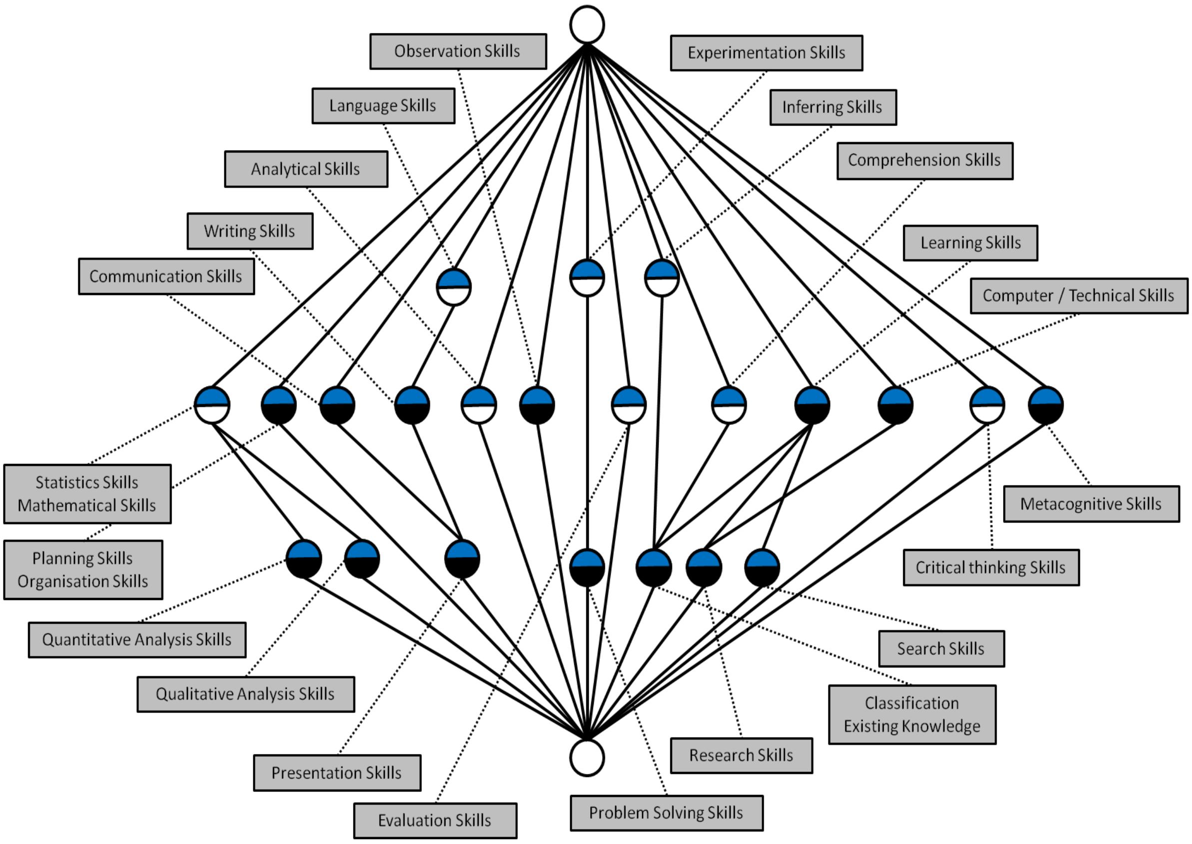


Figure 8. weSPOT IBL Skill Taxonomy / Hierarchy

Second, there are several "clusters" of interrelated skills; clusters of skills which can be described by "sub-supra skill" relations (from left to right):

i) Quantitative Analysis Skills, Qualitative Analysis Skills and Statistical Skills / Mathematical Skills
ii) Presentation Skills, Communication Skills, Writing Skills and Language Skills,
iii) Problem Solving Skills and Experimentation Skills
iv) Classification / Existing Knowledge, Research Skills, Search Skills, Comprehension Skills, Learning Skills and Computer / Technical Skills.

As an example Language skills can be considered as a supra-skill of Writing Skills since they enable for carrying out a larger set of tasks. Or Problem Solving Skills can be considered as a sub-skill of Experimentation Skills since they are assigned to a smaller amount of tasks.

In this sense, Figure 7 can be interpreted as a weSPOT IBL skill taxonomy or hierarchy.

1.2.2 Bottom-up Approach: Shaping Skill-Probabilities by means of Knowledge Indicating Events

Referring to Lindstaedt et al. (2009), Kump et al. (2012), Schoeffeger, Seitlinger, and Ley (2009) and Ley and Kump (in press), "a user model which is only based on tasks performed does not make use of all available information" (Ley & Kump, in press). Rather, so called Knowledge Indicating Events (KIE) that are user interactions carried out during the performance of predefined tasks (such as browsing, searching topics, contacting others, etc.) can help to implicitly develop a more comprehensive user model. The general assumption is that all behaviour is to some extend related to internal knowledge states and by considering additional data that are not explicitly represented in a theoretical model (e.g. the one in Figure 6) a more accurate user model emerges. Therefore, we decided making use of this bottom-up approach that tries to merge as much interaction data as possible to further refine the assessment of a student based on the theory-driven top-down approach (see section above).

