Working Environment with Social and Personal Open Tools for inquiry based learning: Pedagogic and Diagnostic Frameworks

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Abstract: 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 The project focuses on inquiry-based learning with a theoretically sound and technology supported personal inquiry approach and it contains three main development aspects: (a) define a reference model for inquiry-based learning skills, (b) create a diagnostic instrument for measuring inquiry skills, and (c) implement a working environment that allows the easy linking of inquiry activities with school curricula and legacy systems. The current work outlines the pedagogical and diagnostic frameworks for scientific inquiry. The pedagogical 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. The diagnostic framework focuses on the pedagogical diagnosis, which 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. Pilot studies planned to be conducted in 16 test-beds across 6 EU countries will test the reference model and make use of the diagnostic instrument.

Keywords: Inquiry-Based Learning, Pedagogical Framework, Diagnostic Framework

Introduction

Inquiry-based learning (IBL) 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/her own route to build and organize personal knowledge. 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. Learners develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (Anderson 2002). The nature of inquiry-based learning is contested and even the term itself is not in widespread use throughout the educational literature. Many terms are used for learning through inquiry, including 'enquiry-based learning', 'guided-inquiry', 'problem-based learning', 'undergraduate research' and 'research-based teaching' (Spronken-Smith and Walker 2010).

The call for inquiry learning is based on the certainty that science learning is not about memorisation of scientific facts and information, but rather about understanding and applying scientific concepts and methods (Bell et al. 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. According to a concise definition for the domain of science learning, inquiry is

> "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" (Quintana et al. 2004, 341).

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In a more student-centre approach, 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, 23).

When conducting inquiries, students act like real scientists: they 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.

Since inquiry encompasses the application of scientific methods into studying and investigating problems, topics and areas of interest, an IBL model should demonstrate "good" scientific inquiry, basing on "good" scientific research and therefore "good" scientific methods. Which are the attributes, though, of "good" scientific research and "good" scientific methods, which determine in turn "good" scientific inquiry? Answers to these questions are prominent in any effort to construct an IBL model, if it is to mirror "good" scientific inquiry. Yet, a review of related literature reveals the complexity of the field and uncovers the inherent difficulties and challenges in the development of a concise and elaborate IBL model.

Indeed, 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 investigation are as important in social science as in physical science. Social scientists must observe carefully, classify and analyse 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 way 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, analyse the results, and draw conclusions (Hunt and Colander 2010). These steps differ slightly from those used by a natural scientist—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 analysing the results, and formulating new hypotheses, seems to be acceptable by the scientific community.

Scientific methods, on the other hand, refer to a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge (Goldhaber and Nieto 2010). To be termed scientific, methods of inquiry must be based on empirical and measurable evidence subject to specific principles of reasoning (Cohen and Whitman 1999). 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; analyse the data; interpret the data and draw conclusions that serve as a starting point for new hypothesis; publish result; retest (frequently done by other scientists). Each of the above elements is subject to peer review for possible mistakes (Moulton and Schifferes 1960).

From the above it becomes evident that scientific inquiry is more complex than popular conceptions would have it: it is 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). In addition, 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 *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 and Colander 2010).

As such, an IBL model – if it is to mirror “good” scientific inquiry- should encompass the main steps regarding scientific methods described above, but in the same time it should offer flexibility to the learners and their coaches to conduct their *own* inquiries, rather than follow a pre-determined series of steps. In addition, it should allow the development of attitudes to the learners, such as curiosity and scepticism. Other inquiry models in a cyclical fashion – that have been proposed so far- can be an effective initial model that enables students to develop the capabilities of inquiry and understand its basic processes (White and Frederiksen 1998, 2005a, 2005b; White, Frederiksen, and Collins 2009). However, most of them lack in offering the complete scientific inquiry process, as well as the needed flexibility for learners to conduct their own inquiries. Therefore another approach that places the scientific processes of inquiry at its centre is needed. The weSPOT inquiry-based learning model strives to respond to these challenges and is described in detail below.

weSPOT Inquiry-Based Learning Model

The weSPOT model moves on from simplistic cyclical models as it aims to model the complete scientific inquiry process. It is based on the steps required for good research (Crawford and Stucki 1990; Hunt and Colander 2010) such as data collection, data analysis, hypothesis forming, communication and dissemination of findings etc. It shares many of the phases described by Mulholland et al. (2012), but it is more elaborate regarding the sub-phases providing a detailed description of things that teachers and students should consider when doing inquiry.

