Mobile Learning Ontologies:

Supporting Abductive Inquiry-Based Learning in the Sciences

A thesis presented in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

in

Information Technology

at Massey University, Albany, Auckland

New Zealand

Sohaib Ahmed

2012

To my parents for their love, endless support and encouragement!!

Abstract

The use of ontologies has become increasingly widespread in many application areas, particularly in technology-enhanced learning. They appear promising in supporting the generation and adaptive presentation of learning content for specific domains. This thesis examines how ontologies can be applied in abductive mobile science inquiry-based learning, an example of a learning activity that can allow students to learn science by doing science.

Traditionally, school science education has been dominated by deductive and inductive forms of inquiry investigations, while the abductive form of inquiry investigation has previously been sparsely explored in the literature, which emphasizes the development of scientific hypotheses from observed phenomena. Thus, this provides us with an opportunity to explore some new approaches to technology-assisted learning in the sciences.

The main purpose of this thesis is to demonstrate to science educators how an abductive mobile application may be applied in a science inquiry activity, and how ontology-based scaffolding can support technology-enhanced learning environments.

This thesis uses a Design Science Research Methodology (DSRM), supported by Activity-Oriented Design Methods (AODM) tools to create an ontology-driven application 'ThinknLearn' for a science inquiry domain, which has been evaluated using the M3 evaluation framework with high school science students. The results were promising and showed improvements in the students' understanding of the learning domain as well as developing their positive attitudes towards mobile learning.

Acknowledgements

First and foremost, I thank Allah for bestowing upon me the wisdom and perseverance during this research, and indeed, throughout my life.

I am thankful to my funding organization, Higher Education Commission (HEC), Pakistan for providing me this opportunity to achieve this milestone. Thanks HEC; this would not be easy to get without your financial and overall support.

This thesis would not become a reality if I would not able to get assistance and encouragement from many people, in different ways, during my PhD journey. I would like to extend my appreciation especially to the following.

First of all, I am grateful to Associate Professor David Parsons from the core of my heart, for being my supervisor and mentor in these years. I have been fortunate to have the opportunity to learn from and work together with him. Thank you so much for introducing me to research and the research community. Indeed, it is because of you, *Dave*, I managed to accomplish such a difficult task with ease and I believe your constant support, patience, suggestions and constructive criticisms made it possible as a fruitful journey.

I am also under obligation to my co-supervisors including Associate Professor Hokyoung Ryu for his kind support during my first two years of PhD, and Dr. Mandia Mentis for her valuable feedback in this last year and so.

The other most important people to thank are the participants who were involved in both experiments by contributing their time and efforts. Further, I am thankful to the Principal of the school, Albany Senior High School, Auckland, New Zealand to provide such an opportunity to conduct experiments with her students. And most importantly,

Table of Contents

List of Publications

❖ **Ahmed, S.,** & Parsons, D. (2013). Abductive Science Inquiry Using Mobile Devices in the Classroom. *Computers & Education, 63*, 62-72.

❖ **Ahmed, S.,** & Parsons, D. (in press). Abductive science inquiry using technology-enhanced learning. In J. Jovanovic, & R. Chiong (Eds.), *Technology Enhanced Learning.* Santa Rosa, California: Information Science Press.

❖ **Ahmed, S.,** & Parsons, D. **(Best paper award)** (2012). Evaluating 'ThinknLearn': A mobile science inquiry-based learning application in practice. *11th World Conference on Mobile and Contextual Learning (MLearn 2012).* Helsinki,Finland.

❖ **Ahmed, S.,** Parsons, D., & Mentis, M. (2012). Scaffolding in mobile science enquiry-based learning using ontologies. *ICST Transactions on e-Education and e-Learning Journal*, *12*(07-09), 1-17.

❖ **Ahmed, S.,** Parsons, D., & Mentis, M. (2012). An ontology supported abductive mobile enquiry based learning application. *In proceedings of the IEEE International Conference on Advanced Learning Technologies (ICALT 2012)*. Rome, Italy.

❖ **Ahmed, S.,** & Parsons, D. (2011). ThinknLearn: An ontology-driven mobile web application for science enquiry based learning. *In Proceedings of the 7th International Conference on Information Technology and Application (ICITA 2011)* (pp. 255-260). Sydney, Australia: IEEE Computer Chapter NSW.

❖ **Ahmed, S.,** & Parsons, D. (2011). COMET: Context Ontology for Mobile Education. In G. Biswas, S. Bull, J. Kay, & A. Mitrovic (Eds.), *Artificial Intelligence in Education (AIED 2011)* (Vols.LNAI 6738, pp.414-416). Springer-Verlag Berlin-Heidelberg.

❖ **Ahmed, S.,** Parsons, D., & Ryu, H. (2010). Supporting adaptive learning interactions with ontologies. *In Proceedings of 11th Annual ACM SIGCHI NZ Conference on Computer-Human Interaction (CHINZ 2010)* (pp. 17-24). Auckland, New Zealand.

❖ **Ahmed, S.,** Parsons, D. and Ryu, H. (2010). Beyond learning objects - Dynamic adaptation in learning scenarios for lifelong learners. *IEEE Learning Technology Newsletter, 12*(1), January 2010, 49-51.

List of Acronyms

AIM	Abductive Inquiry Model
AODM	Activity Oriented Design Methods
API	Application Programming Interface
AT	Activity Theory
DL	Description Logics
DSRM	Design Science Research Methodology
DTD	Data Type Definitions
HTTP	Hypertext Transfer Protocol
IBL	Inquiry-based Learning
JSP	Java Server Pages
LO	Learning Objects
MCQs	Multiple Choice Questions
NCEA	National Certificate of Educational Achievement
OWL	Web Ontology Language
PBL	Problem-based Learning
RDF	Resource Description Framework
RDF-S	Resource Description Framework Schema

TEL   Technology-Enhanced Learning

W3C   World Wide Web Consortium

XML   Extensible Mark-up Language

List of Figures

List of Tables

Introduction

1.1 Theme Explanation

Since the term 'Ontology' inherited from philosophy, began to be used in computing and information science literature, the field has inspired work in numerous ways. An ontology (or ontologies) is used to support a framework for conceptualization and knowledge modelling (Gruber, 1993). Over the period of the last few years, the use of ontologies has been emerging as one of the cornerstone technologies in a multitude of areas especially in education.

1.1.1 Ontologies in Education

Ontology is a popular term today, appropriately use in the field of education for various purposes. They include domain models (George & Lekira, 2009; Hong & Cho, 2008), adaptive learning content (Ghidini, Pammer, Schier, Serafini, & Lindstaedt, 2007; Jovanovic, Gasevic, & Devedzic, 2009), information retrieval (Al-Yahya, 2011; Papasalouros, Kottis, & Kanaris, 2011) and inference in the creation of learning content (Pessoa, Calvi, Filho, de Farias, & Neisse, 2007; Wang, Gu, Zhang, & Pung, 2004). These mentioned uses may be broadly classified for two purposes in learning environments:

representing knowledge and *communicating knowledge*. The former is used explicitly for supporting the knowledge creation in the form of learning content while in the latter the created knowledge can be communicated and shared among the learners involved. However, in this thesis, the value of ontologies in representing knowledge for particular domains is being explored.

For the last few years, educational researchers have been interested in constructing domain ontologies for scaffolding learning content and its adaptive presentation to learners (Ghidini et al., 2007; Jovanovic et al., 2009; Knight, Gasevic, & Richards, 2006; Pessoa et al., 2007). The Vygotskian term 'scaffolding' (Vygotsky, 1978) is conceptualised as assistance in which learners become increasingly proficient problem-solvers by using guidance from instructors who scaffold through coaching, task structuring, suggestions, without giving learners the final answers straightaway (Quintana et al., 2004).