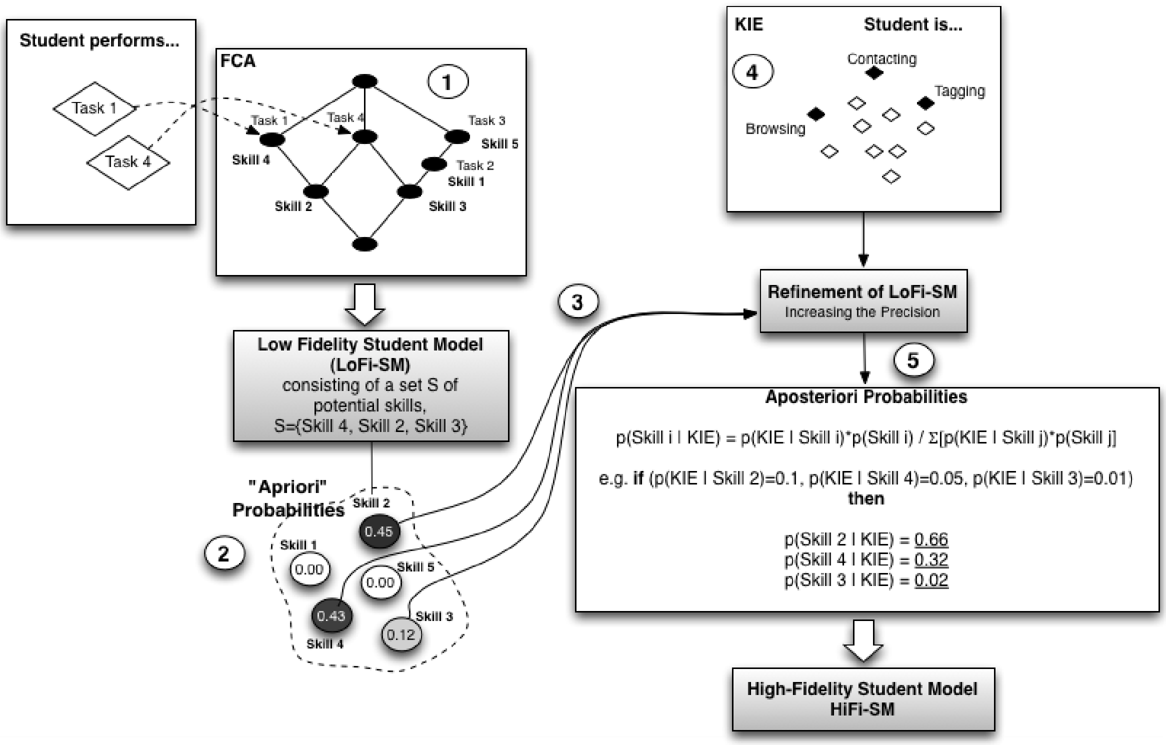


Figure 9. Shaping the probability distribution over skills by KIE-patterns

Figure 9 depicts a draft of an interplay between the top-down approach (FCA), yielding a first distribution of probabilities across the students' skills (the Low-Fidelity Student Model), and the bottom-up approach (processing KIE), further shaping the distribution towards specific, identified skills (the High-Fidelity Student Model). First, the student's tasks performed are fed into the formal context of IBL (elicited by the FCA): skills (e.g. skill 4) that have been found to be associated with the performed tasks (e.g. e.g. Task 1) are assigned higher probabilities (e.g. 0.45) than skills associated with uncompleted tasks (e.g. Task 3). The result is a preliminary, Low Fidelity Student Model (LoFi-SM) that defines a distribution of probabilities over all skills *s*, *P*(*s*), within the formal context (see number 2 in Figure 9). Then, to further refine and shape this distribution (number 3), the KIE (additional learning activities, e.g. browsing or tagging, not covered by the formal context) are taken into account (number 4). The subsequent step 5 consists of computing the aposteriori probability $p(s_i|\mathrm{KIE})$, i.e., the probability of a skill s_i (identified by the FCA) given a particular pattern of observed KIE. This conditional probability could be calculated by applying the Bayes' theorem, which would yield the skill's probability if further evidence (i.e., the KIE) had been considered. To put it more formally, equation (1) expresses the mathematical problem to be solved (see also number 5 in Figure 9 for a fictitious example),

$$p(s_i \mid KIE) = \frac{p(KIE \mid s_i) \cdot p(s_i)}{\sum_j p(KIE \mid s_j) \cdot p(s_j)} \qquad \text{Equation (1).}$$

