TEACHERS' DESIGNS OF WEB-BASED INQUIRY LEARNING ENVIRONMENTS AS A PROBE FOR INQUIRY TEACHING AND LEARNING FRAMEWORKS

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ABSTRACT
A growing number of studies have reported that teachers face many challenges in conceptualizing and enacting inquiry–based teaching and learning. Even though teacher designed approaches are considered an important pathway that could assist teachers in dealing with important aspects of inquiry based-teaching, the development of relevant tools that can scaffold teachers in this process has not received appropriate attention. The purpose of this study was to examine how teachers designed web-based inquiry learning environments on a specific platform that allows them to structure content, and provide technology-realized scaffolding in a variety of ways. Participants in the study were ten graduate students enrolled in a science teacher preparation course. Data were collected using multiple methods and analyzed qualitatively. Our analyses show that the process of design provided a valuable vehicle for teachers' challenges and approaches to surface and be realized. Teachers' designs shared common characteristics, as a result of the scaffolding they received through the course; nevertheless varied in the way pedagogical and epistemological characteristics of inquiry-based learning were weaved together in inquiry sequences and tasks. The results of the study provide implications for the design of tools that will address the diverse needs of teachers and provide them with scaffolding in designing technologically enhanced inquiry-based learning environments.

KEYWORDS
Inquiry-based learning, science, web-based learning environments, science teachers' education, instructional design, design-based learning

THE INQUIRY BASED SCIENCE TEACHER: LEARNING BY DESIGN

Inquiry-based approaches to teaching and learning are placed at the centre of current reform efforts in science education (AAAS, 1993; NRC, 1996). Inquiry, a multifaceted term, consolidates the reasoning and methodological characteristics of authentic science. Being familiar with science as a way of knowing is considered a necessary competency for the citizen of tomorrow, as he will increasingly be involved in shaping collective decisions for important socio-scientific controversies.

Inquiry based learning and teaching is not an easy task for any educational system. It involves an epistemology that often contradicts the conventions traditional schooling is based on, e.g. teaching practices, organizational structure, long-standing beliefs and attitudes by teachers, administrators and students.

As with any innovation in education, curriculum developers rely on teachers to bring inquiry-based teaching to life and successfully deal with the demanding task of transforming theory into practice. Research has shown that teachers face many challenges in conceptualizing inquiry-based approaches (Abd-El-Khalick et al., 2004; Anderson, 2002). These challenges are due to the demanding and non-traditional roles of inquiry teaching (Crawford, 2000) that they come to surface when teachers try to reconcile inquiry teaching and learning with school culture and assessment standards (Kang and Wallace, 2001).

Studies report that teachers and their intention and ability to teach science as inquiry, are influenced by personal beliefs about teaching, students, effective teaching practices, and the purpose of education (Kang and Wallace, 2001; Crawford, 2007). Research in teacher education points out the need to frame teacher learning in constructivist learning theory (Anderson et al., 1994; Borko & Putnam, l996; Carter, l990) and provide teachers professional development contexts where they can reflect on their knowledge, beliefs and understandings (Davis, 2003).

We propose Learning by Design as an approach to teacher preparation for inquiry-based learning and teaching. Learning by Design emerges from the constructionist paradigm, which emphasizes the value of learning through creating, programming, or participating in other forms of designing (Orey, 2001). According to Papert (1991) design, the process of engaging learners in constructing a public artifact in general or a computer-based artifact in particular, is a productive way to support learning. A study by (Kali & Linn, in press) provides evidence showing that the design of educational technologies can provide a context for teachers to examine their own epistemological beliefs, negotiate them with peers and experts, and explore them in relation to theory. In the case of inquiry-based learning and teaching, the process of design can give a context for teachers to confront their beliefs and realizations of learning in general and of inquiry in particular, through concrete and shared examples and experiences.

TECHNOLOGICALLY ENHANCED INQUIRY-BASED LEARNING ENVIRONMENTS

Prior research has highlighted an approach to inquiry-based learning referred to as the evidence-explanation approach (Abd-El-Khalick et al, 2004). This approach seeks to engage students in investigations, often technologically supported, of authentic fuzzy problems and support them in constructing meaning through building scientific models and explanations. A number of technology enhanced learning environments have been developed along the lines of this inquiry-learning paradigm, such as WISE (Linn, 1995); BGuiLe (Reiser et al., 2001); and Stochasmos (Kyza & Constantinou, 2007). These environments afford a style of project-based work that takes advantage of the richness and complexity of data to provide authentic science opportunities (Soloway, Krajcik, Blumenfeld, & Marx, 1996). Students are engaged in tasks where they need to make use of large amounts of data, pursue questions and construct explanations.

