Scaffolding in Mobile Science Enquiry-based Learning Using Ontologies

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Abstract

The use of ontologies has become increasingly widespread in many areas, particularly in technology enhanced learning. They appear promising in supporting knowledge representation and learning content creation for domains of interest. In this paper, we show how ontology-based scaffolding has helped mobile learners to perform scientific enquiry investigations. Enquiry-based learning aims to provide educational activities and tools to assists students to learn science by doing science. In this study, a design science research approach was taken to creating an ontology-driven application for a science content domain, which has been evaluated with high school science students. The results showed the significant value of ontologies in scaffolding learning content in such enquiry-based learning environments. With this application, students were found to learn science in more meaningful and engaged ways as well as developing positive attitudes towards mobile learning.

1. Introduction

There is growing evidence for the potential value of ontologies in education [1] [2] [3] ranging from the use of knowledge representation and inference in the creation of learning content and applications to the definition of domain-specific terminologies. Different ontology applications have been developed in which ontologies are defined as a conceptual model for learning content components [2]. This paper describes how ontologies have been applied for scaffolding learning content in a mobile science enquiry-based learning environment.

1.1 Enquiry-based Learning

Enquiry-based learning aims to provide educational activities and tools to allow students to learn science by doing science, offering resources to help learners comprehend specific domains by engaging in scientific reasoning processes such as hypothesis generation, experimentation and evidence evaluation [4]. Rapid advances in mobile technologies are changing the way that learners access content in enquiry-based learning environments where a great deal of information is easily accessible. Mobile technologies can play an important role in creating these environments, because their portability allows learning on-the-fly "anywhere or anytime" [5]. Further, these handheld devices not only support the learning experience inside the classroom, but also allow learners to perform scientific enquiries in natural environments.

Traditionally, school science has followed a hypothetico-deductive model [6] in which learners are required to process ideas (i.e. hypotheses). This type of enquiry model

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follows a stepwise scientific method, which is based on formulating hypotheses and validating them with experimental results. A less common approach is abductive enquiry, which emphasizes the development of scientific hypotheses that are observed from the natural environment [7]. In the literature related to education, this kind of enquiry has not been widely considered [6] [7]. Therefore, this provides us with an opportunity to explore some new approaches to computer-assisted learning in the sciences.

1.2 Scaffolded Learning

In the area of educational research, the term 'Scaffolding' has been used to describe instructional techniques for computer-assisted learning environments. For example in a bird-watching mobile learning system [8], an outdoor mobile learning activity was developed using wireless technology for scaffolding students' learning about birds. Using pre-designed digital resources in such environments can provide extensive guidance to facilitate learning [9]. Further, this assistance can promote meaningful learning as well as significant gains in learners' performance [10].

Research into scaffolding strategies to support enquiry-based learning is extensive [8] [11] [12]. Scaffolded enquiry tools can support the cognitive regulation skills of learners [12]. The goal of this trait of learning is not just to provide solutions to problems straight away but to create rational, mature thinkers who will be able to comprehend and to appropriately use knowledge in analyzing problems in some meaningful way [13].

1.3 The Role of Ontology

The term *Ontology,* borrowed from philosophy, has become a buzzword in computing and information science literature. It is defined as 'an explicit specification of a conceptualization' [14], an abstract and simplified vision of the world to be represented. It provides the vocabulary for referring to the terms in a particular domain. It also relates to some logical statements that describe what the terms are, and how they are classified, as well as some rules for combining terms and relations to define extensions to the vocabulary [15].

Over the last decade, ontology-based design approaches have been used in technology-enhanced learning environments because they show promise for defining a set of terms and their relations at a conceptual level [16], by adding an intelligent layer based on semantic relations between participating entities to provide adaptive learning content [17]. Thus, an ontology (or ontologies) can provide as a structured knowledge scheme that supports the creation of a personalized learning path [18].

Support for designing enquiry learning activities by using ontology-based scaffolding has been explored in some recent studies, such as the Concept map Learning System (CLS) [19] and the Science Created by You (SCY) project [20]. However none of these projects have been targeted for mobile learning environments. In addition, these tools do not highlight the reasoning capabilities of ontologies to support learning. Therefore, in this paper, the following research question is addressed; 'How can ontology-based scaffolding for scientific learning content be provided in enquiry-based mobile learning environments?

1.4 Study Methodology

To address this question, a design science research methodology (DSRM) [21], supported by Activity-Oriented Design Methods (AODM) [22] tools has been applied. AODM tools are used as an analytical and practical approach for applying key concepts of activity theory to human computer interaction research and practice [23]. Further, a technological framework is provided in these tools, which helps us to identify requirements for the design and evaluation of new technology-mediated mobile learning applications [23]. Using this framework, three sub-activities were identified within the "Tool" component of the defined activity system. These led to sub-questions of the research design which further mapped into four design research iterations.

In these iterations, the use of ontology-supported learning was analyzed. In this paper, only the two iterations that were specifically related to science enquiry-based learning environments are mentioned in detail. In one of these iterations, the mobile learning application was scaffolded with a science domain ontology designed to help learners to generate scientific hypotheses. This iteration was evaluated from a design perspective. In the following iteration, one of the topics from the standard New Zealand NCEA level 1 science curriculum was represented as a domain ontology so that it could be evaluated with high school students. An experiment was conducted with a science class of 15-16 year olds for the purpose of evaluating the application. In this experiment, 23 students took part and evaluated the application in terms of its guidance towards hypothesis generation, and understanding about that particular domain. The mobile learning application asks multiple choice questions (MCQs) regarding scientific measurements and observations taken. Further, it gives suggestions to guide learners to reach a point where they can understand the relationships between the defined variables and are then able to generate hypotheses from their collected data.

The remainder of this paper is structured as follows. Section 2 presents information about mobile science enquiry-based learning and current challenges. In section 3, ontology-based scaffolding in learning environments is discussed. The research design is explained in section 4 while an ontology-driven application, "ThinknLearn", is covered in section 5. Section 6 outlines the evaluation of the application with experimental results and data analyses. Section 7 discusses the application and its results while section 8 covers some related work. Finally, section 9 summarizes the paper and addresses directions for future research.

2. Mobile Science Enquiry-based Learning

Scientific enquiry is one of the most challenging and exciting ventures for today's schools [24]. It is suggested that this style of learning activity fosters learners' motivation and interest in science. In addition, it seems to have twofold advantages: learners not only find out how to perform the steps of scientific enquiry like scientists but also learn how to explain and predict the processes that they observe in the natural world [25]. These two aspects are related to each other in that learners will not learn from enquiry without knowing how to do enquiry and, conversely, a specific domain is always required as a practice arena for enquiry skills [24].