In the area of educational research, ontology-based scaffolding is used for content level adaptation (Brusilovsky, 2001) by providing the same learning content to learners with two different purposes: *course content* and *assessment* (Pahl & Holohan, 2009). For *course content*, the knowledge represented in a domain ontology can be converted into learning content while Multiple Choice Questions (MCQs) are very popular means of assessments in traditional and digital learning settings (Papasalouros et al., 2011). Although, one of these aspects have been explored in the literature (Ghidini et al., 2007; Holohan, Melia, McMullen, & Pahl, 2005; Jovanovic et al., 2009; Vas, 2007; Vas, Kovacs, & Kismihok, 2009), but the evaluation of both these aspects in learning applications, particularly for Technology-Enhanced Learning (TEL) environments, is limited. Hence, the primary motivation of this research is to examine the applicability of such ontology-based scaffolding using current learning technologies.

1.1.2 Mobile Learning Technologies

The opportunities of learning are increasing with the advancement in technologies. The paradigm in learning is shifting from conventional electronic learning (E-leaning) towards advanced forms of mobile learning (M-learning) (Liu & Hwang, 2010).

M-learning can be defined and conceptualised in three ways: (Traxler, 2007) an extended version of E-learning with the use of portable devices (Roschelle, 2003; Trifonova & Ronchetti, 2004), in terms of mobility of learners and the mobility of the learning (Kurti, Spikol, & Milrad, 2008; Lonsdale, Baber, Sharples, & Arvanitis, 2004; Weal, Michaelides, Thompson, & De Roure, 2003), and the learners' experiences of learning with mobile devices (Kukulska-Hulme & Traxler, 2005; Parsons, Ryu, & Cranshaw, 2007). These different perspectives of M-learning depend on the context in which learning activities are carried out (Li, Feng, Zhou, & Shi, 2009) complementing previous classroom learning experiences (Ryu & Parsons, 2009).

The rapid development towards mobile technology deployment at school level, offer students new opportunities for increasing engagement, motivation and learning (Lin, Fulford, Ho, Iyoda, & Ackerman, 2012). In fact, mobile technologies are revolutionizing school education and transforming the conventional classroom into interactive classroom applications that have the potential to enhance students' learning experience (Scornavacca, Huff & Marshall, 2009). These technologies have some prominent features such as computing power and wireless capability which can make learning expedient, immediate, authentic, accessible, efficient and convenient (Curtis, Luchini, Bobrowsky, Quintana, & Soloway, 2002; Ogata & Yano, 2004). Thus, these technologies may increasingly become a convincing choice of technology for classrooms (Lai, Yang, Chen, Ho, & Chant, 2007; Soloway et al., 2001).

There have been great strides in considering the affordances of these handheld devices for various domains, particularly in science education (Looi et al., 2011). Various studies in the literature show that the use of these technologies providing enjoyable learning experiences for learners, increasing motivation towards science learning and enhancing their critical thinking skills and learning performance (Chuang, Shih, & Hwang, 2009; Vavoula, Sharples, Rudman, Meek, & Lonsdale, 2009).

1.1.3 Inquiry-based Learning

Inquiry-based learning (IBL) or Inquiry learning intends to provide educational activities for encouraging learners to learn science by doing science (Mulder, Lazonder & De Jong, 2011), and offer resources to engage learners in understanding specific domains through exploration and experimentation (Van Joolingen & Zacharia, 2009). Thus, achieve basic learning objectives: the acquisition of general inquiry abilities, the acquisition of specific investigation skills, and the understanding of scientific phenomena (Edelson, Gordin, & Pea, 1999). In addition, this learning can also augment learners' critical thinking skills while performing such scientific inquiry investigations (Lim, 2004; Shih, Chuang, & Hwang, 2010).

In school science, IBL aids learners understanding of domain-specific knowledge of the scientific phenomena that they observe in the physical world (Van Joolingen & Zacharia, 2009). The aim of this learning is not just to provide solutions to problems straightaway but to create rational, mature thinkers who will be able to comprehend and to appropriately use knowledge in analysing problems in some meaningful way (Kordaki & Dardoumis, 2009). The educational advantages of these IBL activities are often challenged by learners' understanding about a specific domain in technology-assisted learning environments (Altin, Pedaste, & Aabloo, 2011; Van Joolingen, De Jong, & Dimitrakopoulout, 2007; Mulder et al., 2011). 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 hindrance to learning, additional guidance is needed that can allow them to conceptualise scientific concepts, manage inquiry investigation and articulate their thinking in order to support meaningful learning (Hmelo-Silver, Duncan, & Chinn, 2007).

Traditionally, a hypothetico-deductive and inductive form of investigation has been followed in school sciences (Grandy & Duschl, 2007), where learners are required to process ideas (hypotheses). In contrast, abductive form of inquiry investigation ensures the development of scientific hypotheses, which are observed from the physical environments (Oh, 2010). This form of inquiry is different from inductive and hypothetico-deductive because it enables scientists or researchers to reach beyond a pure representation of facts based on observations (Raholm, 2010). Further, it has been argued that constructing scientific hypotheses helps learners to make sense of phenomena studied, articulate these understandings and engage in constructing explanations about the observed phenomena (Berland & Reiser, 2009). In the literature related to TEL, this kind of inquiry investigation has been sparsely explored (Oh, 2011).

Support for designing inquiry learning activities by using ontologies has been explored in some recent studies, such as the Concept map Learning System (CLS) (Chu, Lee, & Tsai, 2011) and the Science Created By You (SCY) project (De Jong et al., 2010). However, none of these studies have targeted mobile learning environments. Hence, this provides an opportunity to explore some new approaches to technology-assisted learning in the sciences.

1.1.4 Abductive Science Inquiry

The concept of abduction was first coined by C.S.Peirce (1839-1914) who classified abduction as a form of inference. Peirce maintained that the logic of scientific inquiry is divisible into fundamental modes of inference or reasoning (Raholm, 2010): explicative inference (deduction), evaluative inference (induction) and innovative inference (abduction).

There are three distinct viewpoints related to the concept of abduction (Patokorpi, 2009): scientific research or inquiry, logic programming, and everyday reasoning. Scientific inquiry is explored in terms of abduction in this thesis which focuses on mobile science learning activities. This logical inference is well-suited to science inquiry problems in which learners are challenged in both the formulation and evaluation of explanatory theories and scientific hypotheses (Haig, 2005; Oh, 2010). In such abductive inquiry, the generated hypothesis about a given phenomena is one of the possible results but this uncertainty may be tested through hypothetico-deductive and inductive form of investigations (Raholm, 2010). It is suggested in many studies that the construction of hypotheses in inquiry investigations not only help learners to understand domain concepts found in the observed phenomena (Shen, 2010) but also augments their conceptual knowledge about the underlying domain (Hart, 2008; Shen & Confrey, 2007).

Science educators and researchers have recently begun to study the process of hypothesis generation in the context of abductive science inquiry investigation. Thus, the main purpose of the study described in this thesis is to exhibit to science educators and researchers how ontology-driven applications can be implemented practically for abductive mobile science inquiry investigations.

1.2 Research Challenges

The use of ontologies in many domains for different purposes is promising. This thesis explores the use of ontology-based scaffolding in mobile learning applications. With the advancement of technology in education, the learners interact with handheld devices to learn about a particular domain. Specifically, in IBL environments, learners can use their devices to perform scientific investigations. These rapid developments in science education bring about three challenges that are explored in this thesis.