Learning in these environments poses new demands for students and teachers. Students need to become self-monitoring, engage in strategic planning, reflect on strategies used, and evaluate the outcomes of using these strategies, while maintaining goal orientation (Loh et al. 2001). Accordingly, teachers are expected to be able to support students in this reflective process by providing appropriate scaffolding, guiding students to make sense of their observations, using logic and reasoning, and using data as evidence (Crawford, 2007).

Along the lines of the above inquiry-based learning paradigm, we interpret inquiry as a teaching and learning framework that seeks to promote collaborative development of conceptual models with interpretive capacity through classroom practices and discourse that highlights some aspects of authentic science. Our framework draws on the theoretical traditions of conceptual change (Posner et al., 1982), social constructivism (Vygotsky, 1978) and situated cognition (Brown et al., 1989) and translates into a set of competencies that the theoretically informed science teacher should be able to demonstrate. These include:

- Taking into account learners' characteristics and alternative conceptual and epistemological frameworks
- Pursuing goals related to various components that constitute learning in science
- Sequencing activities based on content analysis and characteristics of science as a way of knowing
- Designing activities of constructive nature and providing the necessary scaffolding

The present study sought to explore the affordances of learning by design as a method of preparing teachers for inquiry-based learning and teaching, using a technologically enhanced inquiry-learning platform. Our primary questions were: 1) In what ways did teachers approach inquiry-based learning and teaching through the task of designing web-based inquiry learning environments? 2) How did the context of designing a web-based inquiry learning environment challenge teachers' inquiry learning and teaching frameworks?

METHODS

Developing a context to promote inquiry-based learning and teaching through design

The present study took place during a semester long graduate education course about the role of new technologies in science learning and teaching, at the University of Cyprus. The course followed a design-based learning approach and engaged participants in the task of designing their own web-based inquiry-learning environments using a given web-based authoring tool. The course was structured around three key features: a) a design task that engaged teachers in the design of inquiry-based learning environments, b) a design platform that participants used to develop their environments and c) a web-based course environment seeking to promote collaboration between teachers, and to scaffold them by providing prompts for planning and reflecting on their designs.

Scaffolding teachers in the design of inquiry based learning environments

One of the course's main goals was to scaffold teachers in the task they embarked on, while giving them enough space for self-regulation and reflection. In this respect, scaffolding was provided through the course's web-environment where participants were asked to go through specific tasks that were developed drawing on a general curriculum development framework, the Curriculum Design Principles (Singer et al., 2000), (table 1). These tasks shaped a loosely structured design sequence that participants were asked to follow during the process of designing and share their reflections with their peers.

Participants developed their web-based inquiry learning environments using STOCHASMOS (Kyza & Constantinou, 2007), a web-based, open-ended authoring tool that employs a combination of features seeking to support students with such inquiry activities as identifying and selecting data to use as evidence, organizing data, and making sense and interpreting data in the light of hypotheses. The platform provided implicit scaffolding to teachers since its structure and functionality could guide teachers in taking specific design decisions e.g. not to develop teacher directed tasks, give information rich problems, develop activities for peer collaboration etc.

Table 1. Curriculum Design Principles (Singer et al., 2000)

Curriculum Design Principles adopted in the design of the course	
Context	Meaningful, defined problem space that provides intellectual challenge for the learner.
Standards based	Publication by larger community experts that defines the language and methods of the larger community.
Inquiry	The accepted method of the scientific community for solving problems; a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena.
Collaboration	Interaction among students, teachers, and community members to share information and negotiate meaning.
Learning tools	Tools that support students in intellectually challenging tasks.
Artifacts	Representations of ideas or concepts that can be shared, critiqued, and revise to enhance learning.
Scaffolds	A series of methods that fade over time to control learning activities that are beyond the novices' capabilities so that they can focus on and master those features of the task that they can grasp quickly.

Participants

Participants in the study were ten graduate students that had first degrees in Physics (n=3) and Elementary Education (n=7). All participants but one had some teaching experience, and two of them were at the time carrying a full teaching load. The remaining eight teachers had jobs in the field of education, e.g. giving private lessons, substituting teachers, but not on a regular basis. Participants worked in pairs for their design project for a total of five projects (see table 2 for participants' backgrounds and groupings). All groups of teachers used the course web-environment and submitted answers to the prompts provided and developed a web-based inquiry-learning environment, which they handed in at the end of the course.

Table 2. Backgrounds and groupings of the course participants

Teachers	Certification Area	Grade Level	Teaching experience	Experience with inquiry-based teaching	Project groups
Gloria	Elementary science	1-6	Limited	As part of practical training	Pair1
John	Elementary science	1-6	Limited	As part of practical training	
Chloe	Elementary science	1-6	Limited	As part of practical training	Pair2
Sarah	Elementary science	1-6	Limited	As part of practical training	
Helen	Physics	7-12	5 years	Applied it once	Pair3
Cindy	Physics	7-12	None	No	
Jason	Physics	7-12	10 years	No	Pair4
Mary	Elementary science	1-6	Limited	As part of practical training	
George	Elementary science	1-6	Limited	No	Pair5
Sandy	Elementary science	1-6	Limited	No	

Data Collection, Analysis and Interpretation

The study used a multiple case method and cross-case comparison design to determine commonalities and differences among the five cases of teachers' approaches to designing inquiry-based learning and teaching. Multiple data sources included (a) Researcher's notes from participants' observations; (b) Teachers' written definitions of inquiry, as documented in questionnaires administered during the first and the last course meeting; (c) Responses to reflection prompts submitted through the course's web-environment (d) The web-based learning environments participants designed as part of their course work (see table 3 for an overview of the environments developed by the participants).