While the parameter $p(s_i)$ is the result of the precedent FCA-computations (number 1), the conditional parameter $p(\mathrm{KIE}|s_i)$, i.e. the strength of association between a particular pattern of KIE and the skill s_i, is unknown. At this point, data mining techniques of computer science come into play to gather estimates of the unknown parameter. Machine learning algorithms that automatically learn classifications and associations (e.g. of the Weka toolkit, http://www.cs.waikato.ac.nz/ml/weka/) within a dataset should be well suited to mine the association between KIE-patterns (tracked within the weSPOT-environment) and skills that will be measured by questionnaires during evaluation studies. A first version of this questionnaire can be found in the Appendix (A-D) consisting of four standardized subscales to measure critical thinking (Dependent Variable 1, DV1), communication/collaboration (DV2), intrinsic motivation (DV3) as well as cognitive load (DV4). Each of the subscales was taken from standardized, well-established questionnaires (see Appendix A-D). While the DVs 1 to 3 are essential IBL-constructs to be increased by the weSpot-environment (see Deliverable D2.1), DV4 is a control variable that will be taken into account by the evaluation studies. The questionnaire will be extended by at least three additional sub-scales measuring students' domain knowledge, specific investigation skills and the ability of planning an investigation. Since no standardized questionnaires/tests on these constructs exist so far, we will need to develop new corresponding instruments to operationalise and quantify them (in close collaboration with the test-bed partners). This extension of the questionnaire will be carried out in the course of the next five months.

Basically, the proposed model (to automatically learn classifications based on KIE) will be based on algorithms described in Bishop (2007) and encompass the following four steps:

1. Collecting all low-level interaction data during a task and identifying KIE

2. Considering the captured KIE as conditionally independent, Poisson distributed variables. $p(KIE_n \mid s_i) = Poisson(\lambda_{ni})$

3. Applying the Expectation Maximization algorithm to learn λ_{ni}

4. Calculating the likelihood for each skill (and applying Bayes' rule to obtain the refined aposteriori probabilities.

$$p(KIE \mid s_i) = \prod_{n=1}^{N} p(KIE_n \mid s_i)$$

In further steps we will experiment with slight variations of this approach. One is inspired by Learning Analytics research, such as Taylor et al. (2013), and introduces an additional layer into our model. It assumes that KIE occur in characteristic clusters of patterns, which are indicative of skill levels. Another experiment will be the theoretically lead approach (Wells, 2001) to categorize KIE into three inquiry relevant facets (information search, collaboration, reflection) to therefore simplify the learning algorithm.

6. CONCLUSIONS

Deliverable D2.3.1 has introduced the pedagogical and the diagnostic framework of the weSPOT project.

The aim of the pedagogical framework is to provide a learning and research framework for "young researchers" which allows them to explore "scientifically" specific aspects of their physical environment, and to support the development of the technical tools. The pedagogical model describes the main phases of an inquiry process and is supporting informal, self-regulated learning settings as well as the embedding in a formal learning context. The scientific exploration process can take place independently, or in collaboration with others. The model will be updated continuously and will be informed by the piloting.

The diagnostic framework is also introduced but it will be fully developed in the next six months. The theoretical framework for the pedagogical diagnosis is tailored to the ambitious aim of inferring students' inquiry and meta-cognitive skills as well as domain-specific knowledge from observational data tracked within the weSPOT environment.

This deliverable is strongly related to the technical design and development WPs (3, 4, and 5) to the integration and piloting in different test-beds WP (6), and the evaluation framework WP (7).

7. REFERENCES

Abbott, A. (2001). Chaos of Disciplines. Chicago: University Of Chicago Press.

American Association for the Advancement of Science (AAAS). (2009). *The Nature of Science*. http://www.project2061.org/publications/bsl/online/index.php?chapter=1 (accessed 20/04/13)

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

Anderson, J. R., Betts, S., Ferris, J. L., & Fincham, J.M. (2010). Neural imaging to track mental states while using an intelligent tutoring system. *PNAS, 107*(15), 7018-7023.

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

Augustin, T., Hockemeyer, C., Kickmeier-Rust, M., & Albert, D. (2011). Individualized skill assessment in digital learning games: Basic definitions and mathematical formalism. *IEEE Transactions on Learning Technologies, 4*(2), 138-148.

Barrick, M. R., & Mount, M. K. (1991). The big five personality dimensions and job performance: a meta-analysis. *Personnel Psychology*, *44*, 1-26.

Bell, T., Urhahne, D., Schanze, S., & Ploetzner, R. (2010). Collaborative inquiry learning: Models, tools, and challenges. *International Journal of Science Education, 3*(1), 349-377.

Behrendt, H., Dahncke, H., Komorek, M., Duit, R., Gräber, W., Kross, A., & Reiska, P. (2001). Research in Science Education - Past, Present and Future. Dordrecht: Kluwer Academic Publishers.