In an enquiry process, computer-assisted modelling can be a powerful tool to enhance learners' reasoning skills and guide them to improve their understanding about a specific domain [26]. Enquiry-based learning is often described as a type of learning in which learners construct knowledge from scientific enquiry processes, scaffolded by tools that are knowledgeable about these processes [24].

Mobile technologies support pedagogical ambitions by providing the possibility of extending the learning environment far beyond classroom walls through the use of handheld devices [27]. A number of mobile enquiry-based applications have been discussed in the literature. These applications reflect the diversity of enquiry investigation and its use in different domains including natural science, social science, mathematics and language.

In the Ambient Wood Project [27], a learning experience was designed that encouraged students to explore and hypothesize about different habitats found in woodland. In a similar vein, Maldonado & Pea [28] provided educational activities and tools to help students participate in collaborative science enquiry involving local environmental data in the LET'S GO! (Learning Ecology through Technologies from Science for Global Outcomes) project. In this particular project, the data was collected, analysed, reflected on, and reported through mobile and sensor technologies. In another enquiry project, nQuire [29], a constraint-based toolkit was designed in order to support the continuation of enquiry-based learning between classroom and non-formal settings. Moreover, software running on mobile and desktop computers was used to investigate problems and guide the enquiry process by providing an interactive visual representation of scientific practice.

These learning environments can provide valuable opportunities to achieve the basic three interrelated learning objectives: the development of general enquiry abilities, the acquisition of specific investigation skills, and the understanding of scientific phenomena [30]. However, the educational advantages of enquiry learning are often challenged by the learners' understanding of a particular domain and modelling, and both lie at a conceptual level [4]. For example, learners are often unable to infer hypotheses from data, and they design inconclusive experiments, show inefficient experimentation behaviour, ignore incompatible data and define incorrect relations between variables. As this ineffective behaviour is a serious obstacle to learning,

additional support is required in applications that can enhance learners' reasoning skills at a conceptual level while they are performing enquiry investigations [4] [31].

Traditionally, learners are involved in the following enquiry processes [24] [32]: *orientation*, in which learners identify the initial idea of the domain including variables and their relations; *hypothesis generation*, in which a model of the domain is formulated for consideration; *experimentation*, in which an experiment is used to investigate the validity of the hypothesis or model; and lastly *conclusion*, in which the validity of the hypothesis is drawn or new knowledge is generated. This type of enquiry model is a stepwise scientific method. However the process of hypothesis generation has not been widely considered in the literature [6] [7].

In school science, scientific explanations generally proceed in a deductive or inductive way [6], where learners are required to process ideas (i.e. hypotheses). In contrast, abduction is understood as a form of backward reasoning from a set of observations back to a cause, so searching for an idea itself is central [7]. The concept of abduction was coined by C.S.Peirce (1839-1914) who classified abduction as a form of inference. Peirce maintained that the logic of scientific enquiry is divisible into three fundamental modes of inference [33]:

- Deduction or explicative inference
- Induction or evaluative inference
- Abduction or innovative inference

The following example, taken from our experimental context of heat transfer, will show the relationships more clearly. Here, the ideas relate to black surfaced tins (cans) containing hot water losing heat more quickly than white or shiny surfaced tins. In these examples, the Case (Hypothesis), Result (Observation) and Rule (Condition or Suggestion) are defined to show the differences in order.

Deduction:
Rule–The water particles in a black surfaced tin vibrate faster than the other tins.
Case– A black surfaced tin absorbs more heat energy than the other tins.
Result–A black surfaced tin cools more quickly.

Induction:
Case–A black surfaced tin absorbs more heat energy than the other tins.
Result–A black surfaced tin cools more quickly.
Rule–The water particles in a black surfaced tin vibrate faster than the other tins.

Abduction:
Rule–The water particles in a black surfaced tin vibrate faster than in the other cans.
Result– A black surfaced tin cools more quickly.
Case– A black surfaced tin absorbs more heat energy than the other tins.

From these examples, it can be seen that in both deduction and induction, a Case (Hypothesis) is processed with either a Rule or a Result to generate the other component, while in abduction, the Rule and Result are used together to find a Case. This trait of abduction is well-suited to enquiry problems in which learners are challenged to formulate scientific hypotheses and explain natural phenomena [7]. Therefore, science educators and researchers have recently begun to study the process of hypothesis generation in the context of abductive enquiry investigations.

3. Ontology-based Scaffolding for Learning Content

Scaffolding can be conceptualized as the provision of technology-mediated support to learners as they engage in a specific learning task [34]. It is also a key element of cognitive apprenticeship which provides a model that scaffolds learners through instructions, task structuring, and clues, without explicitly giving solutions [11]. This vision of scaffolding is not only helpful in guiding learners through the complexities of the task but also highlights some important aspects of their work in order to engage them with the defined strategies and frameworks [35].

In previous work, ontology-based scaffolding has been used in learning environments for various purposes; TANGRAM [1], a learning environment for the domain of intelligent information systems, used ontology-based scaffolding for automatic decomposition of learning content into reusable fragments. These fragments are semantically interpreted with concepts from the domain ontology which is used to get adaptive learning content with available learning resources. In the APOSDLE [36] project, the application finds missing competencies of learners and their learning requirements. In another research project, an ontology model [3] has been developed, based on individual learning traits. The model consists of two modules; an adaptive test module and a mobile learning environment. The adaptive test module is used to tailor itself according to the estimated ability level of test takers while the mobile learning environment is designed for testing their learning abilities.

Assessment constitutes a critical component of the instructional process. It serves as a method of measuring the learners' knowledge about a particular domain [37]. Thus ontology-based scaffolding has been used for generating multiple choice questions (MCQs) and answers, which can be helpful in assessing learners' knowledge. Recently, a number of ontology-based applications have been developed, such as OntoAware [38], OntoQue [37] and first aid domain ontology [39], in which domain ontologies are designed to generate questions based on the knowledge defined as concepts, sub-concepts and inter-related relationships of those concepts.

Being partially inspired by the above work, the generation of MCQs in the system described here exhibits some common traits with [39], as an early iteration of this

research project. In order to implement scaffolding for mobile science abductive enquiry, we have designed an ontology-driven application in which MCQs are generated by using domain ontologies. Further, it infers relevant information and guides learners to a point where they can understand the relationships between the defined variables and are able to generate hypotheses from their collected data. This guidance is scaffolded in such a way that learners need to think and to appropriately use knowledge in answering questions. For this ontology-based scaffolding, our system tailors the delivery of content according to the specific learning context. The following sections will describe the application design and its implementation in detail.