Participants' written definitions of inquiry and reflection notes were analyzed qualitatively using the constant comparative method (Glaser & Strauss, 1967). In each analysis, we tracked the emerging themes for each participant and iteratively compared them to the themes emerging from the analysis of the other participants.

The web-based inquiry learning environments that participants developed were analyzed using three content analysis schemes each referring to a distinct characteristic of the end-product: a) for describing the level of inquiry of each environment we used the "five essential features of inquiry" scheme (NRC, 2000), b) for describing the ways scaffolding was provided to students through the environments, scaffolding prompts were analysed according to the scaffolding guidelines and strategies developed by Quintana et al. (2004) and c) we worked inductively, using the constant comparative method, to describe the underlying inquiry pattern on which planned activities and interactions were sequenced. Researcher's notes from participants' observations contributed to the internal validity of the study.

Triangulation of the data sources (participants' background data, analyzed definitions of inquiry, reflection notes, and project work, and author's observation notes) all contributed towards developing a profile for every group of participants. These profiles were arranged in a matrix using a technique described by Miles and Huberman (1994). The displayed profiles contributed to developing cases of each pair of participants (see table 4). In this way a cross-case comparison of the five groups was achieved, in the effort to develop an evidence-based explanation for understanding the way participants approached inquiry-based learning and teaching.

Table 3. Overview of the web-based inquiry learning environments developed by groups of participants

Participants	**Intended Grade Level**	**Topic type**	**Science subject and topic**	**Driving Question**
Pair 1	Elementary 6th grade	Socio-scientific	Environmental education: Water management	Can golf courses be built in Cyprus, without significantly diminishing the island's water reserves?
Pair2	Elementary 6th grade	Science concepts	Physics: Friction	What caused the death of two climbers?
Pair 3	Upper 1st grade	Science concepts	Physics: Acoustic properties of materials	How would you acoustically condition a disco?
Pair 4	Middle 1st – 3rd grade	Socio-scientific	Physics-Chemistry: Air quality	Which part of Cyprus would you recommend for settling as far as its air quality?
Pair5	Elementary 6th grade	Socio-scientific	Biology: Food safety, food borne bacteria	What is the reason for the massive absences of a primary school's pupils?

FINDINGS

Teachers' approaches to inquiry based-learning after design: An overview

Understandings portrayed through definitions

As it was evident at the beginning of the course, all five groups of teachers showed enthusiasm and at the same time scepticism regarding the project work they were asked to engage in. Enthusiasm was mostly related to the fact that they would be using a technological web-based tool in developing their projects, whereas scepticism seemed to be mostly related to their effort to develop and clarify their understanding of inquiry-based learning and teaching. As stated in questionnaires completed at the beginning of the course, participants' past experiences with inquiry-based learning were limited: four teachers noted that they had no previous experience with the approach, five teachers said that they experimented with inquiry-based learning and teaching while they were having their school practice as students, and only one teacher had tried inquiry-based teaching with her own students in authentic school settings (see table 2). This limited experience with the approach made participants impatient to reach or receive from the course instructor a clear definition of inquiry-based learning and its constituent parts. Participants' reactions to the activities on the course's web-environment, aiming to scaffold them through the task of designing, varied; some faced them as a challenging innovative practice and others as an activity adding on to their already heavy workload.

At the end of the course teachers were asked to describe their understanding of inquiry-based learning and teaching. After analyzing their answers two main themes emerged: portraying inquiry-based learning and teaching by articulating its theoretical underpinnings, or by articulating related issues of practice.

All participants (n=10) referred to constructivism as the underlying theoretical model of inquiry-based learning and teaching. Some referred explicitly to the term while some described constructivist characteristics of inquiry-based learning. One pair of participants explicitly referred to social constructivism and how this learning theory can be illustrated by inquiry-based learning. Some participants (n=4) noted that inquiry-based learning in science resembles the way real scientists work. However, only one participant stated explicitly that inquiry-based learning contributes to students' understanding of science as a way of knowing. This is shown in the excerpt below:

> *Inquiry based learning and the underlying STOCHASMOS philosophy of evidence based explanations supports students to reach a scientific way of thinking and*

> *working…The nature of science is one of the best elements portrayed on STOCHASMOS that is absent in traditional teaching approaches. Through my experiences in this course, I was able to appreciate its importance.* (George, questionnaire)

The other way teachers portrayed their understandings of inquiry-based learning was through articulating practical issues having to do with the approach, e.g. methodological characteristics or examples of practice. Most participants (n=8) when asked to give their understandings of inquiry-based learning in science gave descriptions of science related school tasks e.g. producing a research question, collecting, interpreting data, and designing experiments. Some participants (n=5) acknowledged that inquiry-based learning is a process with distinct characteristics without clarifying which these characteristics are, while some mentioned that it is a question driven approach (n=3).

