ThinknLearn: An Ontology-Driven Mobile Web Application For Science Enquiry Based Learning

Sohaib Ahmed and David Parsons

Abstract—**In recent years, there have been major advances in opportunities to learn with mobile devices. These devices provide the possibility of extending the learning environment far beyond classroom walls. Enquiry-based learning, much of which also takes place outside the classroom, aims to provide educational activities and tools to help learn science by doing science. This way of learning can fosters learners' motivation and interest. However, the educational advantages of this kind of learning are often challenged by the learners' misunderstandings and incorrectly inferred hypotheses from collected data. Ontology-driven applications exhibit features such as expressiveness, extensibility, ease of sharing and reuse, and logic reasoning support, and thus may help us to more effectively guide enquiry based learning. In this paper, we use an example scenario to show how mobile ontology-driven applications can support learners during such enquiry investigations.**

***Index Terms*-- Abduction, Enquiry-based Learning, Mobile Learning, Ontology.**

I. INTRODUCTION

The last decade has witnessed a spectacular evolution in mobile technologies, and these technologies have increasingly been used in education. Mobile devices can play an important role in creating more individualized and collaborative learning environments, because their flexibility and portability allow learning on-the-fly [1], "anywhere or anytime". Further, mobile learning not only takes the learning experience outside the classroom, but also improve learners' critical thinking [2]. In this paper we address issues around mobile enquiry-based learning supported by ontologies.

A. *Enquiry Based Learning*

Enquiry-based learning aims to provide educational activities and tools to allow learning 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 [3]. The main goal of enquiry investigations is to develop knowledge about the particular domain being investigated [4]. Learners acquire knowledge about how to do science as a common endeavor, learning about both the nature of science and scientific content. Using pre-designed digital resources in such learning environments can provide extensive scaffolding and guidance to facilitate learning [5] [6]. Further, this guidance can foster deep and meaningful learning as well as significant gains in learners' performance [6].

B. *Computer models and hypothesis generation*

Computer modeling can be a powerful tool to enhance learners' reasoning and help them to improve their understanding [7]. In these modeling approaches, learners are provided with a simulation model to help them formulate hypotheses, deduce consequences from the hypotheses, and make observations to investigate the consequences. This type of enquiry model is like a stepwise scientific method which mainly focuses on designing an experiment and validating hypotheses with experimental results. However the process of hypothesis generation has not been seriously considered in the computer modeling literature related to education. This is because school science has traditionally been dominated by the hypothetico-deductive view of science [8]. However, abductive enquiry emphasizes the development of hypotheses which can effectively explain observed phenomena [9]. This provides us with an opportunity to explore new approaches to computer supported learning in the sciences.

C. *Ontology-Based Models*

Ontology-based models exhibit features including expressiveness, extensibility, ease of sharing and reuse, and logic reasoning support [10]. Therefore, in recent years, ontologies have emerged as one of the most popular and widely accepted tools for modeling information in mobile computing domains [11]. In addition, ontology-based approaches have been used for enquiry-based learning activities in recent projects like the Concept map Learning System (CLS) [12] and the Science Created by You (SCY) project [13]. However none of these approaches have been designed for mobile learning environments. In addition, these approaches do not highlight the semantic reasoning capabilities of ontologies in learning environments. Therefore, in this paper, we are addressing the following research questions; how can we use ontologies to guide learners in formulating hypotheses by using semantic reasoning capabilities? And how can we use ontology-driven applications to support science enquiry-based mobile learning activities?

To address these questions we have designed an ontology-driven mobile web application to show how ontology-based design approaches can support enquiry investigations. A reference scenario is used in which learners

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visit a natural environment to measure soil pH and soil textures while observing the plant types present in that soil. From this data they have to hypothesize about the relationships between their measurements and observations. During such a hypothesizing process, an ontology-driven application can help learners to improve their critical thinking and can also lead them to formulate hypotheses. The pre-defined relationships found in the ontology can be used to guide learners to draw their own conclusions.