Ontology-based scaffolding There are current developments in learning applications that can support ontology-based scaffolding for generating learning content according to the needs of learners. This type of scaffolding offers adaptive presentation of those contents into multiple ways: course content and MCQs. However, the current literature revealed paucity in the use of ontology-based scaffolding for both these ways in mobile learning activities.

Abductive science inquiry There exist a large number of IBL applications that follow deductive or inductive ways of inquiry. But, it is a recent trend in science education to examine abductive ways of science inquiry in which learners are required to identify an idea or hypothesis about a particular domain.

Mobile learning experience The affordances of mobile technologies can provide enjoyable and engaging learning experiences in situ while performing science IBL activities. However, such significant work has not been done previously in abductive science inquiry that highlights the affordances of these technologies. Further, there is a need to consider technology-assisted learning environments that guide learners in understanding the topics and formulating hypotheses in such inquiry investigations.

These challenges address the fundamental research question of this thesis; *how can an ontology-based scaffolding application provide learning content in mobile abductive science inquiry-based learning environments?*

1.3 Approach and Methodology

Design science research methodology (DSRM) (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2008) consists of a sequence of activities that construct an innovative application for a particular problem from in a domain. To address the above research challenges, an innovative application based on ontology-based scaffolding for abductive mobile science inquiry investigations is required. Therefore, this research work adopts DSRM (Peffers et al., 2008) for designing and evaluating such application.

Further, it is supported by Activity-Oriented Design Methods (AODM) (Mwanza-Simwami, 2009) tools that are applied to identify the number of iterations needed in addressing these challenges. These tools are used as an analytical and practical approach for applying key concepts of Activity Theory (Leont'ev, 1981) in the form of a model that is activity system (Engestrom, 1987).

For defining an activity model of the application, a mobile learning framework (Sharples, Taylor, & Vavoula, 2005) is adopted in this research that separates learning activity in two layers: semiotic and technological. A technological layer of the adopted framework is appropriate for this research because this layer proposes requirements for the design and evaluation of technology-assisted mobile learning activity. Using the "Tools" and "Context" components of this layer, three sub-activities are identified of the defined activity model of the proposed application. These activities 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 analysed. In the first iteration, uses of ontology-based scaffolding in accessing learning content in multiple ways were explored. In the last three iterations, science related domain examples were used, which guided learners in order to formulate hypotheses from the observational data. For the evaluating purposes, the first iteration was evaluated internally with a design perspective while the second iteration was examined externally with science educators of a high school. The subsequent iterations, experiments were conducted with high school science classes of 15-16 year olds after getting approval from the University Ethics Committee and the principal of a high school (see Appendix I and II).

In these experiments, one of the topics from the New Zealand NCEA[1] level 1 standard science curriculum was used as a domain example that was evaluated by using the M3 evaluation framework (Vavoula, & Sharples, 2009). In the first experiment, regarded as a pilot study, 23 participants[2] took part and validated the application in terms of its utility towards hypothesis generation, and understanding about the underlying domain. This experiment applied only Micro level evaluation (Vavoula et al., 2009), which included usability (ISO, 2003) and mobile learning quality (Parsons & Ryu, 2006) aspects to be evaluated. Both quantitative and qualitative data were gathered about these aspects using questionnaire and semi-structured group discussions. However, the same Micro level evaluation was conducted with 161 participants in the final iteration along with the Meso level evaluation (Vavoula et al., 2009). This Meso level was used to assess the impact of the application on learners' learning performance between experimental and control groups in their pre-post and retention tests.

---

[1] National Certificate of Educational Achievement
[2] The terms: participants and students are used interchangeably throughout in this thesis

1.4 Research Scope

The work in this thesis is mainly focused on exploring ontology-based scaffolding in abductive mobile science inquiry activities. The scope of this study is defined as follows:

- The uses of ontologies investigated including construction of domain models, generation and adaptive presentation of learning content, and inference capabilities while extracting information.

- A mobile web application 'ThinknLearn' has been designed and implemented. This has been done in the context of the theory of abduction in which formulating a hypothesis from a set of observations is central.

- A scaffolding design framework was applied (Quintana et al., 2004) for designing such IBL activities.

- A technological layer of a mobile learning framework (Sharples et al., 2005) was used in defining an activity model of the application that further lead to the application of AODM tools (Mwanza-Simwami, 2009) in order to generate sub-questions of the research design.

- Experiments were conducted with high school students using mobile devices within classroom settings.

- An abductive Inquiry Model (AIM) (Oh, 2011) was exercised by high school students in the last two iterations.

- A Physics topic "Heat energy & transfer" was used as an experimental context in the last two iterations, taken from the standard New Zealand NCEA level 1 science curriculum. This covers a few important aspects of heat energy: impact

on the movement of water particles, and the loss and absorption of heat energy due to different coloured surfaces.

♦ From the M3 evaluation framework (Vavoula, & Sharples, 2009), Micro and Meso levels were applied for the evaluation of the application 'ThinknLearn'.

♦ Qualitative and quantitative data were collected using a questionnaire and semi structured group discussions.

♦ Objective assessment of the students was also carried out for investigating the impact of the application on their learning performance in pre-post and retention tests.

1.5 Significance of Study

The work in this thesis investigates the use of ontologies in mobile science IBL applications. The main contributions of this thesis are:

♦ Use of ontologies in education specifically in generating and presenting learning content in two ways; course content and MCQs.

♦ The development and evaluation of an abductive mobile web-based application that

    o shows science educators how an abductive mobile application might be used in science IBL activity.

    o provides opportunities to learners to use their critical thinking skills for understanding the given scientific knowledge.

    o explores mobile learning experiences in science education.

    o guides learners in interpreting measurements and observations to help them construct meaningful hypotheses.

♦ Use of DSRM to address how research of this kind should be conducted.

There are some other additional innovative contributions of this research work. Such as, this study is one of the first of its kind where abductive mobile science inquiry is being investigated with high school students. Other innovations include the use of Activity Oriented Design Methods (AODM) tools (Mwanza-Simwami, 2009), Abductive Inquiry Model (AIM) (Oh, 2011), the part of the M3 evaluation framework (Vavoula et al., 2009), a technological layer of a defined mobile learning framework (Sharples et al., 2005), scaffolding design framework (Quintana et al., 2004) and the technical architecture (Draganidis, Chamopoulou, & Mentzas, 2008) for designing such mobile science IBL applications.

This research may help science educators by allowing them to comprehend further how ontology-driven applications can be used to improve both learning performance and cognitive skills during science inquiry investigations. Moreover, this research may be further developed to support the practical implementation of abduction theory in school sciences, which has been sparsely explored in the literature.

This research may also provide guidelines for application developers and engineers to apply abductive form of inquiry in other professional areas that might benefit from ontology-supported mobile learning including scientific theory formulation, accident investigation, training management, jury deliberation and medical diagnostics systems.

1.6 Thesis Outline

The structure of the thesis is as follows:

Chapter 2 consists of a literature review. It introduces different kinds of ontologies and describes the uses of ontologies in learning environments, especially in generating learning content. Following this basic description of ontologies and their uses, this

chapter further illustrates technology-enhanced learning, mobile learning in classroom and the use of activity theory in mobile learning, in the third section of this chapter, followed by the description about IBL in the following section. Further, modes of inference in scientific inquiries are explained including deductive, inductive and abductive. The literature related to the use of mobile learning in different settings while conducting science inquires is also explained in the subsequent sections. Following this, the previous literature about abductive science inquiries in school education is described. In the last section, the role of ontologies in IBL environments is discussed. This chapter concludes by summarizing the research challenges with an opportunity to explore some new approaches to technology-assisted learning in science education.