4. Research Design

The research is designed to examine the applicability of ontology-based scaffolding for providing learning content in mobile science enquiry-based learning environments.

4.1 A Design Science Exploration

Design science is fundamentally a problem-solving paradigm. It brings together two important components: a design focus and the evaluation of design elements [40]. The design process mainly focuses on a sequence of activities that constructs an innovative product (i.e. the design artifact). The evaluation of the artifact then offers feedback information which assists in improving both the quality of the product and the design process [41]. This build-and-evaluate loop is iterated a number of times until the final design artifact is completed [41].

This research falls into the category of design science as it seeks to investigate an ontology-supported learning artefact, specifically in abductive mobile enquiry investigations. The steps of the design process and the associated problems are very similar to those found in IS design [42]. For that reason, the design science research methodology (DSRM) [21] is adopted for this research, which consists of the following six activities in a standard sequence (see figure 1): *Problem identification and motivation*, in which a specific research problem is identified. *Define the objectives of a solution*, in which the objectives of a solution and the possible and feasible knowledge from the problem definition are inferred. *Design and development*, in which an artefact is created with its desired functionality. *Demonstration*, in which the artifact is used to solve one or more instances of the problem. *Evaluation*, in which observation and measurements are taken to know how well the artifact supports a solution to the problem. Finally, *Communication*, in which the problem with its importance is communicated and shared amongst the target audience.

For investigating the given research problem, four iterations were derived by using AODM [22] (see figure 1). In the first iteration, the use of ontology-based scaffolding

for accessing adaptive learning content was analyzed. A first aid domain ontology was defined and presented in multiple ways i.e. a tutorial and MCQs [39]. In the second iteration, COMET (**C**ontext **O**ntology for **M**obile **E**ducation **T**echnology) [43] was developed, showing the retrieval of contextual data from different participating entities within the ontology by using their semantic understandings. In the two subsequent iterations, an ontology-based mobile web application, 'ThinknLearn', was designed. In the third iteration, this science enquiry example was used as a proof-of-concept and evaluated from a design perspective while in

the last iteration it was tested with high school students by using one of the topics from the New Zealand NCEA level 1 standard science curriculum as the domain ontology.

4.2 Activity-Oriented Design Methods (AODM)

AODM was developed as an analytical and practical approach for applying key concepts of activity theory [44] to human computer interaction research and practice [22].
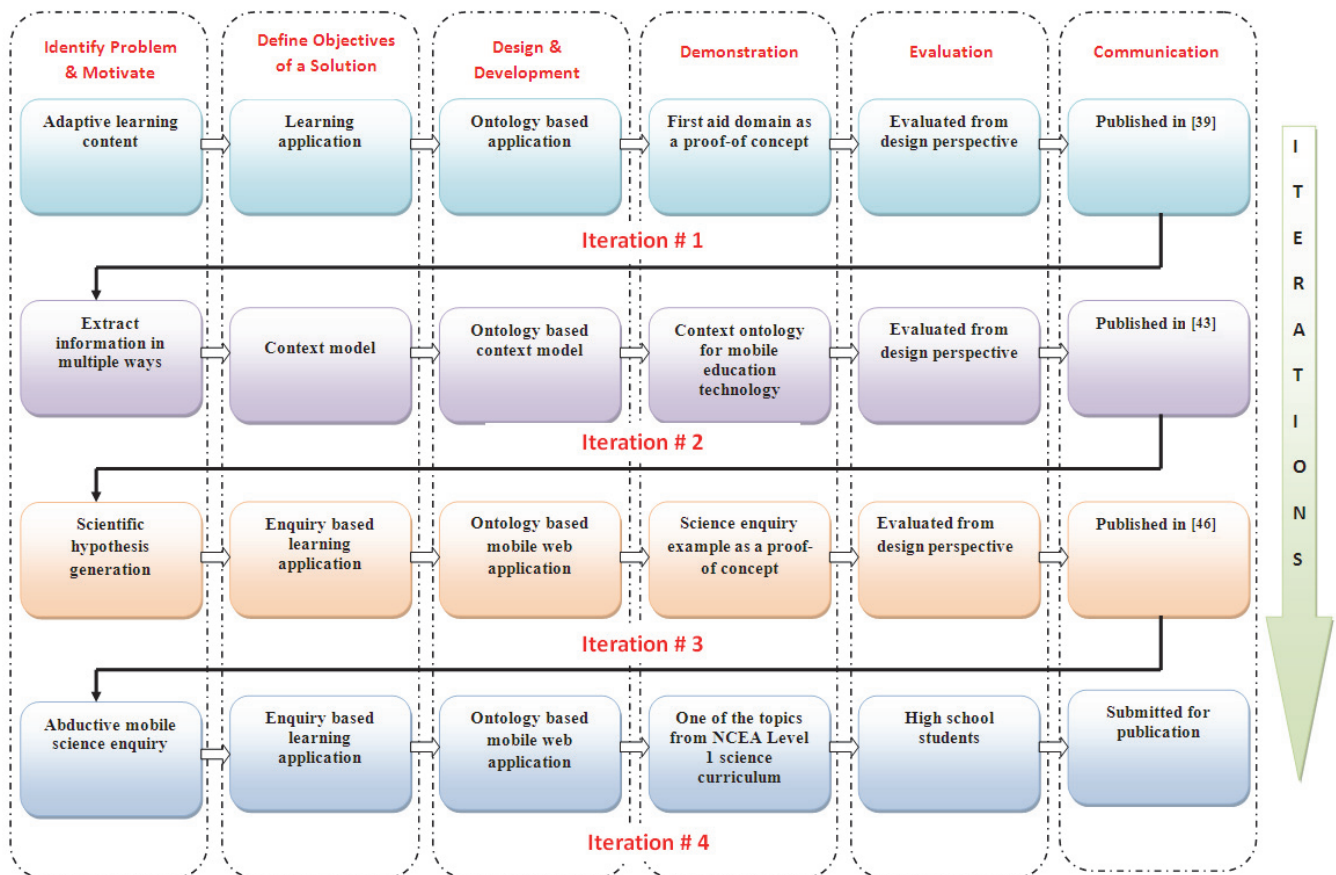

Figure 1. Research design iterations, adapted from [21].

"Activity theory is a descriptive framework for understanding human activities as processes that continuously develop and redevelop over a period of time, and as a result of influences from the context in which human activities are carried out" [44] (cited in [22]). AODM presents four methodological tools designed to support early phases of computer systems design including the processes of gathering and analysing systems design requirements, systems evaluation and communicating design insight to stakeholders [22].