The remainder of this paper is structured as follows. In section 2, related work in enquiry-based learning in science education is discussed. Section 3 highlights some key issues related to modeling and reasoning in enquiry-based learning environments. Some recent ontology-based design approaches are reviewed in section 4. A working prototype with a specific scenario and technical architecture is described in section 5, which shows how the ontology-based design approach can help learners not only to perform enquiry learning processes but also to guide them in the hypothesis generation process. Finally, section 6 contains concluding remarks and discusses some future research directions.

II. RELATED WORK

Various systems for enquiry-based learning activities have been discussed in the literature. These systems reflect the diversity of enquiry investigation and its use in different application domains including natural science, social science, mathematics, languages etc.

In the Ambient Wood Project [14], a learning experience was designed that encouraged children to explore and hypothesize about different habitants found in woodland. In a similar vein, Maldonado & Pea [15] provided educational activities and tools for helping students participate in collaborative science enquiry involving local environmental data in the LET'S GO! Project (Learning Ecology through Technologies from Science for Global Outcomes). In this particular project, the data was collected, analyzed, reflected on, and reported through mobile and sensor technologies. In another enquiry project named nQuire [16], 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. All these enquiry-based applications are designed to engage learners by taking them out of the classroom to perform scientific inquiries by using handheld devices. However, they are not semantically rich enough to enhance students' reasoning skills during these enquiry learning activities.

Support for designing enquiry learning activities by using an ontology-based design approach has been explored in only a few studies. CLS [12] provides visual concept transfer paths that help the learners to comprehend the relationships between the defined course concepts. In this system, the approach is used for structuring content information in which learners navigate through learning material by following their own personalized paths. Similarly, the SCY Project [13] intends to offer learners 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 [17]. This defines a learning platform in order to create link 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.

III. MODELING AND REASONING IN ENQUIRY-BASED LEARNING

Scientific enquiry is one of the most challenging and exciting ventures for today's schools. 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 [18]. As a matter of fact, 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 needed as a practice arena for enquiry skills [4].

In an enquiry process, computer modeling can be a powerful tool to enhance learners' reasoning and help them to improve their understanding [7]. This learning is often characterized as a type of learning in which the processes of scientific enquiry lead to active construction of knowledge by learners, scaffolded by tools that are knowledgeable about the learning processes [4].

When learners are provided with these modeling tools, most learners manage to design and execute experiments; they are capable of building correct models, but often fail to relate knowledge about phenomena to these models [19]. Therefore, the educational advantages of enquiry learning are often challenged by the learners' understanding of a particular domain and modeling, and both lie at a conceptual level [3]. For example, learners are 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 modeling tools that can enhance learners' reasoning skills at a conceptual level while they are performing enquiry investigations.

Traditionally, learners are involved in enquiry processes involving; orientation, hypothesis generation, experimentation and drawing conclusions [20]. In such processes, they are required to formulate a hypothesis, deduce consequences from the hypothesis, and make observations to investigate the consequences. This type of enquiry model is more like a stepwise scientific method which mainly focuses on designing an experiment and validating a hypothesis by the experimental results. However the process of hypothesis generation has not been widely considered in the literature. This is because school science has traditionally been dominated by the hypothetico-deductive view of science [8].

Scientific explanations do not always proceed in a deductive manner but more often than not develop from abduction [21]. The concept of abduction was first introduced by C.S.Pierce (1839-1914) who classified abduction as a form of inference. In abduction, a case or condition (H) is derived from a rule (H → P) to explain a result (P). The following example shows how the abductive inference proceeds [21]:

(Result, P) Fossil fish are found far in the interior of the country
(Rule, H→P) If the sea once washed over this land, fossil fish can be found.
(Case, H) Therefore, this land was once washed over by the sea in the past.