Description of the model

The weSPOT IBL model, presented in Figure 1, consists of six phases, each one involving a number of activities. The main characteristics of each phase are described below.

Question/hypothesis

In this phase of the weSPOT inquiry-based model 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 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 reviewing and evaluating previous evidence from other scientists. If the answer is already known, a different question that builds on the previous evidence can be raised. 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 and 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. 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 8 components or tasks: empirical meaning, embedding, existing knowledge, mental representation, language/definition, field of research, context and reflection.

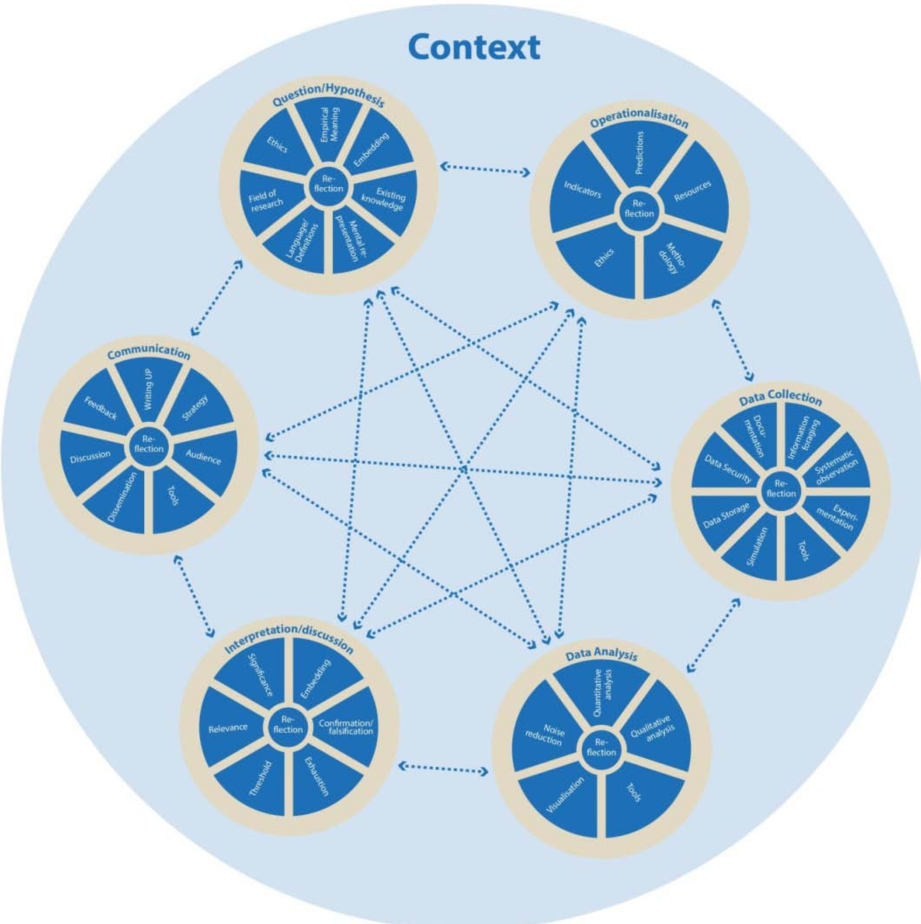

Figure 1: weSPOT Inquiry-Based Learning Model

Operationalisation

Operationalisation refers to the realisation of an idea with an aim to measure. It is the process of defining a concept, so as to make it clearly distinguishable from other concepts and measurable in terms of empirical observations. It attempts to define concepts in terms of specified operations or procedures of observation and measurement (Britannica 2013).

Operationalisation is an integral part of the empirical research process. When there is a complex empirical research question, the conceptual framework that organizes the response to the question must be operationalised before the data collection can begin. If scholars construct 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 and Tajalli 2006).

The phase of the operationalisation consists of 6 different components: indicators, predictions, resources, methodology, ethics and reflection.

Data collection

The data collection phase refers to testing a hypothesis and seeing whether the real world behaves as predicted by the hypothesis. Scientists test hypotheses by conducting experiments, which determine whether observations of the real world agree with the predictions derived from a hypothesis. If they agree, confidence in the hypothesis increases; otherwise, the hypothesis is rejected.