Chapter 3 describes the rationale for selecting a design science research methodology, supported by AODM tools to investigate ontology-supported learning – specifically in abductive mobile science inquiry investigations. Additionally, this chapter justifies the need of a technological layer of a mobile learning framework in defining an activity model of the application. Then, this model leads to the implementation of AODM tools for designing and evaluating the proposed mobile learning application. Before the last section of this chapter, the evaluation along with data collection methods by which this learning application has been evaluated, are discussed. Finally, the summary of the chapter is presented.

Chapter 4 demonstrates the implementation of the DSRM approach through four design iterations to address the research challenges of this thesis. Each of these iterations includes DSRM process model that consists of six activities: problem identification and motivation, defining the objectives of a solution, design and development, design and development, demonstration, evaluation and communication. The summary concludes this chapter at the end.

Chapter 5 presents the evaluation results of the last two iterations in which experiments were conducted with high school students. The description of these experiments is divided into two sections namely the pilot study and the final experiment. In each section, the experimental design, the detail about participants, the procedure and analyses of the experiments are described.

Chapter 6 discusses the research findings of thesis. Following this, the implications of this research in theory and practice are explained.

Chapter 7 summarizes the thesis and explains how research questions are addressed in this thesis. Following this, the main contributions are described. Subsequently, limitations of the research are mentioned, followed by some future research directions.

Background and State of the Art

This chapter begins by introducing the definition of the term 'Ontology' and the kinds of ontologies in terms of their expressiveness, and then discusses the use of ontologies in education. Following this, the previous research related to ontology-based learning content generation and adaptive presentation in learning environments are presented. This leads towards an introduction to technology-enhanced learning, specifically mobile learning environments. Further, this chapter mentions previous related literature about the use of mobile technologies in science education. In the next section, inquiry-based learning is introduced and how scientific inquiry works in current schools. Following the background description about this scientific inquiry, the next section of this chapter presents an in-depth understanding of reasoning processes for conducting such inquiry investigations. The role of ontologies in previous inquiry-based learning applications is also discussed. Finally, the last section highlights abductive inquiry in school science learning activities.

2.1 Ontologies

Ontologies are one of the most popular modelling approaches for vocabularies, classifications, and used in other purposes including knowledge management, database design, information retrieval and in the Web (Fensel, 2001). Ontologies are usually domain dependent and are used to provide a conceptualization of the domain-

dependent knowledge that decomposes into a set of knowledge elements (Brusilovsky & Millan, 2007). These elements have been referred to in the literature with different names for different applications such as concepts, knowledge items, topics, knowledge elements, classes, learning objectives, and learning outcomes, but in all respect ontologies are denoted the basic elements for representing domain knowledge or information. However, the current most popular way to express domain knowledge elements is *concepts.* The word *concepts* may mislead someone to consider it only for conceptual knowledge but as a matter of fact, this word represents as a general term, which denotes a fragment of knowledge of any kind including procedural knowledge (Brusilovsky & Millan, 2007).

2.1.1   The Term – Ontology

The term *Ontology* is borrowed from philosophy and began to be used in artificial intelligence in the 1980s. Now this term has become a buzzword in computing and information science literature. Gruber originally defines the term ontology as an *"explicit specification of a conceptualization"* (1993, p. 1). In 1997, Borst, defined as a *"formal specification of a shared conceptualization"* (Borst, 1997, p. 15). This definition extended the conceptualization to be expressed as shared view amongst different communities rather considering an individual view. In addition, such conceptualization should be used in (formal) machine-readable format. However, Studer, Benjamins & Fensel (1998) combined the both definitions and expressed ontology as "an explicit, *formal specification of a shared conceptualization*" (p. 25). Uschold & Gruninger (2004) explained this definition by further explaining the terms: *explicit specification*, *formal*, *shared* and *conceptualization*. An *explicit specification* describes the concepts and relationships with explicit names and definitions in the given conceptual model. The name is a term, while definition specifies how a term is necessarily related to other terms. *Formal* defines that the meaning specification is arranged in a language (usually

a logic-based language) whose formal attributes are well understood. *Shared* indicates that an ontology is generally designed with a purpose to be used and reused across different applications and communities while *conceptualization* means to provide an abstract model of how people think about of a particular domain.

On the other hand, Guarino (1998) created a redefined distinction between an ontology and conceptualization. According to Guarino (1998), conceptualization is "a set of conceptual relations defined on a domain space" (p. 5). He further gave an example of the relations among a set of blocks on the table. In Gruber's definition, an ontology would express. For example, Block A is over Block B and that Block C is on the side of Block A. In contrast, Guarino stated that the problem with this notion is that it reflects specific arrangement of blocks on the table. He further stated that in this situation, meaning of the relations should be defined instead of the current situation of the table (Guarino, 1998). Therefore, his definition for ontology is that "an ontology is an engineering artifact, constituted by a specific vocabulary used to describe a certain reality, plus a set of explicit assumptions regarding the intended meaning of the vocabulary words" (Guarino, 1998, p. 4). In the context of information sharing, ontology is defined as "a formal theory within which not only definitions but also a supporting framework of axioms is included" (Smith, 2003, p. 160). This implied that ontology is a common vocabulary shared amongst other information system communities.

There has been much discussion in the literature on what exactly defines an 'ontology'; however, there is a common core that runs through all approaches: "a set of knowledge terms, including the vocabulary, the semantic interconnections, and some simple rule of inference and logic for some particular topic" (Hendler, 2001, p. 30). A similar kind of a definition was also proposed by Uschold and Gruninger (2004) but they did not mention 'rule of inference' in their definition. Thus, this thesis follows Hendler's (2001) definition because inferences are important aspects of the designed

application 'ThinknLearn', discussed in this thesis. These inferences are used to provide adaptive suggestions as scaffolding for learners while they are performing science inquiry activities.

2.1.2 Kinds of Ontologies

Ontologies are used for the representation of many different things in a particular domain (Uschold & Gruninger, 2004). These things are usually arranged in hierarchy of *classes* and *sub-classes* (sometimes called *concepts* and *sub-concepts*). In each class, various *properties* (also called as *slots* or *roles*) and *restrictions* (sometimes called *facets* or *role restrictions*) are associated for classifying the ontology. A set of concrete *instances* (also called *individuals*) of the class are also mentioned in the ontology to form a *knowledge base* of a particular domain. For example, let consider an example of a first-aid domain. To explain this domain, with its high level of abstraction, *classes* (concepts) such as Injury and Symptoms are defined. Suppose it states that "Broken nose is a subclass of injury that causes blood to run out of the nose". In this specific example, the 'broken_nose', an *instance* for Injury and the 'blood_runs out_of_the_nose', an *instance* for Symptoms are related to each other with the defined *property* 'has_caused'. However, this *instance* 'blood_runs_out_of_the_nose' of a *class* (Symptoms) is also used as a *restriction* because it restricts the property 'has_caused' to a specific type of Injury that is broken_nose.