Bloom, B. S. (Ed.), Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals*. Handbook 1: Cognitive domain. New York: David McKay.

Boam, R., & Sparrow, P. (eds) (1992). *Designing and achieving competency*. London: McGraw-Hill.

Boon, J., & van der Klink, M. (2002). Competencies: the triumph of a fuzzy concept. *Academy of Human Resource Development annual conference: proceedings, 1*, 327-334.

Britannica, (2013). *Encyclopaedia Britannica*. http://www.britannica.com/EBchecked/topic/429927/operationalism (accessed 13/03/13)

Brown, R. B. (1993). Meta-competence: a recipe for reframing the competence debate. *Personnel Review, 22*(6), 25-36.

Brown, R. B. (1994). Reframing the competency debate: management knowledge and meta-competence in graduate education. *Management Learning, 25*(2), 289-99.

Carlson, R. A., & Yaure, R. G. (1990). Practice schedules and the use of component skills in problem solving. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16*, 484-496.

Carlson, R.A., Khoo, B.H., Yaure, R.G., & Schneider, W. (1990). Acquisition of a problem-solving skill: Levels of organisation and use of working memory. *Journal of Experimental Psychology: General, 119*, 193-214.

Chase, W. G., & Ericsson, K. A. (1982). *Skill and working memory*. In Bower, G.H. (ed.). The psychology of learning and motivation. New York: Academic Press, pp. 1-58.

Chiru , C., Tachiciu, L., & Ciuchete, G. S. (2012). Psychological factors, behavioural variables and acquired competencies in entrepreneurship education. *Procedia - Social and Behavioral Sciences, 46*, 4010 – 4015.

Cockerill, T. (1989). The kind of competence for rapid change. *Personnel Management, 21*(9), 52-56.

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

Cohen I. B., & Whitman, A. (eds). (1999). *Philosophiae Naturalis Principia Mathematica (Newton, Isaac, 1687; 1713; 1726)* (3rd Ed.), University of California Press.

Colombo, A. (2006). Prediction. *The SAGE Dictionary of Social Research Methods.* http://srmo.sagepub.com/view/the-sage-dictionary-of-social-research-methods/n155.xml (accessed 20/04/13).

Convertino, G., Neale, D.C., Hobby, L., Carroll, J.M., Rosson, M.B. (2004). A Laboratory Method for Studying Activity Awareness. In *Proceedings of NordiCHI 2004* (pp. 313-322), ACM Press.

Corno, L. (1986). The metacognitive control components of selfregulated learning. *Contemporary Educational Psychology, 11*,(4), 333-346.

Corno, L., & Rohrkemper, M. (1985). The intrinsic motivation to learn in classrooms. In C. Ames & R. Ames (Eds.), *Research on motivation: Vol. 2. The classroom milieu (pp. 53-90).* New York: Academic Press.

Cox, J. W. (1934). *Manual skill: its organisation and development*. Cambridge: Cambridge University Press.

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.

Crawford, S., & Stucki, L. (1990). Peer review and the changing research record. *Journal of the American Society for Information Science, 41*(3), 223-228.

Cseh, M. (2003). Facilitating learning in multicultural teams. *Advances in Developing Human Resources, 5*(1), 26-40.

Dale, M., & Iles, P. (1992). Assessing management skills. London: Kogan Page.

Deci, E. L., & Ryan, R. M. (2004). *Intrinsic Motivation Inventory* [Online]. http://www.psych.rochester.edu/SDT/measures/IMI_scales.php (accessed 26/04/13).

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

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*. Holt, Rinehart and Winston.

Dewey, J. (1989). *The Later Works 1925-1953*. Carbondale and Edwardsville: Southern Illinois University Press.

Directorate for Education, Employment, Labour and Social Affairs Education Committee of the Organisation for Economic Co-operation and Development (DeSeCo). (2005). *Definition and Selection of Key Competencies – Executive Summary.* http://www.deseco.admin.ch/bfs/deseco/en/index/02.html (accessed 18/01/13).

Duval, E. (2011). Attention please!: learning analytics for visualization and recommendation. In *Proceedings of the 1st International Conference on Learning Analytics and Knowledge (9-17*). New York: ACM.

Dyckhoff, A. L., Zielke, D., Bültmann, M., Chatti, M. A., & Schroeder, U. (2012). Design and Implementation of a Learning Analytics Toolkit for Teachers. *Journal of Educational Technology & Society, 15*(3), 58-67.

Elkin, G. (1990). Competency-based human resource development. *Industrial and Commercial Training, 22*(4), 20-25.

Elleström, P-E. (1997). The many meanings of occupational competence and qualification. *Journal of European Industrial Training, 21*(6/7), 266-273.

Engle, A. D., Mendenhall, M. E., Powers, R. L., & Stedham, Y. (2001). Conceptualizing the global competency cube: a transnational model of human resource. *Journal of European Industrial Training, 25*(7), 346-353.