As this example shows, abduction is understood as a form of backward reasoning from a set of observations back to a cause [9]. This trait of abductive reasoning is well-suited to enquiry problems in which learners are challenged to formulate scientific hypotheses and explain the natural phenomena such as earth-scientific investigations [9]. Therefore, science educators and researchers have recently begun to study the process of hypothesis generation and abductive reasoning in the context of enquiry investigations.

IV. ONTOLOGY-BASED DESIGN APPROACH

Ontology-based design approaches have gained interest as a technology in learning environments because they appear promising for improving information retrieval, by adding an intelligent layer based on semantic representations of the domain, the activities or pedagogical models [22]. From an educational perspective, an obvious added value of using an ontology-based design approach is to define a set of terms and their relations at a conceptual level [17]. In addition, ontology helps to infer semantic relations between participating entities and provides adaptive learning content for learners; thus, ontology can serve as a structured knowledge scheme that assists in the construction of a personalized learning path [23].

Ontology technology has previously been used in education technology [24] [25] [26] for different purposes ranging from the definition of a domain-specific terminology to the use of conceptual models and inference in the generation and composition of learning technology content and applications. Different ontology applications for learning technology systems are developed in which ontologies are defined as a conceptual model for learning content components [25].

Ontology-based design approaches are usually domain dependent. The domain model is used to provide a conceptualization of the domain-dependent knowledge with which the learner is concerned during the learning process. Similarly, assessment constitutes a critical component of the instructional process. It serves as a method of measuring the learners' knowledge about a particular domain [27]. Thus ontologies are also used as a framework for generating multiple choice questions (MCQs) and answers which can be helpful in assessing learners' knowledge. Recently, many ontology applications have been designed in which MCQs are generated by using domain ontologies. Applications such as OntoAware [28], First-Aid domain ontology [29] and OntoQue [27] have been developed 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. Ontology-based applications that have addressed enquiry-based learning environments include CLS, which provides visual concept transfer paths that help the learners to comprehend the relationships between the defined course concepts [12] and the SCY Project [13], which intends to offer learners a learning experience that includes both enquiry and collaboration. None of these projects have been targeted at mobile learning, but there are a few examples of ontology-based design approaches for mobile learning environments, taking account of the contextual aspects of learning while mobile [30]-[31].

V. ThinknLearn: A PROTOTYPE

As a proof of concept, the use of an ontology-based design approach is presented for generating scientific hypotheses. The implementation of this approach in a prototype called 'ThinknLearn' has allowed us to evaluate the roles of semantic understanding and reasoning capabilities between different concepts defined in the ontology. A reference scenario is used to support enquiry-based learning activities using a domain ontology. Further, a technical architecture for ontology-driven mobile web-based applications is described.

A. *Usage Scenario*

In this section, a reference scenario is defined for mobile learning science enquiry investigations. In this particular example, learners need to formulate hypotheses from the collected data. They have to visit a natural environment and collect a soil sample from there. Three measures, including an observation, are needed for their data collection process. The soil pH value, the percentage of the different soil texture types found in the sample and the plant type which grows in that soil sample need to be identified. Learners have to understand the relationships between these measures and construct hypotheses by using the application as well as the information collected from the given sample. The application uses an ontology and its defined relationships to infer knowledge for the learners' guidance. The ontology defines suggestions throughout this enquiry process which may lead learners towards generating scientific hypotheses. The application is supported throughout by the technical architecture which is described in the following section.

B. *Technical Architecture*

In this section, the technical architecture is outlined for the application as depicted in fig. 1. This architecture is influenced by the approach used in [32]. The basic requirements in such enquiry-based learning activities are to provide a flexible architecture that could support the generation of hypotheses and offer an environment that could potentially enhance critical thinking. A Java platform has chosen for developing this prototype because it allows for portable applications. In addition, Java has useful open source libraries for ontology deployment and adaptive web interfaces.