Ontologies can be categorized in terms of the level of expressiveness (Ye, Coyle, Dobson, & Nixon, 2007): heavyweight ontologies and lightweight ontologies. The lightweight ontologies are based on a conceptualization including concepts, taxonomies, and relationships between these concepts and their properties. On the other hand, heavyweight ontologies apply axioms and constraints to lightweight ontologies (Corcho, Fernandez-Lopez, Gomez-Perez, 2003). However, lightweight ontologies are further classified into informal lightweight ontologies and formal

lightweight ontologies (Giunchiglia & Zaihrayeu, 2009). Informal lightweight ontologies are used to refer as terms, as controlled vocabularies, as thesauri, and as web directories such as Yahoo! (Uschold & Gruninger, 2004) while formal lightweight ontologies can be obtained from informal ones by converting their natural language node labels into concepts which are represented in a formal language (Giunchiglia & Zaihrayeu, 2009), which belong to a family of description logic languages (Baader, Horrocks, & Sattler, 2005). These informal and formal lightweight ontologies are commonly used in a variety of Semantic Web applications (Fensel, 2001). Figure 2.1 shows some of the well-known lightweight ontologies found in the literature.
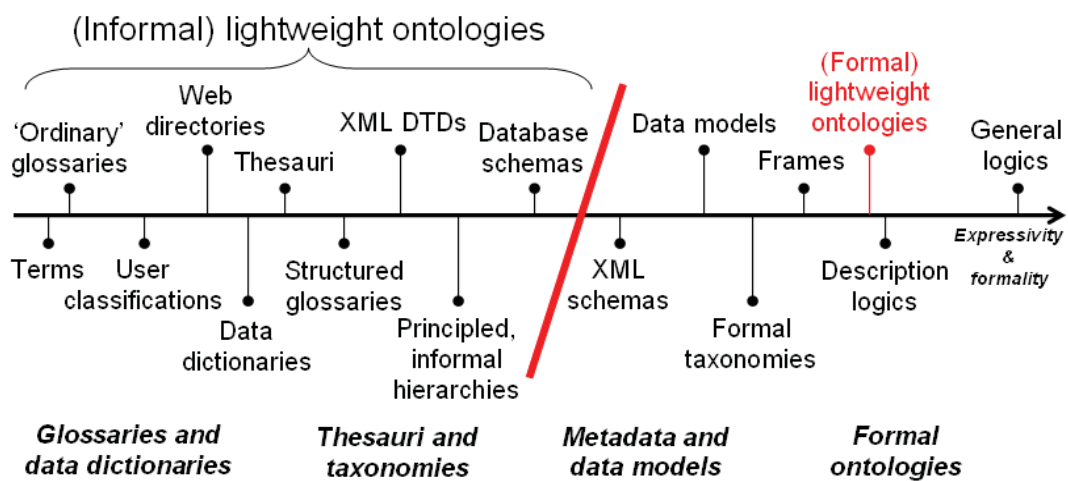
Figure 2.1 Kinds of ontologies (Giunchiglia & Zaihrayeu, 2009, p.1614)

According to Figure 2.1, informal lightweight ontologies are at one extreme, which defines terms with little or no specification (Uschold & Gruninger, 2004). On the contrary, formal lightweight ontologies are presented on the other side. The amount of the specification of the meaning and the degree of formality and expressivity increases while moving along the given spectrum (see Figure 2.1). There is also increasing support for automated reasoning in formal ontologies with the help of

available known reasoners such as FaCT++ (Tsarkov & Horrocks, 2006), Pellet (Sirin, Parsia, Grau, Kalyanpur, & Katz, 2007) and Racer (Haarslev & Moller, 2003).

As a comparison, Let's take two different kinds of ontologies: XML DTDs (Data type definitions) (informal) and XML schemas (formal). Both XML DTDs and XML schemas specify the names of elements and attributes (the vocabulary) but XML schemas provide a stronger expressive power than XML DTDs (Lee & Chu, 2000). In a particular example, XML DTDs might prescribe that every *person* element must have a *name* attribute and may have a child element called *phone.* However, in XML Schemas, the *phone* element can be defined with more specific information, for example, it comprises twelve digits. Then, the *phone* element may be customized with a user-defined data type as 'country code (3 digits)-area code (2 digits)-phone number (7 digits)'. This type of expressivity distinguishes the different kinds of ontologies as depicted in Figure 2.1.

Description Logics (DLs) are one of the most expressive and formal kinds of ontologies (see Figure 2.1), belonging to a family of concept-based knowledge representation languages that can be used to represent domain knowledge formally and in a structured way (Baader et al., 2005). They are perhaps best known as the foundation of ontology languages such as OIL, DAML+OIL and OWL (Horrocks, Patel-Schneider, Van Harmelen, 2003) because they are not only able to solve key inference problems but also provide practical and efficient implementation of the systems (Horroks, 2005).

Amongst description logics, OWL (Web Ontology Language) has a World Wide Web Consortium Recommendation (W3C)[3]. This extends RDF (Resource Description Framework), an XML (eXtensible Markup Language) –based language, which describes resources like files, concepts, or images. OWL actually consists of three sub-languages

---

[3] http://www.w3.org/

20

(McGuinness & Van Harmelen, 2004): OWL-Lite, OWL-DL and OWL-Full. OWL Lite can provide a class hierarchy together with some simple constraints while OWL-Full can enable maximum expressiveness, without regard for computational limits. However, OWL-DL is based on description logic formalisms which allow maximum expressiveness while retaining computational completeness. These ontology languages are used to express semantics explicitly so that ontologies are possibly useful in automatic processing and integration (Noy, 2005).

In the literature related to information systems, particularly in educational systems, different kinds of lightweight ontologies have been used previously such as Web directories (Labrou & Finin, 1999), XML DTDs (Bota, Farinetti, & Rarau, 2000; Pastor, Sanchez, & Dormido, 2003), RDF (Jovanovic et al., 2009; Wang & Hsu, 2006) and OWL (Al-Yahya, 2011; Ghidini et al., 2007; Vas, 2007; Vas et al., 2009). However, in this thesis, OWL has been used for designing ontologies because OWL not only has a World Wide Web Consortium Recommendation but also provides more facilities for expressing meaning and semantics than any other ontology languages found in the literature (McGuinness & van Harmelen, 2004).

2.1.3   Applications of Ontologies

Ontologies can be used for number of different purposes and applications, and their generation and structuring vary widely. In (Uschold & Gruninger, 2004), four main categories of ontology application scenarios are described including neutral authoring, ontology as specification, common access to information and ontology-based search. In *neutral authoring*, a neutral ontology is designed for authoring in a single language and then translators are developed from this ontology to the vocabulary required by multiple target applications. The scenario for *common access to information* is very similar to neutral authoring but with a difference in the interoperability technique, which is bidirectional between the applications. However, the term data integration is

21

used by (Giunchiglia & Zaihrayeu, 2009) for combining these two application scenarios. The idea behind *ontology as specification* is to develop an ontology for a specific domain and further use it as the foundation for the development of some application. In *ontology-based search*, an ontology is designed for structuring an information repository at a conceptual level which can be used in order to retrieve particular information. These general application scenarios of ontologies have been applied in many domains including (Happel, Maalej, & Seedorf, 2010):

♦ Enabling new and efficient way to the information reusability

♦ Enabling to extend easily

♦ Providing consensus on the understanding of domain knowledge

♦ Supporting better understanding of domain knowledge

♦ Defining problem and solution domain knowledge separately

♦ Assisting in analysing the structure of domain knowledge

♦ Facilitating a machine to use the knowledge in an application

♦ Sharing common semantics among people and applications.

Aside from their potential for domain knowledge construction and sharing, ontologies have been used for automated reasoning purposes with the help of inference engines or specific ontological reasoners (Baader, Knechtel, & Penaloza, 2009; Niu & Kay, 2010). In addition to the above, ontologies are also used in defining standards and strategies, especially in learning domains (Friesen, 2005; Knight et al., 2006). However, in this thesis, ontologies are designed for the purpose of developing a learning application. Hence, only *ontology as specification* (Uschold & Gruninger, 2004) is

explored in this thesis, which is one of the general categories of ontology application scenarios.