Understandings portrayed through designs

Groups of teachers developed a total of five web-based inquiry learning environments, using the authoring tool on STOCHASMOS platform. These environments consisted of two main parts: a part called "Inquiry environment" where data in various forms (pictures, text, quotes from the press, databases) are organized in pages and sub-pages, and a part called "Workspace" where students can work with data that they select from the Inquiry Environment independently or using pre-designed by the teacher templates for data elaboration.

Level of inquiry

The web-based inquiry learning environments developed by participants were analyzed for the level of inquiry (level 1, 2, or 3), using a content analysis rating scheme based on the five essential features of inquiry as developed by the National Science Education Standards, (NRC, 2000). For reaching an overall rating for the environments, all planned activities portrayed in each environment were categorized according to the five essential features of inquiry and were given a grade. Finally an average for each feature was estimated that was again averaged with all five grades corresponding to each essential feature of inquiry. All five environments received a rating between 1.5 and 2 (for details see table 5).

Ways of providing scaffolding

A central feature of STOCHASMOS authoring platform are the tools provided for organizing scaffolding and making it available to students in a variety of ways. Main tools for providing scaffolding are: a)"Hints Pages", pop-up screens that are available for each page in the "Inquiry Environment", b) "Templates" worksheets developed by teachers for students to use in order to progress with their inquiry, c) Functionality that allows collaboration between groups of students through peer review activities, a chat tool and a forum.

Participants used most of the tools available by the platform to provide scaffolding. They included scaffolding prompts in Hints pages and in Templates, some incorporated peer review activities and chatting at specific points of their unit's activity sequence. Scaffolding prompts were analysed according to the Scaffolding Design Framework (Quintana et al., 2004) and placed in the following three categories: a) Prompts for Process Management, aiming at supporting students in taking strategic decisions involved in controlling the inquiry process, b) Prompts for articulation and reflection which aim at supporting the process of constructing, evaluating and articulating what has been learned and c) Prompts for sense making, aiming at supporting students in the basic operations of testing hypotheses and interpreting data.

Figure 1 illustrates how the overall scaffolding provided on the environments by each group is distributed to the three types of strategies. All groups followed the same trend in the kinds of prompts they provided: Process management prompts were employed amply around the environments and in all five cases presented more than the 50% of all prompts provided. This type of prompts aimed at assisting students in dealing with routine tasks as the organization of work products, and the navigation between tools and activities. Reflection and articulation prompts were used at a lower frequency. Finally, sense making prompts were scarcely employed, mainly providing learners with advance organizers as incomplete tables or concept maps that aimed at assisting them to deal with new knowledge.

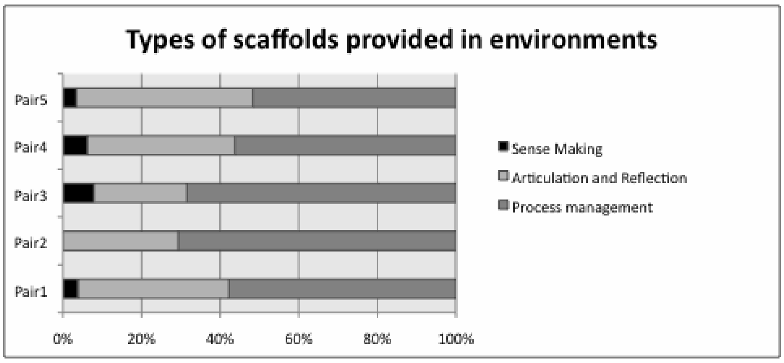

Figure 1. Appearance of the three types of scaffolding prompts in teachers' designs

Coherence of inquiry patterns

The environments were also analyzed as far as the way learning activities were sequenced on the environment. First we developed a matrix showing the sequence of activities for all environments. Using the constant comparative method we traced common characteristics and patterns and ended up to the following three characteristics that contributed to what we named "coherence of inquiry pattern": a) Recurrence of data selection and analysis activities, b) Blending of reflection and articulation activities with data selection, and c) Correspondence of tasks to required skills.

The first characteristic that became apparent in this analysis was the recurrence of data selection and analysis activities. Three out of five groups structured their environments in a way that students were guided to collect and analyse data over and over again for two main reasons: to refine their existing work or to extend their work in order to include more data types. Two environments did not bear this characteristic. In one of these two cases students had to go through a series of different tasks in order to complete their work, each task relating to demonstrating different skills, whereas in the other case, the data selection task a straightforward retelling task and students were not prompted to refine or extend their data selection and analysis process.