Eraut, M. (1994). *Developing professional knowledge and competence*. London: Falmer Press.

Eraut, M., Alderton, J., Cole, G., & Senker, P. (1998). *Development of knowledge and skills in employment*. Research Report No. 5, University of Sussex Institute of Education, Brighton.

European Parliament and the Council. (2008). Recommendation of the European Parliament and of the Council on the establishment of the European Qualifications Framework for lifelong learning. *Official Journal of the European Union*, C111/111.

Fitts, P. M., Bahrick, H. P., Noble, M. E., & Briggs, G. E. (1961). *Skilled performance*. New York: John Wiley.

Fitts, P. M., & Posner, M.I. (1967). *Human performance*. Belmont, CA: Brooks/Cole.

Gale, S. T. F. (2007). *Generative Instruction and Learning: Strategies for Increasing Student Achievement in Low Performing and At-risk Students*. ProQuest: South Carolina.

Ganter, B., Stumme, G., & Wille, R. (2005). *Formal Concept Analysis: Foundations and Applications*. Berlin: Springer.

Goldhaber, A. S., & Nieto, M. M. (2010). Photon and graviton mass limits. *Reviews of Modern Physics, 82*(1), 939-979.

Gonczi, A. (1994). *Developing a competent workforce*. Adelaide: National Centre for Vocational Education Research.

Gonczi, A., & Hager, P. (2010). The Competency Model. *International Encyclopedia of Education (3rd Ed.), 8*, 403-410.

Guasch, T., Alvarez, I., & Espasa, A. (2010). University teacher competencies in a virtual teaching/learning environment: Analysis of a teacher training experience. *Teaching and Teacher Education, 26*(2), 199-206.

Graham, S., Harris, K.R., & Reid, R. (1992). Developing self-regulated learners. *Focus on Exceptional Children, 24*(6), 1-16.

Hager, P. (1994). Is there a cogent philosophical argument against competency standards? *Australian Journal of Education, 38*, 3-18.

Halpern, F. D. (1998). Teaching Critical Thinking for Transfer Across Domains. *American Psychologist, 53*(4), 449-455.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of experimental and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload* (pp. 139-183). Amsterdam: North Holland.

Hartle, F. (1995). *How to re-engineer your performance management process*. London: Kogan Page.

Haury, D. L. (1993). *Teaching Science through Inquiry*. ERIC/CSMEE Digest, ED359048. http://www.ericdigests.org/1993/inquiry.htm (accessed 15/03/13).

Hendry, C., Arthur, M.B., & Jones, A.M. (1995). *Strategy through people: adaptation and learning in the small-medium enterprise.* London: Routledge.

Heller, J., Levene, M., Keenoy, K., Albert, D. & Hockemeyer, C. (2007). *Cognitive aspects of trails. A stochastic model linking navigation behaviour to the learner's cognitive state*. In J. Schoonenboom, M. Levene, J. Heller, K. Keenoy & M. Turcsányi-Szabó (eds.). Trails in education (pp. 119). Rotterdam: Sense Publishers.

Healy, F. A., & Weiner, B. I. (Eds). (2007). *Experimental Psychology, 4*. Wiley.

Hoffmann, T. (1999). The meanings of competency. *Journal of European Industrial Training, 23*(6), 275-285.

Hunt, F. E., & Colander, D. C. (2010). *Social Science: An Introduction to the Study of Society: International Edition*. Boston, MA: Pearson Education.

Irny, S. I. & Rose, A. A. (2005). Designing a Strategic Information Systems Planning Methodology for Malaysian Institutes of Higher Learning (isp- ipta). *Issues in Information System, 6*(1), 325-331.

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

Kirschner, P., Vilsteren, P., Hummel, H., & Wigman, M. (1997). The design of a study environment and professional competence. *Studies in Higher Education, 22*(2), 151-171.

Kuhn, T. S. (1970). *The Structure of Scientific Revolution, (2nd Ed.).* Chicago: University of Chicago Press.

Kuhn, T. S. (1996). *The Structure of Scientific Revolution, (3rd Ed.).* Chicago: University of Chicago Press.

Kump, B., Seifert, C., Beham, G., Lindstaedt, S., & Ley, T. (2012). Seeing What the System Thinks You Know - Visualizing Evidence in an Open Learner Model. *LAK '12 Proceedings of the 2nd International Conference on Learning Analytics and Knowledge, Vancouver/Canada, 29 April – 2 May 2012* (pp. 153–157). New York: ACM.

Kuznetsov, S.O., & Obiedkov, S.A. (2001). Algorithms for the Construction of Concept Lattices and Their Diagram Graphs. In L. de Raedt (ed.), Proceedings of the 5th Conference on Principles of Data Mining and Knowledge Discovery (PKDD'2001), *Lecture Notes in Artificial Intelligence*, *2168*, 289–300.