This phase starts with the design of the research and determining ways and procedures of gathering data. Data collection can take place through a survey, an experiment, an observational study, a secondary analysis of existing sources or a combination of these methods. 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.

The phase of data collection contains 10 components: information foraging, systematic observation, experimentation, tools, simulation, data storage, data security, documentation and reflection.

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.

In cases where an experiment has been performed, a statistical analysis is required. In hypothesis testing for example, a null hypothesis (referring to a general or default position that there is no relationship between two measured phenomena) is contrasted with an alternative hypothesis (the initial hypothesis in the inquiry process) and these are decided between on the basis of data, with certain error rates.

The phase of analysis consists of 6 components: qualitative analysis, quantitative analysis, tools, visualisation, noise reduction and reflection.

Interpretation/discussion

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

This phase starts with a summary of the steps one has already taken. It includes an overview and a discussion of the findings. 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 components: embedding, confirmation/falsification, exhaustion, threshold, relevance, significance and reflection.

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 8 components: strategy, audience, tools, writing, dissemination, discussion, feedback and reflection.

Innovative elements of the model

The weSPOT IBL model is not only elaborate in terms of the specific tasks that learners do when conducting inquiry, by providing a meticulous description of the whole inquiry process. It also shows a number of innovative characteristics that aim at helping learners when conducting their own inquiries.

Context

All the IBL model phases are placed in the "Context" (see Figure 1) where the different phases of inquiry can take place. The context refers to the physical or theoretical settings of the whole inquiry process, from the initial hypothesis and data collection to the analysis and the dissemination. As such, the context groups together all the phases, emphasising the background that the inquiry will take place. The question under consideration can come from direct observation of the natural environment or from theoretical discussion/sources during the learning process. Although, the context is particularly important during the phases of data collection and data analysis, it influences the overall inquiry process and affects the result of the empirical studies.

The continuous relation of the inquiry process to the context is one of the innovative elements of the weSPOT IBL model, as it makes explicit the role of the outside word during scientific inquiries. Dewey (1989) has 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.

Flexibility

The different phases of the weSPOT IBL model are interconnected. Students/learners and teachers can start their scientific inquiry at any phase depending on their educational goals. 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 pedagogic 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. Students and teachers can move from one phase to the next depending on their needs and their focus without following a pre-determined series of steps.

Reflection

The weSPOT inquiry-based learning model places reflection at the centre of each inquiry phase, sees 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 even at the very beginning when students need to develop a question or a hypothesis. Students need to reflect upon the question, and evaluate it before they decide to proceed. They also need to reflect while deciding what kind of data they need to collect, how to proceed to data analysis, how to communicate their results.

To highlight the importance of reflection at each stage of the inquiry process and not only at the end is essential for successful scientific inquiries. Indeed, as mentioned earlier, successful scientific investigations require from the investigator certain mental attitudes such as, curiosity, scepticism, and objectivity (Hunt and Colander 2010), which are more likely to be developed when students reflect at every step of their inquiries.

weSPOT Diagnostic Framework

Apart from defining a reference model for inquiry-based learning skills, another developmental aspect within weSPOT project is the creation of a diagnostic instrument for measuring inquiry skills. The diagnostic framework for the pedagogical diagnosis –that will be presented below- 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.

General Approach

In recent years, several research groups, both in the field of computer science (Lockyer and Dawson 2011; Duval 2011; Dyckhoff et al. 2012) and cognitive science (Anderson et al. 2010; Augustin et al. 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. The framework proposed here integrates measurement/inference algorithms built upon bottom-up approaches as well as top-down, i.e. theory-driven approaches. The general research question to be addressed is "*What tells us the behavior in* [virtual environments] *about psychological constructs*..." (Schönbrodt and Asendorpf 2011, 8). By successfully addressing this question a huge potential for pedagogical and psychological research can be expected. First, while the observation of human behaviour 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.