4.2.1. AODM Tool 1: Eight-Step Model

The Eight-Step model (see Table 1) is used to translate the various components of Engestrom's model [45] of human activity in terms of the situation being examined. This model helps to capture and unify key concepts of activity theory by adding the 'rules and regulations', 'community' and 'division of labour' components to Vygotsky's original model of human activity. However, Sharples et al. [23] redefined Engestrom's framework to show a dialectical relationship between technology and semiotic layers. Moreover, they further changed the terms 'rules and regulations', 'community' and 'division of labour' to 'control', 'context' and 'communication' respectively.

The Eight-Step Model		
	Identify the:	Answers
Step 1	Activity of Interest	Mobile Science Enquiry Investigations
Step 2	Objective	Accessing Learning Content
Step 3	Subjects	Learner (Mobile)
Step 4	Tools	Ontology-based Scaffolding
Step 5	Rules & Regulations / Control	Human Computer Interaction (Usability of a system)
Step 6	Division of labour / Communication	Mode of Interaction and support of a co-worker
Step 7	Community / Context	Enquiry-based learning
Step 8	Outcome	Revised Knowledge & Skills

Table 1 **Eight-Step Model, adopted from [22].**

The semiotic layer represents learning as a semiotic system in which learners' actions are supported by cultural tools and signs while the technological layer defines learning as an engagement with technology, in which tools such as computers and mobile phones are embedded with functionality in order to communicate with learners. These layers present either a semiotic framework for educational theorists to analyze learning in the mobile age, or a technological framework for software developers and engineers to propose requirements for the design and evaluation of new mobile learning systems [23]. As far as our research is concerned, ontology-based abductive mobile science enquiry-based learning activities are designed and investigated. Therefore, only the technological layer is being followed in the research design of this application, as shown in figure 2.
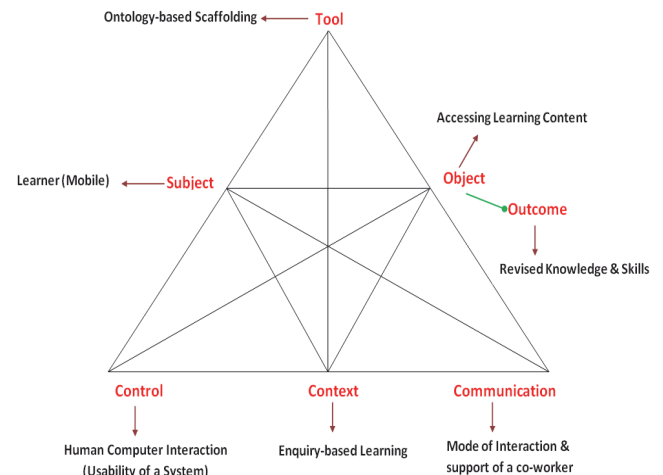

Figure 2. Technological layer, adopted from [23].

4.2.2 AODM Tool 2: Activity Notation

AODM's activity notation helps to reduce complexity in activity analysis by decomposing the activity system through the production of sub-activity triangles [22]. The sub-activity triangles are united through the shared object of the main activity system. This enables the researcher to investigate a more focused analysis of human activity by generating research questions based on sub-activity triangles.

4.2.3 AODM Tool 3: Generating Research Questions

The technique for generating research questions facilitates detailed abstraction resulting from the decomposition process so as to support data gathering and analysis from an activity theory perspective [22]. Three general research questions based on the 'Tool' component of the activity system are presented as shown in figure 3. These questions are derived from sub-triangles related to the 'Tool' component found in the activity system. These research questions can be used to analyse user interactions with the given tool being used to mediate activity (see figure 3). These questions can also be used to examine the main research question regarding the applicability of an ontology-supported application in enquiry-based learning environments.

4.2.4 AODM Tool 4: Mapping Operational Processes

This technique works like a concept mapping tool that makes it easier to comprehend AODM entities and operational procedures by presenting a visual representation of all the transitions of the activity analysis [22]. It is further used to interpret study findings. In this tool, the generated research questions are mapped into four research design iterations in order to investigate ontology-supported learning in enquiry-based learning environments as depicted in figure 3.
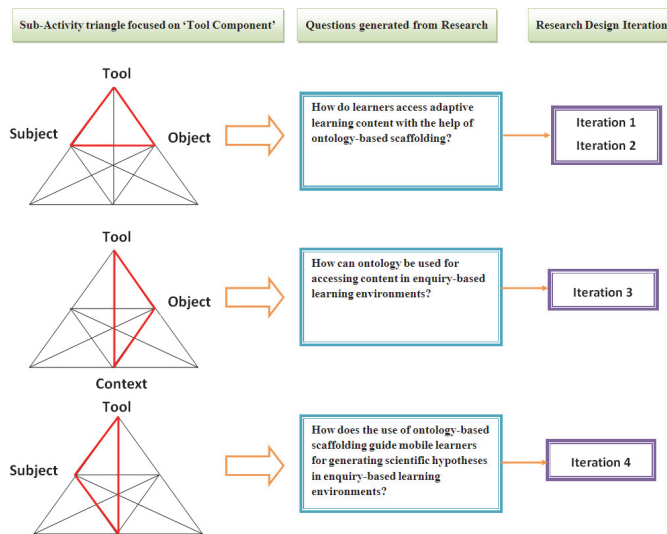
Figure 3. Mapping AODM operational processes with design iterations.

In the subject-tool-object sub-activity triangle, a research question is generated about the use of ontology-based scaffolding for accessing information by mobile learners. For that purpose, the first two iterations were developed. In the first iteration, ontology-based scaffolding was supported in multiple ways (i.e. MCQs and tutorials) while in the second iteration an application was designed which extracted information by using multiple relationships defined in the ontology. In this iteration, multi-directional adaptation was exploited from resource to device and vice versa.

In the tool-object-context sub-activity triangle, a research question is generated which is related to an enquiry-based learning environment. A third iteration was designed with the purpose of showing how ontology-based scaffolding can guide learners to generate scientific

hypothesis in an enquiry-based learning environment. A science domain ontology was scaffolded in an application in the form of MCQs and suggestions which guided the learner during the hypothesis generation process.

The subject-tool-context sub-activity triangle defined a research question which was examined in the design of iteration 4. In this iteration, an experiment was conducted with high school students in order to evaluate the use of ontology-based scaffolding in mobile science enquiry investigations. These iterations are discussed in more detail in the following sections.

5. An Ontology- driven Application

The use of ontology-based scaffolding in enquiry-based learning environments and its evaluation with students are presented in this remainder of this paper. The implementation of such scaffolding in an application called 'ThinknLearn' has allowed us to evaluate the roles of semantic understanding and reasoning capabilities between different concepts defined in the ontology. These two iterations are defined in this paper with different reference examples. Further, a technical architecture is described for the iterations of this ontology-based mobile learning application.