Lakatos, I., & Musgrave, A. (1970). *Criticism and the Growth of Knowledge*. Cambridge: Cambridge University Press.

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

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.shef.ac.uk/cilass/resources (accessed 28/04/13).

Ley, T., & Kump, B. (in press). Predicting Levels of Expertise in Work-integrated Learning from Naturally Occurring User Interactions.

Lindstaedt, S.N., Beham, G., Kump, B. & Ley, T. (2009). Getting to Know Your User. Unobtrusive User Model Maintenance within Work-Integrated Learning Environments. *Learning in the Synergy of Multiple Disciplines: Proceedings of the 4th European Conference on Technology Enhanced Learning, ECTEL 2009, Nice, France, September/October 2009*. U. Cress, V. Dimitrova, and M. Specht, eds. Springer. 73-87.

Lockyer, L., & Dawson, S. (2011). Learning designs and learning analytics. In *Proceedings of the 1st International Conference on Learning Analytics and Knowledge* (153-156). New York: ACM.

Logie, R., Baddeley, A., Mane, A., Donchin, E., & Sheptak, R. (1989). Working memory in the acquisition of complex cognitive skills. *Acta Psychologica, 71*, 53-87.

Mansfield, R.S. (2004). Competence in Translation. *Journal of European Industrial Training, 28*(2/3/4), 296-309.

McKeithen, K. B. (1981). Knowledge organisation and skill differences in computer programmers. *Cognitive Psychology, 13*, 307-325.

Mangham, I. (1986). In search of competence. *Journal of General Management, 12*(2), 5-12.

McBeath, G. (1990). *Practical management development: strategies for management resourcing and development in the 1990s*. Oxford: Blackwell.

McClellan, D. (1998). Identifying competencies with behavioural-event interviews. *Psychological Science, 9*(5), 331-339.

Messick, S. (1984). The psychology of educational measurement. *Journal of Educational Measurement, 21*, 215-238.

Miller, D. (1985). *Popper Selections*. Princeton: Princeton University Press.

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.

Mitrani, A., Dalziel, M., & Fitt, D. (1992). Competency based human resource management. London: Kogan Page.

More, C. (1980). *Skill and the English working class, 1870-1914*. London: Croom Helm.

Moulton, F. R. & Schifferes, J. J. (1960). *The Autobiography of Science (2nd Ed.).* Doubleday.

Mourtos, N.J., DeJong Okamoto, N., & Rhee, J. (2004). Defining, teaching, and assessing problem solving skills. *UICEE Annual Conference on Engineering Education*, Mumbai, India, 9-13. http://www.engr.sjsu.edu/nikos/fidp/pdf/UICEE%2004%20-%20Mumbai.pdf (accessed 25/04/13).

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.

Murtonen, M., Olkinuora, E., Tynjälä, P., & Lehtinen, E. (2008). “Do I need research skills in working life?”: University students’ motivation and difficulties in quantitative methods courses. *Higher Education, 56*(5), 599-612.

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

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

Newell, K.M. (1991). Motor skill acquisition. *Annual Review of Psychology, 42*, 213-237.

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

National Science Teachers Association (NSTA). 2004. NSTA Position Statement: Scientific Inquiry. http://www.nsta.org/about/positions/inquiry.aspx (accessed 22/03/13).

Pate, J., Martin, G., & Robertson, M. (2003). Accrediting competencies: a case of Scottish vocational qualifications. *Journal of European Industrial Training, 27*(2/3/4), 169-176.

Pear, T.H. (1927). Skill. *Journal of Personnel Research, 5*, 478-489.

Pear, T.H. (1948). Professor Bartlett on skill. *Occupational Psychology, 22*, 92-93.

Pirolli, P., & Card, S. K. (1999). Information Foraging. *Psychological Review, 106*, 643-675.

Popper, K. (2002). *The Logic of Scientific Discovery*. London and New York: Routledge Classics.

Proctor, R.W., & Dutta, A. (1995). *Skill acquisition and human performance*. London: Sage.

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.

Reid, R., & Harris, K. R. (1993). Self-monitoring of attention versus self-monitoring of performance: Effects on attention and academic performance. *Exceptional Children, 59*, (6), 1-13.

Robotham, D., & Jubb, R. (1996). Competences: measuring the unmeasurable. *Management Development Review, 9*(5), 25-29.

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.

Salthouse, T.A. (1986). Perceptual, cognitive and motoric aspects of transcription typing. *Psychological Bulletin, 99,* 303-319.

Sapsford, R. (2006). Indicators. *The SAGE Dictionary of Social Research Methods.* http://srmo.sagepub.com/view/the-sage-dictionary-of-social-research-methods/n98.xml (accessed 19/03/13)

Schmidt, R.A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82,* 225-260.

Schmidt, R.A. (1988). *Motor control and learning: a behavioural emphasis (2nd Ed.)* Champaign, IL: Human Kinetics.