A second emergent characteristic was whether groups managed to blend reflection and articulation activities with the actual data selection and analysis process. Four out of five groups related reflection and articulation activities with data selection and analysis, however each one at a different degree: in three out of four cases reflection and articulation activities were structured in a consistent way, while only in two cases peer review activities were included. In the case of the fourth environment that included articulation and reflection activities, this was done at a small degree, and the placement of these activities in did not seem to make any contribution to the data selection and analysis process.

A third characteristic that emerged from the analysis of environments' inquiry patterns was the correspondence of activities to required reasoning skills. In other words whether the skills required to perform the various tasks in the environments were addressed through the environment or were faced as pre-requisite skills. Three out of five environments had a high degree of correspondence between required skills and tasks. In the remaining two cases, data analysis was closely related to demonstrating skills – decision-making skills in one case, design of experiments skills in the other case – that were not addressed through the environments and could not be thought of as pre-existing skills, taking in mind the age level of the students the environments were addressed to. In the case of the environment that required students to demonstrate decision-making skills, these were not addressed at all; in the case of the environment that design-of-experiments skills were required, teachers provided relative scaffolding, however this approached only the formality and not the reasoning related to such a task.

Table 5. Teachers' designs of web-based inquiry learning environments

Pair	Theoretical underpinnings reported in written definitions of inquiry	Approaches to inquiry pedagogy as reported in written definitions of inquiry	Coherence of inquiry pattern	Level of inquiry	Percentage of scaffolding prompts employed in web-based environment	Challenges reported by both participants in each group
1	Constructivism, The reflective learner	• Reference to inquiry related tasks • Acknowledging that this learning and teaching approach has specific characteristics • Question driven learning and teaching approach	• No recurrence of data selection and analysis activities • No blending of reflection and articulation activities with data selection • Required reasoning skills not addressed through environment tasks	1.6	Sense making 4% Articulation and reflection 38% Process management 58%	• Specifying an inquiry topic • Specifying and sequencing tasks • Goal setting
2	Constructivism	• Reference to inquiry related tasks • Acknowledging that this learning and teaching approach has specific characteristics • Distinguishing the learning approach from the process followed by scientists • Question driven learning and teaching approach	• Recurrence of data selection and analysis activities • Blending of reflection and articulation activities with data selection • Required reasoning skills not addressed through environment tasks	1.6	Sense making 0% Articulation and reflection 29% Process management 71%	• Specifying an inquiry topic
3	Constructivism Epistemologically oriented approach	• Reference to inquiry related tasks	• Recurrence of data selection and analysis activities • Blending of reflection and articulation activities with data selection • Required reasoning skills addressed through environment tasks	1.8	Sense making 8% Articulation and reflection 24% Process management 68%	• Concept elaboration and understanding • Experimentation • Specifying and sequencing tasks
4	Constructivism Epistemologically oriented approach	• Reference to inquiry related tasks	• No recurrence of data selection and analysis activities • Blending of reflection and articulation activities with data selection • Required reasoning skills not addressed through environment tasks	1.6	Sense making 6% Articulation and reflection 38% Process management 56%	• Goal setting
5	Constructivism, prior knowledge Social constructivism Epistemologically oriented approach	• Reference to inquiry related tasks • Question driven learning and teaching approach	• Recurrence of data selection and analysis activities • Blending of reflection and articulation activities with data selection • Required reasoning skills addressed through environment tasks	1.6	Sense making 3% Articulation and reflection 45% Process management 52%	• Specifying an inquiry topic • Goal setting • Specifying and sequencing tasks • The open-ended nature of the approach

Two cases of approaches to inquiry-based learning and teaching through design

The web-based learning environments that the five pairs of teachers developed are in fact their own personal learning artifacts that were built through the process of developing understandings about inquiry-based learning and teaching. These environments displayed a range of approaches to inquiry-based learning and teaching. Following we present two cases of environments, that of pair 1 and pair 5, as we believe these can illustrate some important findings of the study. In both groups participated two pre-service elementary school teachers. Both environments dealt with a socio-scientific issue and received a 1.6 rate for their level of inquiry (for details about the environments, see table 3).

Pair 5: The most coherent inquiry environment

Sandy and George, the teachers that were grouped together in pair 5, as they both stated at the beginning of the course, had no previous experiences with inquiry-based learning and teaching. The definitions they gave to inquiry-based learning and teaching at the end of the course included both theoretical and methodological characteristics of the approach, and were the only couple to refer to social constructivism, a term introduced through the course. George explicitly pointed out how inquiry-based learning contributes to the development of students' understanding of science as a way of knowing, and Sandy was the only participant to refer to how inquiry-based learning should make use of students' prior knowledge.