5.1 Technical Architecture

The technical architecture [46] of the application is influenced by the approach used in [47]. In this architecture, a Java web application processes mobile client requests from multiple web browsers. The process of the mobile client interacting with the server using an HTTP request to a Java servlet is shown in figure 4. This servlet reads the ontology from the server using the Jena API (see http://jena.sourceforge.net), a Java framework for building semantic web applications. The Jena API provides a programmatic environment for RDF (Resource Description Framework), RDF-S (Schema) and the OWL Web ontology language. In addition, Pellet (see http://clarkparsia.com/pellet/), an OWL reasoner which is a core component of ontology-based data management applications, is also used in this architecture for extracting inferred knowledge from the ontologies. Adaptive web pages are returned to the client using the WALL library, which adapts Java Server Pages (JSPs) to the browser being used by the client device.
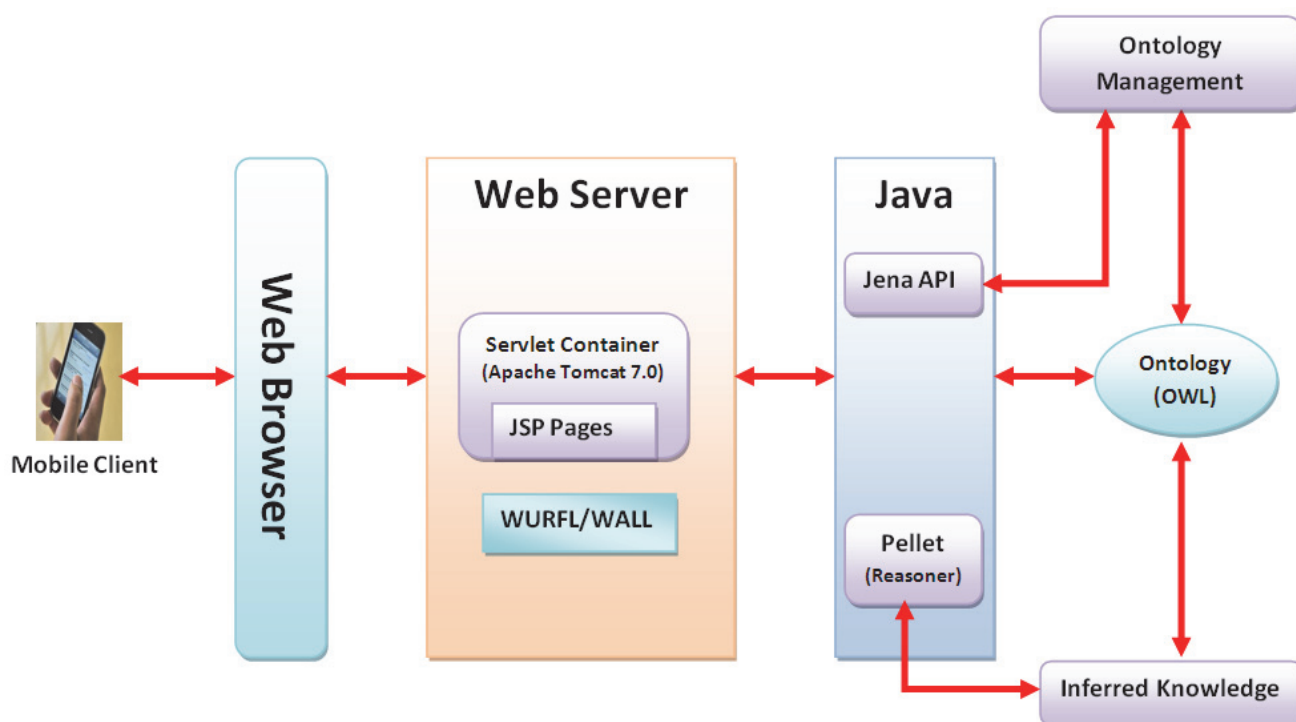
Figure 4. Technical architecture of the 'ThinknLearn' system.

5.2 ThinknLearn – An iterative design application

In this section, we discuss the last two iterations of the application 'ThinknLearn'. In these iterations, science related domain examples were used which guide learners in order to formulate hypotheses from the collected data. The application can be accessed by any internet-enabled handheld device, but for readability the screen captures here are taken from a desktop browser.

Earlier iterations helped us in understanding how learners access adaptive learning content with the help of ontology-based scaffolding. However, these iterations did not specifically apply ontology-based scaffolding to science enquiry-based learning domains, which are one of the most challenging ventures in today's schools [24]. Further, abductive mobile science enquiry is also investigated in these iterations, an approach not previously considered in the literature [6] [7].

5.2.1 Iteration – Ontology-based scaffolding for scientific hypotheses generation

In this iteration, an example scenario is defined in which learners need to visit a natural environment and find the given location of a sample plant. First, they have to take a soil sample and then identify the values of the given

measures by using their data probes. Soil pH, soil texture type and plant types are the key elements to be identified in this iteration, as shown in figure 5. The values of soil pH of the samples are taken from 1 to 14 while three main soil texture types; sandy, silt (loam) and clay are measured in percentages. For this iteration, only three plant types are considered; herb, shrub and tree, which can grow in these soil samples.

After submitting these values, the application asks a series of MCQs regarding the collected values of these measures one-by-one and then gives suggestions based on the answers chosen by the learners. This question-suggestion module of the application guides learners towards a point where they are able to formulate hypotheses about the given measures. The ontology uses complex relationships and its reasoning capabilities in order to extract the information regarding the given suggestions (see figures 6 and 7).

At the end, the application presents a summary of the activities conducted by the learners during this science enquiry learning process as depicted in figure 8. Inputs are placed at the top of the page with all the suggestions given by the ontology during this science enquiry learning activity. These suggestions about the collected measures are based on the answers to the MCQs given by the learners. Finally, the application asks about suitable hypotheses from the domain. Inputs and the given suggestions may lead learners towards the point where