In this architecture, a 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 Fig. 1. This servlet reads the ontology from the server using the Jena API, a Java framework for building semantic web applications [33]. The Jena API provides a programmatic environment for RDF (Resource Description Framework), RDF-S (Schema) and the OWL Web ontology language [33]. Protégé, an open source ontology editor and knowledge base framework has been used for developing this domain ontology. 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 ontology [34]. Adaptive web pages are returned to the client using the WALL library, which adapts Java Server Pages to the browser being used by the client device.

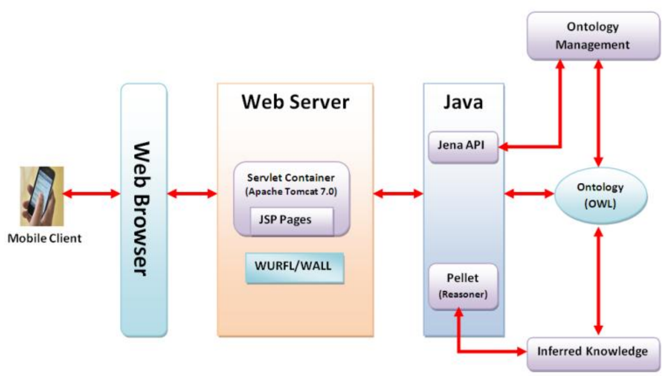

Fig. 1. Technical architecture of the system.

C. Ontology-driven Application

In this section, the use of an ontology-based design approach is described for enquiry-based investigations using a mobile web application. An example scenario is outlined in which learners need to formulate hypotheses from the collected data. During the data collection process, measures of soil pH and soil texture are required while the type of a plant that grows in that soil needs to be observed. The knowledge base is defined by a domain ontology which elaborates semantic relationships between the defined concepts found in this example (e.g. Soil and Plant) as depicted in Fig. 2.

In this particular example, 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. For soil pH value, the value lies between 1-14 while three sub-components are required to measure the texture of a soil sample; sand, silt (loam) and clay. The different combinations in percentages of these sub-components enable the soil texture of a sample to be identified. There are three main soil texture types, *Sandy*, *Loam* and *Clay*, included in the ontology, while

the value of the soil pH is defined in three categories; *7* (i.e. Neutral), *greaterthan7* (i.e. Alkaline) and *lessthan7* (i.e. Acidic) as shown in fig. 2. These soil types, *Neutral*, *Acidic* and *Alkaline* are inter-related with the *SoilPH* and *SoilTexture* concepts found in the ontology. For this specific example, only three plant types are considered; *Herb*, *Shrub* and *Tree* (see fig. 2). The relationships between all these concepts are defined in the ontology which is used to help learners to extract information for generating hypotheses during the enquiry-based learning process.

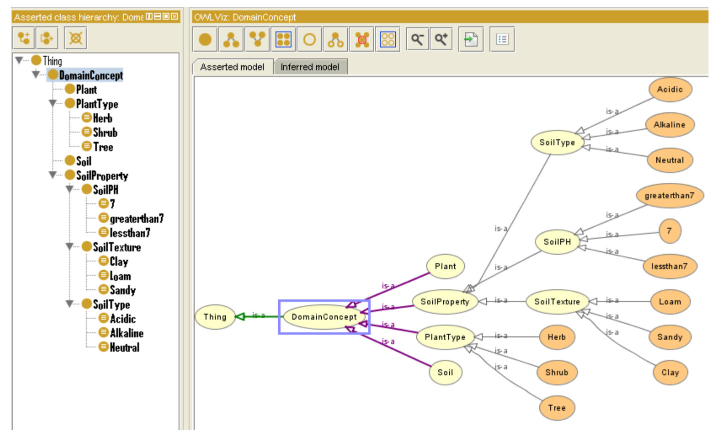

Fig. 2. Domain Ontology

The application initially asks for the soil pH value, the percentages found in the soil texture and the observed plant type which grows in that soil sample. Fig. 3 shows the welcome screen of the prototype 'ThinknLearn', which is used to get the measured values taken by the learners during this example. This web-based application can be accessed by any internet-enabled handheld device, but for readability the screen captures here are from a desktop browser.