Analyzing their reflection notes revealed four common challenges that they were faced with through the development of their environment: specifying an inquiry problem, goal setting, specifying and sequencing tasks and dealing with the open-ended nature of the approach. The following excerpts illustrate the way Sandy and George faced similar methodological challenges: a) in sequencing and specifying inquiry tasks, and b) in trying to comply with the open-ended nature of inquiry-based learning.

> *George: A problem we have to deal with is that the students' final learning products have to come out from the elaboration of various parameters. (George, reflection notes)*
> *Sandy: Developing a sequence of activities is not as hard as finding a way to present the activities so that they will serve your goals. We had to deal with the problem of how to present students the data at each stage. (Sandy, reflection notes)*
>
> *George: I am worried about students' final product, if it will demonstrate all the desired characteristics. Will students manage to back up their views with arguments, taking in mind all the sub-products of their work? (George, reflection notes)*
> *Sandy: I am worried about the fact that there is no single answer for students to reach. (Sandy, reflection notes)*

The web-based learning environment developed by group 5 presented all three relative characteristics of coherence in the environment's inquiry pattern and received a rate of 1.6 regarding its level of inquiry. The environment was built on a carefully planned inquiry pattern, where information selection and analysis activities were blended with reflection and articulation activities. Students engaged in the environment had to repeat the same steps a number of times, each time dealing with a different knowledge issue, e.g. food borne bacteria, school records of absences etc, and send reports to their peers informing them about the progress of their work. The required student skills of prioritizing data as evidence were addressed through activities that preceded students' data selection and analysis process. Scaffolding prompts provided in the environment were almost equally distributed between process management prompts (52%) and articulation and reflection prompts (45%). Sense making prompts (3%) had a very limited appearance in the environment, however this could be interpreted taking in mind that only one scientific concept –food borne bacteria- was introduced.

Pair 1: The least coherent inquiry environment

John and Gloria, the teachers that were grouped together in pair 1, both reported that they have planned inquiry-based lessons in science before as part of their school practice experience when they were undergraduate students. The definitions they gave to inquiry-based learning and teaching both referred to constructivism as the learning foundation of inquiry-based learning and teaching, while Gloria referred explicitly to the reflective nature of learning that takes place. They both gave the examples of design of experiments and data analysis as inquiry related tasks. As far as the methodological issues related to the approach, John noted that inquiry-based learning follows a specific scientific process without clarifying its characteristics and Gloria that it is a question driven approach.

Analyzing the reflection notes submitted through the course website revealed three common challenges that both teachers were faced with: specifying an inquiry topic, specifying and sequencing tasks and goal setting. Both teachers were doubtful about the broadness of the inquiry problem and how much direction should it give to the students. The following excerpts illustrate this issue:

> *We are very much concerned with our scenario and I believe it is too directing and shows what the problem is… so we should not ask students to inquire into this problem. (John, reflection notes)*

> *As far as our scenario is concerned we used a newspaper article, which I find very useful because it makes our learning environment authentic. I am concerned though whether we should let the students find out themselves about the problem of water shortage or whether we should state this in our scenario. (Gloria reflection notes)*

The environment they produced presented none of the three relative characteristics of coherence in the environment's inquiry pattern, while it received a rate of 1.6 regarding its level of inquiry. A main challenge that teachers faced was to specify and embed their chosen science topic into a meaningful and relevant problem for the students to solve. Through their reflection notes became evident that they managed to find such a problem, but then they were faced with the challenge of how to provide and sequence activities so that students can elaborate on the problem. Even though the driving question they finally chose was a decision making one, they did not provide students with sufficient data that could portray the complexity of the issue. Not being clear about the problem they were dealing with resulted in an environment with a series of activities that seemed disconnected and could not guide learners to build understanding. Scaffolding prompts provided in the environment were again distributed between process management prompts (58%) and articulation and reflection prompts (38%), whereas sense-making prompts, since scientific concepts introduced through the environment were only few, had a very limited appearance (4%).

DISCUSSION

Through the study, it has become clear that designing for inquiry-based learning and teaching is a complex, multifaceted task. We were able to determine some of the challenges related to the task through approaching inquiry-based learning and teaching through design, by assigning teachers the role of designers. Through the analysis of the written definitions that participants gave at the end of the course, became evident that from a pedagogical viewpoint they could give clear descriptions of the characteristics that inquiry based learning approaches should entail e.g. learners being active, promoting collaboration, reflection, designing of experiments, and skills as learning how to learn. However, no participants referred to the epistemic characteristics that should be evident in inquiry-based learning, e.g. building models with interpretive capacity, evaluating and prioritizing data in light of hypothesis, developing explanations based on evidence. Even though teachers gave descriptions of inquiry related classroom tasks, these descriptions were made using the school science formalism and not in an effort to portray science as a way of knowing. The following excerpts illustrate this point:

> *Inquiry-based learning is a method of teaching in which students are asked to answer to a problem by following the stages of the scientific process (produce research*

questions, recognize and control variables, experiment, record observations, organize, and analyze data, record findings and explanations). (Chloe, post-questionnaire)

Students inquire aiming to discover knowledge that is not just served to them. Therefore students do not become consumers of knowledge, but are treated as being responsible for their own learning, since they are asked to design experiments, study sources of information, make observations, collect, organize and interpret data, write explanations and make conclusions in an effort to grasp scientific knowledge. (Sandy, post questionnaire)

Overall, three out of five environments produced (pair1, 2 and 4) also portray the above tension. In these three cases inquiry patterns that guided the sequence of activities were neither epistemic nor pedagogic in nature; they rather served an administrative purpose. Students were not guided to approach the problem presented to them in a systematic way that showed characteristics of authentic science. However, the remaining two environments (pair3 and 5) systematically dealt with student developing understandings through recurrent cycles of data selection and analysis.

Two characteristics were found to be common across all environments: the level of inquiry, according to NRC five essential features of classroom inquiry (2000), and the way scaffolding was distributed on the environment according to three scaffolding types of prompts. Level of inquiry describes how open, student-directed (level 1) or closed, teacher-directed an inquiry activity is (level 3). All five environments were given an average rating between 1.5 and 2, meaning that they allowed the learner a level of independence in carrying out the various tasks, but the task descriptions, the sequence of activities, and the questions pursued were always provided by the environment. Accordingly, the majority of scaffolding prompts (figure 1) aimed at providing process management guidance, while sense-making guidance was almost absent in most environments.

Teachers seemed to be concerned about the flow of activities and over-emphasized the sequence of steps that students needed to follow. According to Kyza and Constantinou (2007) the intent behind the software-based scaffolding is to support students when engaged in scientific inquiry largely independently and to minimize the need to continually refer to the teacher for tasks they could accomplish on their own. It is expected that this type of scaffolding will be complemented by other teacher and task-related scaffolding, such as teacher-group assessment conversations, whole class discussions, peer-review opportunities, etc. However in the case of the teachers' environments, many routine directions, not consisted with the platform's philosophy, were included as scaffolding prompts. Figure 2 illustrates this point.

The above findings support those of Kali and Ronen-Fuhrmann (2007) who examined how graduate education students design educational technologies. Some of the challenges they reported were that their students' sequences focused on which content should be learned first and how to communicate a hierarchy of knowledge, tended to start their sequences with instructions, instead of designing guidance that diagnoses learners' possible confusions, or enables learners to link to specific instructions when and if these are needed.

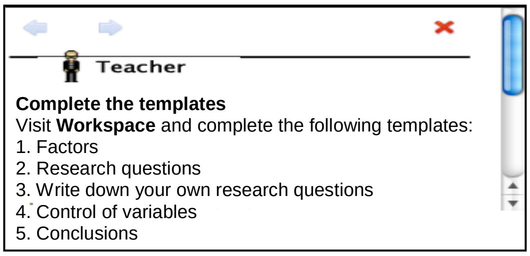

Figure 2. Scaffolding prompt provided on the environment developed by Pair 3

CONCLUSION

Using design as an approach to prepare teachers for inquiry-based learning and teaching, allowed us to identify, and more importantly, to illustrate challenges that teachers are up against when dealing with this task. Moreover it gave us the chance to break into teachers' beliefs and understandings when these were put into practice – in our case, when designing an inquiry-based learning environment.

A possible element that might have added to the complexity of teachers' design task was the technological nature of the environment they were asked to develop. Teaching with technological tools is not a well-established practice, and it is possible to produce uncertainty in realizations of the role of the teacher and the role of the students. On the other hand, developing an inquiry-based learning environment on a given platform, even though technological, provided teachers a framework where inquiry-based learning principles were embedded that could scaffold them in their task. This was evident in two characteristics that were common across all five environments; the level of inquiry pursued, that is the level of openness of the various inquiry tasks that teachers developed and the way scaffolding was provided through prompts.

Our analysis indicates a consistency between understandings emerging from written definitions of inquiry-based learning and teaching and understandings emerging from teachers' learning artifacts. A main theme reported was teachers' ability to describe inquiry-based learning in pedagogic terms but not in scientific terms and this resulted in developing environments with vague or oversimplifying inquiry tasks, aiming at a specific "scientific process".

The present study has implications in the design of teacher preparation for inquiry-based learning and teaching. Future research should focus on how to provide teachers with appropriate scaffolding so that they can overcome challenges posed by the complex nature of science and by the even more complex task of designing teaching and learning in an authentic, inquiry-based scientific context. A possible direction that this could take is to develop a methodology e.g. on how to elaborate on scientific concepts and promote sense-making, how to sequence authentic inquiry patterns and blend with constructivist learning characteristics, using teachers' own language of practice.