they can select one of the options from the specified hypotheses.
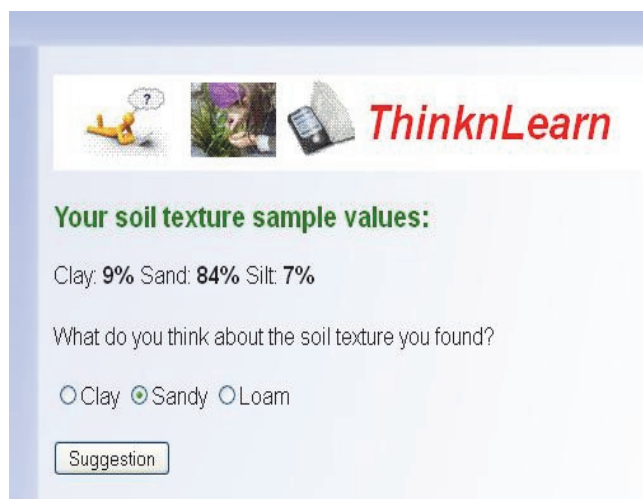
Figure 5. Measurements and observation.
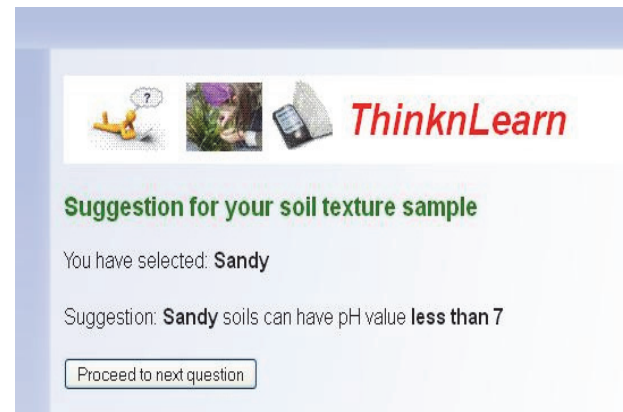
Figure 6. MCQ about soil texture type.
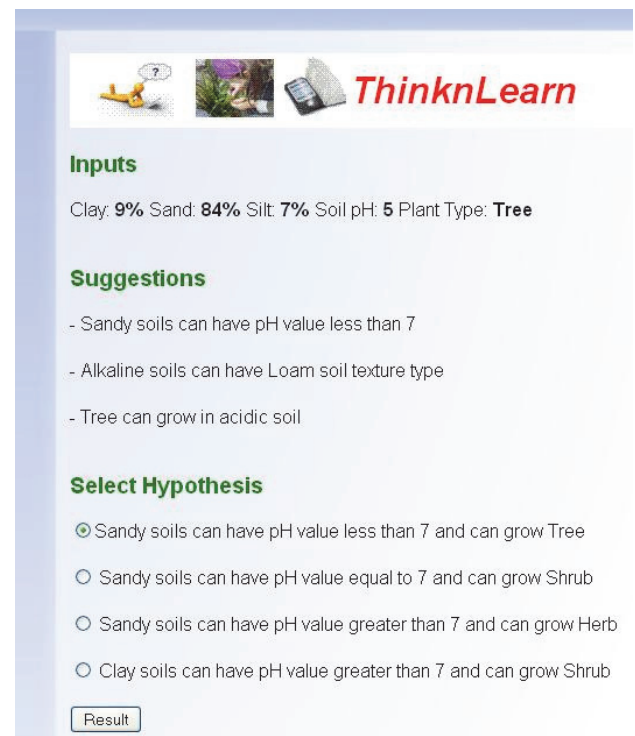
Figure 7. Ontology extracts suggestions based on the chosen answer.

Figure 8. Summary and hypothesis generation.

The ontology extracts all the possible hypotheses by using its inbuilt relationships. From that, the application selects one correct and three incorrect answers from a pool of those hypotheses. A random function is used for extracting the incorrect answers and also for placing these answers in different positions. In addition, learners can further validate their chosen hypotheses in the real environment which can assist them to draw some conclusions about a specific domain.

This iteration was evaluated as a proof of concept by a group of educators. Feedback from this evaluation was used to inform the following iteration.

5.2.2 Iteration – Abductive Mobile Science Enquiry

In the previous iteration, ontology-based scaffolding in science enquiry application was designed but evaluated from a design perspective only. As a proof-of-concept, a science domain example was implemented in that iteration. However, the iteration described in this section was developed to be evaluated with high school science students. Therefore, the domain ontology used in this iteration is based on one of the standard school science topics. It consists of a few important aspects of heat energy that have impact on the movement of water particles, and the loss and absorption of heat energy due to different coloured surfaces.

In this particular example, three tins with different surface colours are provided in order to compare the way they radiate heat energy. Tin A is painted white, tin B black and tin C is silver (shiny). Each tin has a small hole at the top and is filled with water at 100 ^{0}C. Learners have to record the temperature of each tin at a particular time interval. For the temperature, the range lies between 20-100 ^{0}C while the time can be recorded between 0-20 mins. Figure 9 shows the measurement screen for one of the tins defined in the application. In this iteration, based on feedback from the previous iteration, separate measurement screens are defined for each measure, whereas one screen contained all the key measures in the previous version.
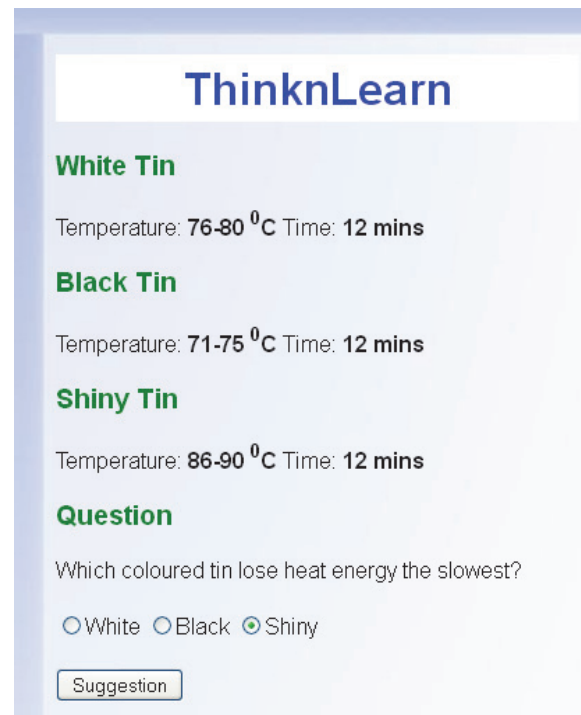
The application does not give the answers immediately after the values for all three tins have been submitted. Instead, the application asks a series of MCQs regarding the collected values of these measures one-by-one, similar to the previous iteration. The question-suggestion module (see figures 10 and 11) of the application guides learners to generate hypotheses about the given measures and understand the domain-specific knowledge presented. Further, this application makes learners think about the numerous aspects of heat energy related to differently coloured surfaces.
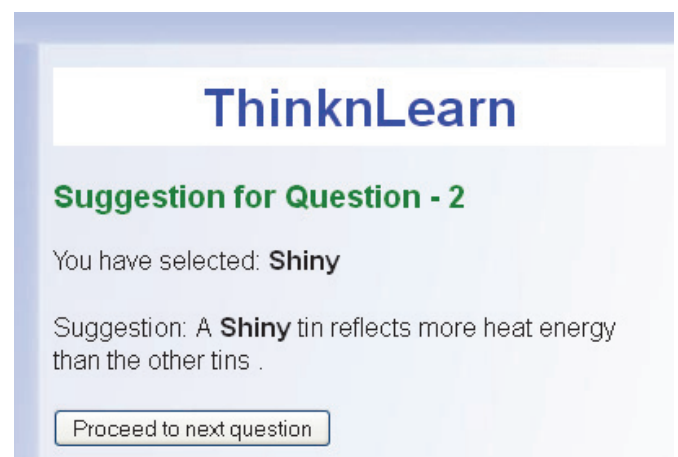
Figure 10. MCQ regarding one of the aspects of heat energy.