Fig. 3. Welcome Screen - ThinknLearn

After submitting these values, the application does not give the answers straightaway; it does not state that ‘this’ soil pH value belongs to ‘that’ soil type. Instead, the application asks a series of MCQs regarding the collected values of these measures one-by-one and then gives suggestions or hints based on the answers chosen by the learners (see Fig. 4 and 5). 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 inter-related relationships and its reasoning capabilities in order to extract the information regarding the given suggestions.

Fig. 4. MCQ about the soil texture type

Fig. 5. Ontology suggestion based on the chosen answer

In the end, the application presents a summary of the activities conducted by the learners during this science enquiry learning process as depicted in Fig. 6. Inputs are placed at the top of the page with all the suggestions given by the ontology during this enquiry-based 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. The ontology extracts all the possible hypotheses by using its inter-related 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.

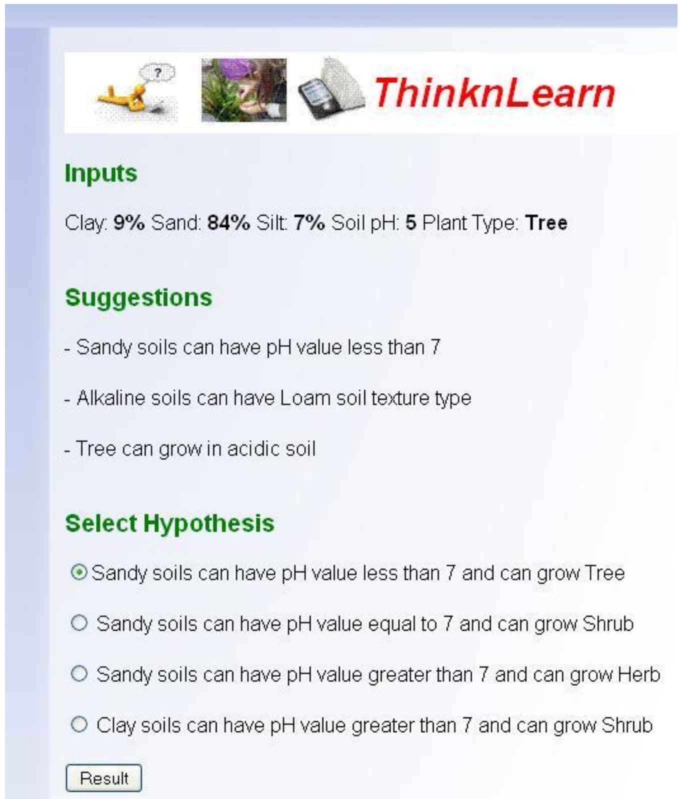

Fig. 6. Summary Page - Hypothesis Generation

VI. CONCLUSIONS & FUTURE WORK

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

In our work, the value of an ontology-based design approach in science enquiry mobile learning investigations has been investigated. To evaluate the feasibility of this approach, an ontology-driven mobile web application ‘ThinknLearn’ has been designed which shows how an ontology-based design approach can be used in enquiry-based mobile learning activities and how this approach can help learners to construct hypotheses relating to measurements and observations. For the implementation of a prototype, an example scenario is defined while a technical architecture is applied that can support mobile learners during such enquiry investigations.

The prototype described in this paper was not designed with field tests in mind, and has therefore not been evaluated with learners. Instead, its purpose was to be used as a proof of concept to demonstrate to science educators the way that an abductive mobile application might be used in a science enquiry activity. It served as a working prototype that was used in discussions regarding subsequent work that will involve field trials. The resulting proposal is that a revised version of this application will be evaluated by testing it with science level-1 school children investigating heat transfer as part of their standard science curriculum. The effect of the application on learning performance of the participants will be assessed during the experiments. This may help us to comprehend how practical ontology-driven applications can be used to support mobile learning activities during scientific enquiry investigations.

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