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

Top-Down Approach: Applying the Formal Concept Analysis

In a first step, we draw on the Formal Concept Analysis (Ganter, Stumme, and Wille 2005) to define relationships between objects and attributes, which – in the context of weSPOT – correspond to inquiry skills and observable tasks performed by the students, respectively. To this end, skill × task-tables (number 1 in Figure 2) will be given to experts (i.e., pedagogues). They will be asked to set a cross in a particular cell whenever they assume that the corresponding attribute/task (e.g. conducting simulations) belongs to the given object/skill (e.g. quantitative skills). In this way a structure of the domain emerges, which is called *formal context*. By means of FCA-algorithms, the consistency of different formal contexts defined by different experts can be examined and *sub-superconcept* relations can be derived (see number 2 in Figure 2). Finally, the identified mapping of tasks on skills is a prerequisite for conducting a non-invasive measurement within the weSPOT environment (number 3): In case of valid and reliable mappings that can be tested in the course of evaluation studies, observing a student's tasks allows for inferring a first set of potential skills.

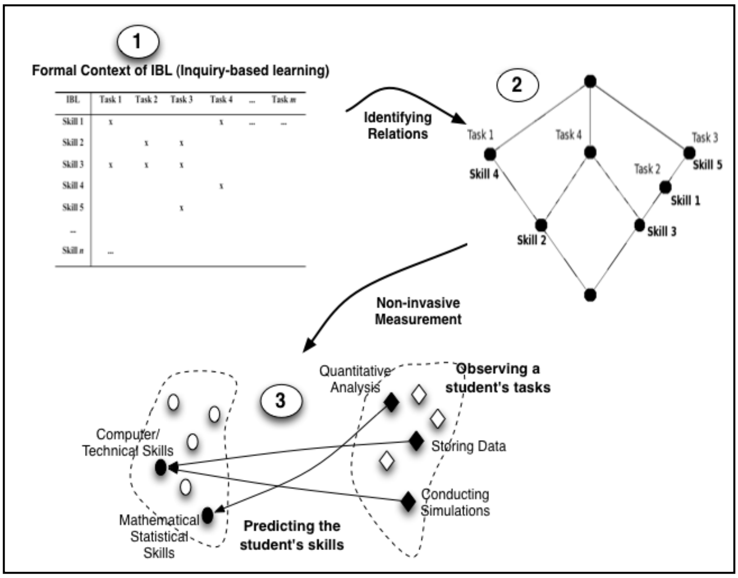

Figure 2: Procedure of applying FCA in weSPOT

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

Referring to Lindstaedt et al. (2009), a user model only based on predefined tasks performed does not exploit all available information. 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 a more accurate user model emerges. Therefore, we suggest 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 3 depicts a draft of an interplay between the top-down approach (FCA), yielding a first distribution of probabilities across the students' skills (that we call ‘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. 0.43) than skills associated with unperformed 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 3). 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 $p(s_i|\text{KIE})$, i.e., the probability of a skill s_i (identified by the FCA) given a particular pattern of observed KIE. This conditional probability can be calculated by applying the Bayes' theorem, which yields 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 3),

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

While $p(s_i)$ is the result of the precedent FCA-computations (number 1), the conditional parameter $p(\text{KIE}|s_i)$, 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 extract the association between KIE-patterns (tracked within the weSPOT-environment) and skills that will be measured by questionnaires during evaluation studies.