2.2   Using Ontologies in Education

Ontologies have been used in education for various purposes including domain-specific terminologies (Bourdeau, Mizoguchi, Psyche, & Nikambou, 2004; George & Lekira, 2009; Hong & Cho, 2008), interoperability, exchange and search for learning resources (Berri, Benlamri, & Atif, 2006, Dimakopoulous & Magoulas, 2008; Dufrense, Rouatbi, & Guerdelli, 2008; Yee, Tiong, Tsai, & Kanagasabai, 2009), and generation of learning content according to the needs of learners (Cassel, Davies, Le Blank, Snyder, & Topi, 2008; Ghidini et al., 2007; Jovanovic et al., 2009; Pessoa et al., 2007).

These mentioned uses may be classified into seven different educational applications, which include ontology development, creation and generation of learning content, adaptivity and presentation, packaging and interoperability, organization and sequencing, metadata and annotation, and sharing and exchange (Pahl & Holohan, 2009). From a broader perspective, there are two main purposes for using ontologies in learning environments (Pahl & Holohan, 2009): *representing knowledge* and *communicating knowledge*. The former is used explicitly for supporting the development of learning content, which creates knowledge while in the latter case the created knowledge can be communicated and shared among the learners involved. However, in this thesis, the value of ontologies in representing knowledge for particular domains is being explored.

Ontologies have often been used to represent different concepts or subject matters to be taught in a course (Breuker, Muntjewerff, & Bredeweg, 1999). However, the significance of structuring and specification of educational content and its visual representation followed with such inter-related issues as design, usability and

adaptation has been underestimated to a certain extent previously in the literature (Gavrilova, Gorovoy & Petrashen, 2009). For the last few years, educational researchers have been interested in constructing domain ontologies for generating learning content and its adaptive presentation to learners (Ghidini et al., 2007; Jovanovic et al., 2009; Knight et al., 2006; Pessoa et al., 2007).

2.2.1   Ontologies for Content Generation in Education

Content generation tools, often known as content authoring tools (Brusilovsky, 2003; Grigoriadou & Papanikolaou, 2006); allow an author or instructional designer to support learning content generation either from scratch or using some resources such as ontologies (Pahl & Holohan, 2009). One of the main aims of these tools is to guide authors in developing content based on the underlying instructive rules (Grigoriadou & Papanikolaou, 2006). In these tools, learning content is considered as the digital representation of learning objects (LOs). LOs can be used, reused or referenced in a technology-supported learning system (IEEE LTSC, 2002). These objects are rather small and are usually assembled into larger units to provide adaptive learning content according to the needs of individuals or groups of learners before they are presented to them (Pahl & Holohan, 2009).

Content level adaptation (Brusilovsky, 2001) is one of the levels of adaptation in educational systems and consists of selecting different information such as images, videos, text, and animations depending on the learners' needs (Dolog, Henze, Nejdl, & Sintek, 2003; Koch & Rossi, 2002). There are several possible techniques for content level adaptation (Popescu, Trigano, & Badica, 2007) such as specific media filtering, specific item filtering, content hiding, additional explanation, and different web page versions for different student learning styles, but these techniques are not supported appropriately in reusing LOs for different purposes. However, the richness of

ontologies makes it possible to reuse LOs and repurpose them dynamically (Verbert, Klerkx, Meire, Najjar, & Duval, 2004).

In the educational domain, ontologies are used for content level adaptation by providing the same learning content to learners with two different purposes: course content and assessment (Pahl & Holohan, 2009); the knowledge represented in the ontology can be converted into course learning content. The domain ontology is built on a hierarchy of concepts of a particular domain which guides the sequentialisation of the concepts and their descriptions (Fischer, 2001). While in the instructional process, *assessment* constitutes a critical component which serves as a method of measuring the learners' knowledge about a particular domain (Al-Yahya, 2011). Additionally, multiple choice questions (MCQs) are a very popular means of assessment in traditional and digital learning settings (Papasalouros et al., 2011). In ontology-based assessment tools, the generation of MCQs (and answers) is possible by using related and unrelated concepts found in the subject ontology of a particular domain (Pahl & Holohan, 2009). Moreover, closely related false answers (distracters) can also be generated by using other irrelevant concepts found in the ontology. Being partially inspired by the above approach, the generation of MCQs in the application described in this thesis exhibits some common traits with the work presented in (Papasalouros et al., 2011).

2.2.2 Previous Use of Ontologies in Generating Learning Content

In previous work, the use of ontologies has been discussed for generating learning content for course content and/or assessment as summarized in Table 2.1.

Table 2.1 Summary of the ontology-based systems used in generating learning content

Project Name / Authors	Use of Ontologies	Learning Environment	Kind of Ontologies	Domain Knowledge	Learners
TANGRAM	Course contents	E-learning	RDF	Intelligent Information Systems	University Students
APOSDLE	Course contents	E-learning	OWL	Work-based Scenarios	Professional Trainers
Teachware On Demand	Course contents	E-Learning	XML	IT Courses	Professional Trainers
TDMC	Course contents	E-learning	RDF	Network Management	University Students
Vas, 2007	Assessment	E-learning	OWL	Business Informatics	University Students
Vas et al., 2009	Assessment	M-learning	OWL	Business Informatics	University Students
OntoQueue	Assessment	E-Learning	OWL	History	8th Grade Students
QuGAR-OWL	Assessment	E-Learning	OWL	Environmental Pollution	School Students
O-DEST	Both	E-Learning	OWL	Software Engineering	University Students
OntoAware	Both	E-Learning	OWL	Navigation-based material	Students

TANGRAM (Jovanovic et al., 2009) is one of the recent examples in which an ontology-based design approach is used for the domain of intelligent information systems in order to decompose learning content into reusable fragments. These fragments are semantically interpreted with concepts from the domain ontology which helps in order to get adaptive learning content from available learning resources. The dynamic assembly of learning content in this approach follows the process developed by (Farell, Liburd, & Thomas, 2004). Further, this system also considers the content adaptation according to the learning traits of the learners such as learning style, preferences, and knowledge of the domain topics (Jovanovic et al., 2009).

Similarly, APOSDLE (Ghidini et al., 2007) provides relevant learning resources according to learners' current working scenarios. In particular, based on the immediate work context of a learner, the system identifies missing competencies of learners, their learning requirements and recommends appropriate learning resources. The main focus of that system was also to reuse learning content in small fragments. For example, a paragraph, a page, an image.

In another system, Teachware on Demand (Hollfelder et al., 2001) generates automated course material, based on reusable content fragments. These fragments are annotated with a metadata schema that provides effective mechanisms for the assembly of new courses. Each fragment contains one or more concepts from the domain knowledge which is encoded purely in XML. In a similar vein, TMDC (Teaching Material Design Centre) (Wang & Hsu, 2006) offers an environment for constructing customized reusable material for course contents. This system contains four modules including teaching material repository, ontology, course database and course authoring. However, although all these systems provide content adaptability to some extent they do not explore other important aspects of learning content, such as assessment.