Figure 9. Measurement and observation of Silver (Shiny) surfaced tin.

Figure 11. Suggestion about the given question.

At the end, the application presents a summary of the activities conducted by the learners during this science enquiry learning process as depicted in figure 12. The difference in this summary page from the previous iteration is that it contains only inputs and suggestions, while the MCQ regarding the selection of the hypothesis is defined on the separate screen.

Figure 12. Experimental Summary.

In this iteration, the students are asked to formulate two types of hypotheses which differ from the one type of hypothesis defined in the previous iteration. One is related to the vibration of the water particles and loss of heat energy from the different coloured tins. The other is about heat absorption and loss of heat energy from the different coloured tins. The application uses a random function to ask about one of these hypotheses. Inputs and the given suggestions may lead learners towards the point where they can select one of the options from the specified hypotheses. The ontology extracts all the possible hypotheses by using its inter-relationships (see figure 13). From that, the application selects one correct and three incorrect answers from a pool of those hypotheses. Another random function is used for extracting the incorrect answers and also for placing these answers in different positions (similar to the previous iteration).

Figure 13. Hypothesis selection.

6. Assessment and Analyses

It is suggested in [48] that mobile learning applications evaluation can inform systems by examining how the learning activity and the underlying technology can be developed to enhance learning and offer new learning opportunities. Therefore, the evaluation of this ontology-driven application in terms of its guidance towards hypothesis formation and learners' reasoning skills in comprehending the defined topic is discussed in this section. In the evaluation, 23 students participated, divided into eight groups. In this experiment, each group had to measure the temperature inside each coloured tin at a particular time and observe the different properties of each tin.

For the purposes of data collection, both quantitative and qualitative data were gathered using multiple approaches: A questionnaire was administered to the participants after using the application; Semi-structured group discussions were also conducted with the participants. In this section, we report on the quantitative and qualitative analyses on the experimental results of our evaluation.

6.1 Questionnaire Responses

The questionnaire was administered by the participants after they had completed the mobile science enquiry learning activity. The 9 questions in the questionnaire attempted to address different aspects of the mobile science enquiry investigations including mobile application (experience, use and navigation), hypothesis generation (guidance, suggestion relevance and understanding of relationships) and comprehension (topic understanding, reasoning skills and effectiveness). The questionnaire used a five-point Likert Scale where 1 was

'strongly disagree' and 5 was 'strongly agree'. When this application was tested with science students, their overall responses were very positive and encouraging as described in the following subsections.

6.1.1 Value related to the mobile application

Several questionnaire statements were intended to investigate the mobile application perspective. Table 2 shows the three statements relating to this part of the evaluation.

The responses to statement 'S1' revealed that the respondents found using the mobile science enquiry-based application an enjoyable learning experience. Similarly, the responses to statements 'S2' and 'S3' showed that participants considered this application was easy to use and navigation was straightforward. A one sample T-test against the neutral value 3.00 confirmed these interpretations ($t_{22} = 3.36$, p< .01 for S1; $t_{22} = 8.67$, p< .01 for S2; $t_{22} = 9.05$, p< .01 for S3).

No.	Statements	Mean Response ± S.E (Standard Error)
S1	This mobile learning experience was enjoyable.	3.74 ± 0.22
S2	This mobile application was easy to use.	4.13 ± 0.13
S3	Navigation through this application was easy.	4.35 ± 0.15

Table 2. **Responses related to the mobile learning aspect.**

6.1.2 Hypothesis generation aspect

In order to evaluate the hypothesis generation aspect of the application, the questionnaire addressed the fundamental points of using ontology-based scaffolding in the hypothesis generation process; the use of relationships defined between the domain concepts and the extraction of the learning content in the form of suggestions which may guide learners to formulate hypotheses from the collected data.

The statements in Table 3 address aspects of guidance towards hypothesis generation, suggestion relevance, and understanding of relationships between the variables. Generally, the responses were positive. The ratings on these statements (i.e. S4, S5 and S6) ($t_{22} = 3.10$, p< .01 for S4; $t_{22} = 5.80$, p< .01 for S5; $t_{22} = 5.50$, p< .01 for S6) also revealed our participants perceived that the guidance towards hypothesis generation and the suggestions given

during that process would significantly benefit them in formulating scientific hypotheses.

No.	Statements	Mean Response ± S.E (Standard Error)
S4	This application guides me to formulate a hypothesis.	3.61 ± 0.20
S5	The given suggestions in the application were relevant.	4.09 ± 0.19
S6	This application helps me understand the relationships between different variables.	3.87 ± 0.16

Table 3. **Responses related to the hypothesis generation aspect.**

6.1.3 Comprehension aspect

The statements listed in Table 4 were intended to ascertain if the respondents revealed positive characteristics of comprehension during the activity. This part of the evaluation relates to comprehension about the topic, reasoning skills improvement and the effectiveness of this application.

No.	Statements	Mean Response ± S.E (Standard Error)
S7	The given suggestions help me to understand the topic.	3.96 ± 0.19
S8	This application helps me to improve my reasoning skills.	3.65 ± 0.16
S9	It is an effective learning application.	4.00 ± 0.21

Table 4. **Responses related to comprehension.**

Overall, the responses suggest that positive aspects of comprehension were experienced by the students ($t_{22} = 4.94$, p< .01 for S7; $t_{22} = 4.03$, p< .01 for S8; $t_{22} = 4.60$, p< .01 for S9).

In summary, participants agreed with the given statements which suggest that the application can benefit learners in a number of ways. The questionnaire responses revealed that students were able to understand the relationships between different variables being presented in the application and the given suggestions helped them to generate scientific hypotheses, and may also improve their reasoning skills.

6.2 Qualitative Data

Qualitative responses were also gathered in semi structured group discussion. Three of the questions (see Table 5) in the interview were asked to evaluate the application.