Schoeffeger, K., Seitlinger, P., & Ley, T. (2009). Towards a User Model for Personalized Recommendations in Work-Integrated Learning: A Report on an Experimental Study with a Collaborative Tagging System. *Procedia Computer Science, 1*, 2829-2838.

Schönbrodt, F. D., & Asendorpf, J. B. (2011). Virtual social environments as a tool for psychological assessment: dynamics of interaction with a virtual spouse. *Psychological Assessment, 23*, 7-17.

Schraw, G., Bendixen, L.D., & Dunkle, M.E. (2002). Development and validation of the epistemic belief inventory (EBI). In B.K. Hofer & P.R. Pintrich (Eds.*), Personal Epistemology: The psychology of beliefs about knowledge and knowing* (pp. 261-275). Mahwah, NJ: Erlbaum.

Schuster, J. W., & Powers, P. D. (2005). *Translational and Experimental Clinical Research.* Lippincott Williams and Wilkins.

Sekretariat der Ständigen Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland (KMK)(Ed.). (2005). *Bildungsstandards im Fach Physik für den Mittleren Schulabschluss [Physics education standards for middle school graduation].* Neuwied: Luchterhand.

Shadish, R. W., Cook, D. T., & Campbell, T. C. (2002). *Experimental and Quasi- Experimental Designs for Generalized Casual Inference.* Boston-New York: Houghton Mifflin Company.

Shields, P., & Tajalli, H. (2006). Intermediate Theory: The Missing Link to successful Student Scholarship. *Journal of Public Affairs Education, 12*(3), 313-334.

Smith, B. (1993). Building managers from the inside out: competency based action learning. *Journal of Management Development, 12*(1), 43-48.

Snyder, A., & Ebeling, H.W. (1992). Targeting a company's real core competencies. *Journal of Business Strategy, 13*(6), 26-32.

Stephenson, J., & Weil, S. (1992). *Quality in Learning: A Capability Approach in Higher Education.* London: Kogan, Page.

Sternberg, J. R. (2009*). Cognitive Psychology (5th Ed)*. Wadswoth Cengage Learning.

Spektor-Levy, O., Eylon, B-S., & Scherz, Z. (2008). Teaching communication skills in science: Tracing teacher change. *Teaching and Teacher Education, 24*(2), 462‑477.

Swift, E. J. (1904). The acquisition of skill in typewriting: a contribution to the psychology of learning. *Psychological Bulletin, 1,* 295-305.

Swift, E. J. (1910). Learning to telegraph. *Psychological Bulletin, 7*, 149-153.

Tafoya, E., Sunal, D., & Knecht, P. (1980). Assessing inquiry potential: A tool for curriculum decision makers. *School Science and Mathematics, 80*(1) 43-48.

Tovey, L. (1993). A strategic approach to competency assessment. *Executive Development, 6*(5), 26-28.

Taylor, M., Aghababyan, A., Pfaffman, J., Olsen, J., Baker, S., Janisiewicz, P., Phillips, R., & Petrick Smith, C. (2013). Nanogenetic learning analytics: illuminating student learning pathways in an online fraction game. In *Proceedings of the Third International Conference on Learning Analytics and Knowledge* (LAK '13), Dan Suthers, Katrien Verbert, Erik Duval, and Xavier Ochoa (Eds.). ACM, New

York, NY, USA, 165-169. DOI=10.1145/2460296.2460328.
http://doi.acm.org/10.1145/2460296.2460328

Van der Klink, M., & Boon, J. (2002). The investigation of competencies within professional domains. *Human Resource Development International, 5*(4), 411-424.

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 15/04/13).

Weinert, F. E. (1999). Concepts of competence. Munich: Max Planck Institute for Psychological Research. Published as a contribution to the OECD project Definition and selection of competencies: theoretical and conceptual foundations (DeSeCo). Neuchâtel: DeSeCo.

Weinert, F. E. (2001). Concept of competence: a conceptual clarification. In D.S. Rychen, & L.H. Salanik (Eds.), *Defining and selecting key competencies*, Ashland (pp. 45–65). OH: Hogrefe & Huber.

Welford, A.T. (1968). *Fundamentals of skill*. London: Methuen.

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

Westera, W. (2001). Competences in education: A confusion of tongues. *Journal of Curriculum Studies, 33*(1), 75–88.

White, R.H. (1959). Motivation reconsidered: The concept of competence. *Psychological Review, 66,* 279-333.

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., & 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.

Wille, R., (2005). Formal Concept Analysis as Mathematical Theory of Concepts and Concept Hierarchies, In B. Ganter , G. Stumme and R. Wille, (eds.), *Formal Concept Analysis* (pp. 1-34), Berlin: Springer.