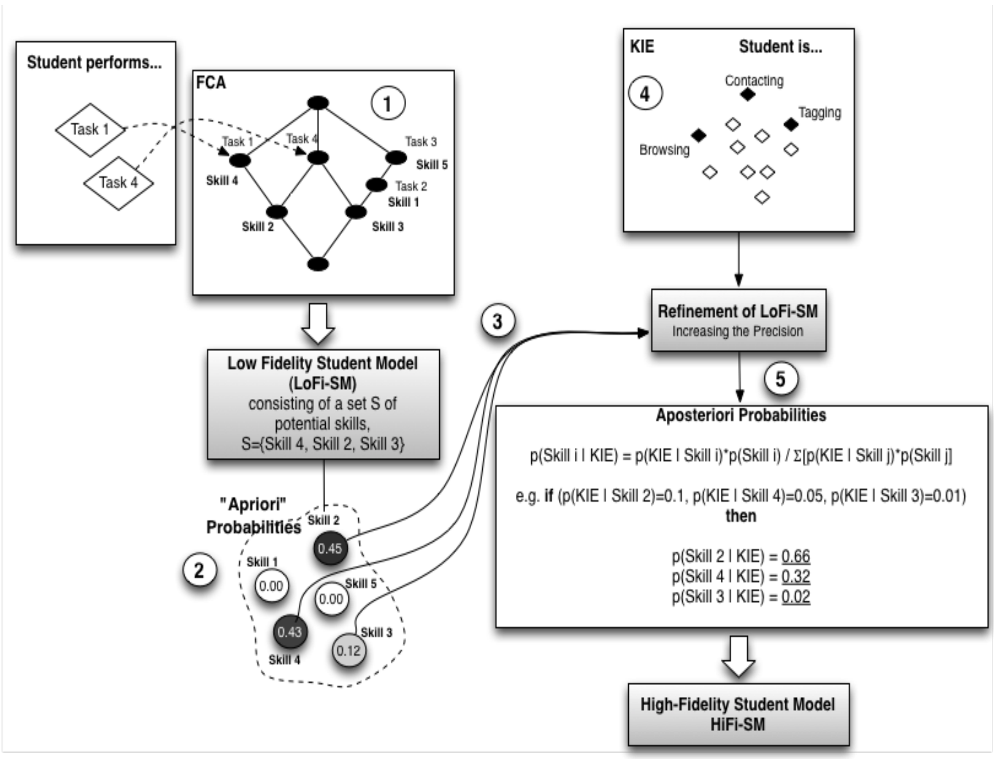

Figure 3: Shaping the probability distribution over skills by KIE-patterns

Testing

Pilot studies planned to be conducted during the 2013-14 Autumn-Winter period across 6 EU countries within the weSPOT project will test the reference model and make use of the diagnostic instrument described above.

In specific, during pilot testing, the weSPOT project plans to implement a working environment that allows the easy linking of inquiry activities with school curricula and legacy systems. The working environment will be based on technological products developed within the project:

- smart support tools for orchestrating inquiry workflows including mobile apps, learning analytics support, and social collaboration on scientific inquiry,

- social media integration and viral marketing of scientific inquiry linked to school legacy systems and an open badge system.

The working environment will also be based on the theoretical framework described in this paper, with an ambitious aim to integrate pedagogical advances to technological innovation.

The products will be customized and evaluated in 16 test-beds (schools, institutes, universities) across 6 European countries (United Kingdom, Netherlands, Greece, Germany, Bulgaria, Slovenia). The pilot studies will engage 58 teachers and 1000 students, from 12 to 25 years old. The working environment will work in 8 domains:

Food: Examples of plastics contaminating food have been reported with most plastic types. Learners involved in this scenario will be acting as chemical engineers and food scientists.
Biodiversity: Biodiversity is increasingly recognized as critical to human life. Species are more threatened than ever by human activities like urbanization, climate change, deforestation, agricultural expansion, overexploitation of marine ecosystems. Students' inquiry projects could be related to breeding program for endangered species, bird populations in a garden, bug populations in a flower bed, fauna in a pond-ecosystem, other food webs or succession.
Earthquake: Students will download and format near real-time and historical earthquake data and seismogram displays from various sources (e.g. FORTH's seismological station). Students will create spreadsheets and graphs to explore earthquake magnitude, wave amplitude, energy release, frequency occurrence and location.
Sea: High school students go on ½ year trip across the Atlantic Ocean, on their journey; they have normal class and run the clipper. In addition they explore their environment (water, air, physics on board, astronomy…) in personal projects.
Energy: Using discussion students should identify disadvantages of the current building from the energy-efficiency point of view. They should try to predict (providing evidence) future energy problems. Forming teams, they will work on developing reasonable ideas for future energy-efficient buildings.
School: The student should provide research on expected changes in the future school. Possible directions:dropping and new courses; the future classroom – real or virtual; new ICTs in education; the role of the teacher; students relationships; new educational approaches; formal-informal learning, the role of lifelong learning etc.
Innovation: The students will reflect their learning environment (or other environments) to determine some of the most pertinent problems, obstacles, "things they do not like", etc. With the help of a teacher those points will then be contemplated form the view point of what out of that could be changed and what (unfortunately) could not be changed.
Economy: In recent published Economic Complexity Atlas Slovenia is the 10th country with high Economic Complexity Index (ECI), and Bosnia is ranked on 8th place as country which has large ECI and small GDP (so it is expected that it will develop fast in next period). It would be interesting to research how these facts can be used for faster economic and social developments.

During the pilot studies, data will be collected through the diagnostic instrument in regard of learners' inquiry skills, as well as users' feedback on the applicability of the products and the theoretical approach followed. The analysis of the data will elaborate further theoretical work in regard of the theoretical orientation , which will be taken into account for the next development iteration.

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