No.	Questions
1	What type of difficulty do you find in using this application?
2	How do you feel after using this application?
3	What do you think about suggestions given in the application?

Table 5. **Qualitative questions.**

The responses for question 1 showed that the most of the participants consider this application as a guiding tool to encourage thinking skills. One of the participants said "*…it makes you think and that is why I enjoy it*". However there were three participants in a group who found it a little confusing. One student described how "*…it guides me but I am little bit confused to choose the correct hypothesis*". We believe that this difficulty in using this application may be due to their understanding about the topic but this aspect may be considered further in future experiments.

Responses to question 2 in group discussion revealed that the experience of using this application was enjoyable, interactive and interesting, though two participants were unhappy about using this application on mobile devices. According to one of them, *".....I don't prefer to do web browsing on my phone because I have to use the zoom function again and again while using it*". However, most of them found it an interactive application. One student stated that "*... there is no doubt that it is an interesting and interactive application because it makes you think about the topic.*" Overall, participants valued the interactivity, enjoyed the innovative way of learning, and found the application engaging.

With respect to how suggestions were relevant and guided learners to generate hypotheses, some challenges were presented so the application can make learners think about the given domain. It may be argued that a certain level of challenge makes the application more engaging and rewarding, but that a fine balance needs to be maintained between challenge and skill. The overall responses for the above question were promising and most of the students felt that the suggestions were relevant, though one group said *"...why doesn't this application give correct answers straightaway rather than suggestions?"* Our answer to this question is that it is an analytical learning application which helps learners to

think, and the given suggestions help them to understand the domain-specific knowledge and generate hypotheses in the end. However we may need to find ways to convince students of the value of this approach.

In short, the qualitative data suggest that the application was engaging and the suggestions given make learners think about the knowledge space under investigation, and may improve their critical thinking and analytical skills.

7. Discussion

In this research project we intended to provide a working mobile science enquiry-based learning application using ontology-based scaffolding. The aim was to improve student engagement and learning outcomes and support new approaches to teaching science related concepts and analytical skills. In addition we planned to provide an opportunity for learners to comprehend the domain knowledge and formulate scientific hypotheses from the collected data. We certainly feel that we have gained these outcomes. In particular we have shown that the application that we have developed results in high levels of student engagement.

The analyses of the data collected suggest that the application can benefit learners in a number of ways. Among other things, survey responses revealed that learners were able to learn the domain knowledge being presented in the application and generate scientific hypotheses. Similarly, semi-structured group discussion revealed that the application was engaging and it made them think about the defined domain concepts.

We have categorized our outcomes and reflections adapting the scaffolding design framework to support science enquiry found in [11]. The summary below identifies the degree to which specific similarities were found between them. The framework could be applied to similar science enquiry applications using our design features as a guideline.

(i) Use representations and language that bridge learners' understanding

The given suggestions in the application may help learners to comprehend the domain-specific knowledge.

(ii) Organize tools and artefacts around the semantics of the discipline

The application uses the same terminologies of the domain concepts as defined in the standard science curriculum.

(iii) Use representations that learners can inspect in different ways to reveal important properties of underlying data

In the application, a series of MCQs and suggestions are provided to the learners about the underlying collected data.

(iv) Provide structure for complex tasks and functionality

Ontology is used in the application for defining relationships between the domain concepts. The application uses these relationships and gives suggestions which may help learners to understand the domain-specific knowledge.

(v) Embed expert guidance about scientific practices

The given suggestions guide learners in such a way that they are able to formulate scientific hypotheses during such enquiry investigations.

(vi) Automatically handle nonsalient, routine tasks

Data input is simple, avoiding the need to type in data manually. The application presents a summary of inputs and suggestions in the end which may reduce cognitive load for remembering each task individually.

(vii) Facilitate ongoing articulation and reflection during the investigation

In this abductive enquiry process, learners need to generate hypotheses from the collected data. Suggestions are given throughout the learning process instead of giving correct answers to MCQs. This feature not only guides learners to find a correct hypothesis but also fosters their analytical skills.

8. Related Work

No significant work has previously been done in which ontology-based scaffolding is used in abductive mobile science enquiry. Nevertheless there is some significant related work that should be acknowledged. Certainly, in the education field, there are a large number of applications that cover the broad spectrum of ontology-based scaffolding (e.g., [1, 3, 36-38]). However, the use of ontology-based scaffolding in enquiry learning applications has been explored in only a few studies.

CLS [19] provides visual concept transfer paths that assist learners to comprehend the relationships between the defined course concepts. In this application, the ontology is used for structuring content information in which learners navigate through learning material by following their own personalized paths.

In a similar way, the SCY Project [20] intends to offer a learning experience that includes both enquiry and collaboration. To help learners navigate through SCY-Lab (the SCY learning environment), learning activities are grouped into so-called Learning Activity Spaces (LASs) such as experimentation, conceptualization and orientation etc. In this project, the specific roles of ontologies are addressed, including semantic representation for human-human interdisciplinary exchange. They serve as meta-level descriptions for repositories, standardize and interlink metadata vocabulary, and facilitate high level inter-operability between tools and services [16]. This defines a learning platform in order to create links between different tools used at each enquiry processes (i.e. LASs).

However, none of the above approaches highlight the semantic reasoning capabilities of ontologies in such enquiry learning activities. Creating an ontology-driven application for abductive mobile science enquiry investigations therefore provides us with an opportunity to explore some new approaches to computer-assisted learning in the sciences.

9. Conclusion & Future Work

The work presented in this paper is about an innovative mobile learning environment which can engage learners in exploring and experimenting in science enquiry investigations. This can also promote deeper understanding of a particular science domain and can guide learners in interpreting data to create meaningful hypotheses.

In our work, ontology-based scaffolding for science enquiry mobile learning investigations has been developed. To evaluate the feasibility of this scaffolding, an ontology-based mobile web application 'ThinknLearn' has been designed in iterations using a design science approach. The third iteration of this application was designed to show how ontology-based scaffolding supports learners to generate hypotheses in science enquiry investigations, while the fourth iteration has been tested with high school science students. A technical architecture is applied that was able to support both iterations. Overall, the result of that evaluation was promising and it showed that ontology-based scaffolding in such environments may not only guide learners to construct hypotheses relating to measurements and observations but may also help them to think about a particular domain.

The main purpose of the study described in this paper is to demonstrate to science educators the way that an abductive mobile application might be used in a science enquiry activity. A revised iteration of the application will be evaluated with an increasing number of science students during the next evaluation phase. The impact of the application on learning performance of the participants will also be assessed in that phase. This may help us to comprehend further how practical ontology-based tools can be used to improve both learning performance and analytical skills during such enquiry investigations.

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