In other work that is applicable to this area, an ontology-based domain model (Vas, 2007) has been developed by the Department of Information Systems at the Corvinus University of Budapest. In that work, an interface of a customized qualification program was introduced, based on individual learning traits of the learners. The model itself consists of two modules including the test module and the e-Learning environment. The main idea behind adaptive testing is that the test should tailor itself to the estimated ability level of test takers. A similar model is used for the mobile learning domain (Vas et al., 2009) by the same research group. The difference from their prior approach to that is only the mobile learning environment. That particular system is also able to tackle the challenges of communication, collaboration and content delivery regardless of time and space. Although, the latter model is used to adapt testing according to the needs of test-takers, however, it does not consider the adaptive generation of questions for testing learners' domain knowledge.

O-DEST, an ontology-driven e-learning system for a Thai learning environment (Snae & Brueckner, 2007) is a learning system designed for delivering learning contents to students. It also provides a unified platform for logging, accessing, planning, managing records and monitoring from instructors' and administrators' perspectives. Although this system has a test module it does not provide any form of adaptive testing or adaptive generation of MCQs.

In OntoAware (Melia, Holohan, McMullen, & Pahl, 2005), a knowledge-based content creation, management and delivery system enables semi-automatic generation of course content if rich domain ontologies are given as input. This system generates two types of LOs: Interactive (Assessment) and non-interactive (Course Content) (Holohan et al., 2005). Learners need to select one concept and its related sub-concepts from a list of target learning concepts of a particular domain ontology. For generating non-interactive LOs, a lesson plan/outline was introduced with a corresponding slideshow sequence that consists of bullet-pointed slides showing relevant concepts and sub-

concepts directly taken from the domain ontology. The above generated learning content can be modified in order to generate interactive LOs in the form of MCQs (Holohan et al., 2005). This system uses an ontological model of a domain with limited relationships such as class-subclass and class-instance relationships for generating MCQs (Al-Yahya, 2011). However, it does not exploit all other relationships or constraints found in the ontology to generate MCQs and correct answers with distracters.

Another system, OntoQue (Al-Yahya, 2011), generates a set of assessment items for learners. The OntoQue engine supports the automatic generation of MCQs from a domain ontology. The semantic relationships between various entities in the ontology are used to assert sentences including answers and distracters. These sentences are used for generating MCQs by using three main strategies; class-based strategies, property-based strategies, and terminology-based strategies (Papasalouros et al., 2011). In a class-based strategy, correct answers and distracters are generated with the help of a *class* (concept) and its individuals. Property-based strategies are based on *properties* (roles) for creating question items and distracters. There are two types of properties in OWL (Antoniou & Van Harmelen, 2009) object properties are the relationships between individuals, and data type properties are related to data type values, for example, numerical or string with individuals. In contrast, terminology-based strategies follow only concept-sub-concepts relationships in order to generate MCQs including questions items and distracters.

Similarly, QuGAR-OWL (Automatic Generation of Question items from Rules and OWL ontologies) (Papasalouros, Kotis, & Nikitakos, 2010) is an e-learning environment that uses these strategies in order to generate MCQs from populated OWL ontologies in an automatic fashion. It focuses on the domain of environmental pollution for the purpose of the evaluation. This system not only handles the generation of text-based question items but also image-based question items in which MCQs are presented

with images (in this thesis, only text-based question items are followed for generating MCQs with correct answers and distracters).

The above mentioned systems highlight the importance of ontologies in education, particularly in course content generation. However, most of these systems are designed in e-learning environments for either one of course content or assessment as presented in Table 2.1. In contrast, the applicability of the use of ontologies in generating learning content for both purposes in mobile learning activities has been sparsely explored. Therefore, it provides an opportunity to explore these approaches in mobile learning activities.

In addition, these systems including TANGRAM (Jovanovic et al., 2009), APOSDLE (Ghidini et al., 2007), Vas (2007) and Vas et al. (2009) are mainly designed for the purpose of providing content-level adaptation (Brusilovsky, 2001) according to different student learning traits. The main problem of these systems is that they only deal with the learners' prior knowledge by providing different web page versions for students' needs. However, they do not consider the adaptive nature of learning content while undergoing the course or activity. Apart from these, Vas (2007) and Vas et al. (2009) follow adaptive testing in which question items are given according to the needs of test-takers, but these question items are not generated from the domain ontologies rather than being pre-defined in the systems.

The richness of ontologies makes it possible to reuse LOs and repurpose them dynamically by using the same domain ontology (Verbert et al., 2004). OntoAware (Melia et al., 2005) and O-DEST (Snae & Brueckner, 2007) are examples of systems that take into account the reusability of learning content from the same ontology. The generation of MCQs and correct answers with distracters in OntoAware (Melia et al., 2005) is limited to only class-sub-class and class-instance relationships (Al-Yahya, 2011). Similarly, OntoQueue (Al-Yahya, 2011) and QuGar-OWL (Papasalouros et al.,

2010) not only follow class-based but also property and terminology based strategies for generating MCQs. However, the generation of MCQs in these projects are not dynamically inferred with the help of any available reasoners such as FACT++ (Tsarkov & Horrocks, 2006), Pellet (Sirin et al., 2007) or Racer (Haarslev & Moller, 2003). On the other hand, O-DEST (Snae & Brueckner, 2007) assesses learners before and after taking the given lessons but these assessments do not consider any form of adaptive nature of testing.

Apart from the above shortcomings, only two systems, namely OntoQueue (Al-Yahya, 2011) and QuGar-OWL (Papasalouros et al., 2010), deal with science inquiry topics and target only school students, while other projects are designed for University students or professional trainers (see Table 2.1). In this thesis, an ontology-driven mobile web-based application 'ThinknLearn' is designed for high school students in order to utilize domain ontologies as knowledge representation. These ontologies provide well-defined domain conceptualization to support automatically generating MCQs for assessment and adaptive suggestions as course content while performing inquiry learning activities. These adaptive suggestions are constructed according to the answers chosen by the learners during learning activities.

2.3 Technology-Enhanced Learning (TEL)

Recent advancements in digital technologies have increasingly attracted the interest of educators, researchers and companies that develop learning systems in order to provide educational or professional content to learners. Various names have been used in the literature for systems that utilize digital technology to enhance human capabilities to work or learn, including computer-assisted learning, educational technology, information and communication technology in education and so forth. However, in this thesis, Technology-Enhanced Learning (TEL) is used for this purpose.

31

The term Technology-Enhanced Learning (TEL) has been used broadly in the educational world as the improvement of learning support with the help of information and communication technologies (Specht, 2009). From a socio-technical perspective, TEL aims to design, develop and test socio-technical innovations that can improve learning of both individuals and organizations, especially using digital technologies (Chan et al., 2006; Manouselis, Drachsler, Vuorikkari, Hummel, & Kopper, 2011). It is therefore considered as an application domain that generally covers different types of education settings, such as formal and informal settings (Vuorikari & Berendt, 2009).

In a formal setting, learners are involved in a learning process which is pre-defined by teachers or instructors within a specific curriculum for achieving a particular accreditation from educational institutions like university, school or college (Manouselis et al., 2011). On the other hand, an informal setting is described as a learning setting in which learners are participating in daily life activities related to work, family or leisure, and are responsible for their own learning pace and path, and it does not lead to a specific accreditation (Drachsler, Hummel, & Koper, 2008; Longworth, 2003). A formal learning activity has been used in this thesis for conducting experiments with the high school students, who are preparing for a specific accreditation.