As Crawford (2007) points out, "responsibility for enhancing prospective teachers' understandings of scientific inquiry, abilities regarding the nature of scientific inquiry, and abilities to design and carry out reform based instruction, all fall squarely upon the shoulders of the science teacher educator" (pg. 638). Aligned with the call for constructivist teacher preparation approaches, our work gives evidence that suggest *design* as a possible pathway that can support teachers in dealing with the complex nature of inquiry-based learning and teaching.

REFERENCES

Abd-El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., Niaz, M., Treagust, D., and Tuan, H.-L. (2004). Inquiry in science education: International perspectives. Science Education, 88(3): 397-419.

American Association for the Advancement of Science. (1990). Science for all Americans. New York: Oxford University Press.

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

Anderson, R. D., & Mitchener, C. P. (1994). Research on science teacher education. In D. L. Gabel (Ed.), Handbook of research on science teaching and learning: A project of the National ScienceTeachers Association (pp. 3–44). New York: Macmillan.

Borko, H.,&Putnam, R. T. (1996). Learning to teach. In R. C. Calfee & D. Berliner (Eds.), Handbook on educational psychology (pp. 673–708). New York: Macmillan.

Brown, J.S., Collins, A. and Duguid, P. (1989). Situated Cognition and the Culture of Learning. Educational Researcher, 18(1) 32-41.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. Journal of Research in Science Teaching, 37, 916-937.

Crawford, B.A. (2007). Learning to teach science and inquiry in the rough and tumble of practice. Journal of Research in Science Teaching, 44(4), 613-642.

Carter, K. (1990). Teachers' knowledge and learning to teach. In W. R. Houston (Ed.), Handbook on research on teacher education (pp. 291–310). New York: Macmillan.

Davis, K. (2003). Change is hard: What science teachers are telling us about reform and teacher learning of innovative practices. Science Education, 87(1), 3 – 20.

Miles, M., & Huberman, A.M. (1994). Qualitative data analysis: An expanded sourcebook (2nd ed.). California: Sage.

Kali, Y., & Linn, M. C. (In Press). Curriculum design - as subject matter: Science. In B. McGraw, E. Baker & P. Peterson (Eds.), International Encyclopedia of Education (3rd Edition): Elsevier.

Kyza, E. A., & Constantinou, C. P. (2007). STOCHASMOS: a web-based platform for reflective, inquiry-based teaching and learning. Cyprus: Learning in Science Group.

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

Loh, B., Reiser, B. J., Radinsky, J., Edelson, D.C., Gomez, L.M., Marshall, S. (2001). Developing Reflective Inquiry Practices: A Case Study of Software, the Teacher, and Students. In K. Crowley, C. Schunn, & T. Okada, (Eds.), Designing for Science: Implications from Everyday, Classroom, and Professional Settings. Mahwah, NJ: Erlbaum.

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

National Research Council (NRC). (2000). Inquiry and the National Science Education Standards: A Guide for Teaching and Learning. Washington, DC: National Academy Press.

Orey, M. (Ed.). (2001). Emerging perspectives on learning, teaching, and technology. Retrieved on January 29, 2010, from http://projects.coe.uga.edu/epltt/

Papert, S., & Harel, I. (1991). Constructionism: Ablex Publishing Corporation.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66, 211-227.

Quintana et al. (2004). A scaffolding design framework for software to support science inquiry. The Journal of the Learning Sciences 13(3), 337-386.

Reiser, B. J., Tabak, I., Sandoval, W. A., Smith, B., Steinmuller, F., Leone, T. J., BGuILE: Stategic and Conceptual Scaffolds for Scientific Inquiry in Biology Classrooms in S.M. Carver & D. Klahr (Eds.) (2001). Cognition and Instruction: Twenty five years of progress. Mahvah, NJ: Erlbaum

Ronen-Fuhrmann, T., Kali, Y., & Hoadley, C. M. (2008). Helping education students understand learning through designing. Educational Technology, 48 (2).

Singer, J., Marx, R.W., Krajcik, J., & Clay Chambers, J. (2000). Constructing extended inquiry projects: Curriculum materials for science education reform. Educational Psychologist, 35(3), 165 - 178.

Soloway, E., Krajcik, J. S., Blumenfeld, P., & Marx, R. (1996). Technological support for teachers transitioning to project-based science practices. In T. Koschmann (Ed.), CSCL: Theory and practice of an emerging paradigm (pp. 269-305). Mahwah, NJ: Erlbaum.

Vygotsky, L. S. (1978). Mind in society: the development of higher psychological processes. Cambridge: Harvard University Press.

Wallace C. S. & Kang, N. H. (2004). An investigation of experienced secondary science teachers' beliefs about inquiry: An examination of competing belief sets. Journal of Research in Science Teaching, 41, 936-960.

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TESTING/ASSESSMENT