Winterton, J., Delamare-Le Deist, F., & Stringfellow, E. (2006). Typology of knowledge, skills and competences: clarification of the concept and prototype. *Cedefop Reference series; 64*, Luxembourg: Office for Official Publications of the European Communities.

Wolff, K. E. (1994). A first course in formal concept analysis. *Advances in Statistical Science, 4*, 429-438.

Yevtushenko, S. A. (2000). System of data analysis "Concept Explorer", In *Proceedings of the 7th national conference on Artificial Intelligence KII-2000*, 127-134.

8. APPENDIX

A. Subscale on Critical Thinking (Items from the Epistemic Belief Inventory; Schraw, Bendixen & Dunkle, 2002)

	Strongly Disagree				Strongly Agree
1. Most things worth knowing are easy to understand.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
2. What is true is a matter of opinion.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
3. Student who learn things quickly are the most successful.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
4. People should always obey the law.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5. People's intellectual potential is fixed at birth.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6. Absolute moral truth does not exist.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7. Parents should teach their children all there is to know about life.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8. Really smart students do not have to work as hard to do well in school.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9. If a person tries too hard to understand a problem, they will most likely end up being confused.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10. Too many theories just complicate things.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11. The best ideas are often the most simple.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12. Instructors should focus on facts instead of theories.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
13. Some people are born with specific gifts and talents.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14. How well you do in school depends on how smart you are.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15. If you don't learn something quickly, you won't ever learn it.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
16. Some people just have a knack for learning and others don't.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
17. Things are simpler than most professors would have you believe.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
18. If two people are arguing about something, at least one of them must be wrong.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
19. Children should be allowed to question their parents' authority.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
20. If you haven't understood a chapter the first time through, going back over it won't help.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

21. Science is easy to understand because it contains so many facts.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
22. The more you know about a topic, the more there is to know.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
23. What is true today will be true tomorrow.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
24. Smart people are born that way.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
25. When someone in authority tells me what to do, I usually do it.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
26. People shouldn't question authority.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
27. Working on a problem with no quick solution is a waste of time.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
28. Sometimes there are no right answers to life's big problems.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

B. Subscale on Communication and Collaboration (Items from the Activity Awareness Questionnaire, Convertino et al., 2004)

Communication and Common Ground	Strongly Disagree				Strongly Agree
1. I found it difficult to keep track of the conversation	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
2. During the conversation I was able to focus on the task at hand	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
3. Over time, I got to know my partners better	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
4. My partners and I communicated well with each other	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5. Over time, my partners and I came to share more and more ideas about the project	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Shared Practices					
6. My partners and I have developed our own ways of working together	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7. My partners and I have learned to work efficiently together	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Human Development					
8. I clearly felt part of a team after working with my partners on the project	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9. My partners and I have gradually become a team	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10. I became more capable of collaborating remotely with my partners now than when I started	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11. As a team, my partners and I became more capable of collaborating remotely with my partners now than when we started	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12. My partners and I are a more productive team now than we were when we started	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
13. My partners and I have supported each other during the collaboration	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Trust and Mutual Support					
14. My partners and I support each other more now than when we started.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15. My partners and I are more willing to spend extra effort to help each other now than when we started.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
16. If I had to start a new project, I would feel more confident working with my current partners.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
17. If my partners could not do part of her/his work, she/he could count on me to help out.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

18. If I could not do a part of my work, I could count on my partners to help out.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
19. I trust that my partners will do everything she/he has committed to do.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
20. My partners and I planned adequately.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Quality of Collaboration					
21. My partners collaborated with me to complete the project.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
22. My partners and I contributed equally to this project.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

C. Subscale on Intrinsic Motivation (Items from the Intrinsic Motivation Inventory; Deci & Ryan, 2004)

	Strongly Disagree				Strongly Agree
1. I thought this was a boring task.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
2. I think that working on this task could be useful.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
3. I didn't try very hard to do well at this activity.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
4. This task was fun to do.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5. I believe working on that task could be beneficial to me.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6. It was important to me to do well at this task.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7. I would describe this task as very interesting.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8. I believe working on this task could be of some value for me.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9. I put a lot of effort into this.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

D. Subscale on Cognitive Load (Items from NASA-TLX; Hart & Staveland, 1988)

In the following you will be asked to indicate how demanding you found several aspects of the task you just fulfilled. In order to answer each of the following questions, please place an "X" on the line under each question.

1. How much mental and physical activity was required (e.g., thinking, remembering, looking, searching etc.)? That is, were the tasks easy (simple) or demanding (exacting)?

easy demanding

2. How hard did you have to work in your attempt to understand the contents of the knowledge resources?

not hard at all very hard

3. How successful do you think you were in your attempt to understand the contents of the learning environment?

not successful very successful

4. How much effort did you have to invest in order to navigate through the environment (e.g. finding your way around)?

low effort high effort

5. How stressed (insecure, discouraged, irritated, annoyed) did you feel during the activities?

not stressed at all very stressed