As a matter of fact, it has been witnessed a paradigm shift in the digital technologies for supporting different forms of learning, such as 'E-learning' (Trifonova & Ronchetti, 2004), 'Mobile learning (M-learning)' (Vavoula & Karagiannidis, 2004), 'Ubiquitous learning' (Liu & Hwang, 2010), 'Pervasive learning' (Shen, Wang, & Shen, 2009) and 'Ambient learning' (Li et al., 2009). However, there is growing evidence that the use of M-learning in educational settings has been rapidly increasing over the last decade or so. The term M-learning covers the personalized, connected and interactive use of handheld devices or computers in classrooms (Kong, 2012; Zhang et al., 2010), in

collaborative learning (Pinkwart, Hoppe, Milrad, & Perez, 2003), in fieldwork (Facer et al., 2004; Rogers et al., 2005), in teacher training (Lin et al., 2012; Seppala & Alamaki, 2003), in workplace education (Stone, 2011) and numerous other disciplines. In many of these cases, M-learning provides uniquely situated and personalized learning experiences to learners or professionals.

There are some key characteristics that make M-learning differ from other learning technologies, which include: urgency of learning need, initiative of knowledge acquisition, mobility of learning setting, interactivity of the learning process, situating of instructional activity and integration of instructional content (Chen, Kao, & Sheu, 2003). In addition, these devices support educational ambitions by providing the possibility to explore natural environments in outdoor areas like parks, woodlands, museums, and indoor areas such as the home, school and workplace (Rogers et al., 2005). Despite having these unique capabilities and characteristics, M-learning is still in its relative infancy in its potential to enable new and engaging forms of learning activities.

2.3.1   The Emerging Paradigm: Mobile Learning (M-Learning)

Early approaches at defining M-learning focused predominately on technology, for example both Pinkwart et al., (2003) and Trifonova & Ronchetti (2004) defined M-learning as an extended version of E-learning in which learning can take place with the use of mobile or wireless devices such as mobile phones, smart phones, palmtops, and handheld computers. Laptops, PDAs (Personal Digital Assistant), tablet PCs, and personal media players can also fall into this category (Kukulska-Hulme & Traxler, 2005). In a similar vein, Traxler (2005) defined M-Learning as "any educational provision where the sole or dominant technologies are handheld or palmtop devices" (p. 262). However, these early definitions are now too techno-centric and imprecise. Moreover, the diversity of the devices, systems, and platforms make these definitions

vulnerable in a sense because they merely consider mobile learning somewhere on E-learning's spectrum of portability such as ubiquitous, pervasive and wearable learning (Traxler, 2009).

Other advocates of M-learning viewed it in terms of mobility of learners and mobility of the learning in which learning can take place on-the-fly and the learners can take advantage of mobile devices anywhere, anytime due to their portability (T.H.Brown, 2005; Khaddage, Lanham, & Zhou, 2009; Svetlana & Yonglk-Yoon, 2009). One definition that focuses on mobility is "any sort of learning that happens when the learner is not at a fixed or pre-determined location or learning that happens when the learner takes advantage of learning opportunities offered by the mobile technologies" (Vavoula & Karagiannidis, 2005, p. 537). In other words, this type of learning can be achieved through the use of portable devices without time and space constraints when learners can utilize their leisure time for different purposes (Al-Hmouz, Shen, & Yan, 2009). For example, when learners are waiting for public transport or in airport lounges, in free time between lectures, and travelling to and from school on the bus. Thus, they can make the use of this time more efficiently in terms of their learning (Martin, Carro, & Rodriguez, 2006).

In contrast, Kakihara & Sorensen (2002) argued that mobility should not be related entirely to the movement of learners across places but basically linked to different dimensions of human interactions such as temporal, spatial and contextual. According to them, the concept of mobile learning are changed due to "the patterns of social interactions [that] are dynamically reshaped and renegotiated through our everyday activities significantly freed from spatial, temporal and contextual constraints" (p. 1760). Similarly, Kukulska-Hulme, Sharples, Milrad, Arnedillo-Sanchez and Vavoula (2011) extended the notion of mobility, defined by Kakihara and Sorenson (2002) earlier. They defined five different aspects of mobility including mobility in physical

space, mobility in conceptual space, mobility of technology, mobility in social space and learning dispersed over time (KuKulska-Hulme et al., 2011).

Another classification of mobile learning was in terms of the context but only related to the categories of the learning activities, namely behaviourist, constructivist, situated, collaborative, informal/lifelong, and support/coordination (Naismith, Lonsdale, Vavoula, & Sharples, 2004). Mobile learning was also defined while considering motivational or affective aspects. Jones, Issroff, Scanlon, Clough, and Mcandrew (2006) described six mobile learning defining characteristics including freedom, ownership, communication, fun, learning-in-context, continuity between contexts.

There are some proponents who conceptualise M-learning in terms of learners' experience of learning with mobile devices (Kukulska-Hulme & Traxler, 2005; Parsons et al., 2007; Traxler, 2007). According to them, this type of learning cannot be just limited to the mobility aspects of mobile devices but it can provide learning opportunities by accessing learning resources and collaborating with people even at a fixed location. In such learning experiences, learners can have access to digital information and means of communication with other learners, instructors and with the world, on their mobile devices without the need of any movement across different locations (Kukulska-Hulme, 2010). This simple fact introduces profound changes in conceptualizing M-learning in terms of learners' experiences of learning using mobile technologies that cannot be ignored (Kukulska-Hulme, 2010). Apparently, educational activities become a ubiquitous part of our lives with the use of these handheld devices. Therefore, the focus of current mobile learning applications has turned towards the user's learning experience (Parsons et al., 2007).

For designing such learning experiences, it is important for system designers to evaluate their products not only from usability aspects but also consider user

experience aspects such as satisfaction, motivation and enjoyment (Preece, Rogers, & Sharp, 2002). Therefore, while considering M-learning experience, application designers may design learning environments in ways that leverage the positive qualities of handheld devices and engage learners by providing rich learning experiences (Ryu & Parsons, 2009). Moreover, these learning experiences reflect diversity in learning across various contexts; spatial, temporal and conceptual boundaries, when supported with blend of technologies and educational approaches (Kukulska-Hulme, Sharples, Milrad, Arnedillo-Sanchez, & Vavoula, 2009).

There is no fixed definition of M-learning, because of the rapid evolution of technologies in this field and some ambiguity found in describing the term 'mobile' as described earlier in this section; does it relate to mobile technologies, or learning experiences with mobile technologies, or the more general notion of the mobility of learners and the mobility of the learning? In fact, all these aspects are important according to the context in which learning activities take place. However, in this thesis, a specific incarnation of M-learning is investigated; learning experiences with mobile technologies at a fixed location, specifically, in the science laboratory.

The use of mobile learning at a fixed location (static technology) still distinguishes it from the conventional forms of E-learning because in E-learning environments, learners are involved in a learning process where they can engage with their static desktop computers. In contrast, with the use of mobile technologies in the classroom or a fixed location, learners can get different learning experiences as compared to traditional forms of E-learning environments because of the following characteristics: *ownership* (Jones et al., 2006; Traxler, 2009; Twining & Evans, 2005), in which learners can get a very strong sense of control and ownership while using mobile devices in the classroom. *Wireless connectivity* (Curtis et al., 2002; Roschelle, 2003), in which learners can get an opportunity to carry their mobile devices easily within the classroom and that connectivity also support accessible to their learning tasks, data, or videos.

Immediacy (Ogata & Yano, 2004; Lai et al., 2007), in which learners can get any information immediately, wherever they are. For instance, if learners are performing science experiments in a laboratory then they can perform tasks quickly. Otherwise, they have to record questions or observations from the experiments and look for the answers or assistance from the desktop computers later. *Enjoyable* (Jones et al., 2006; Looi, Wong, So, & Seow, 2009), in which learners, especially young learners, are used to mobile devices for entertainment, so these devices can be used for providing interactive and interesting content design which influences enjoyment and motivation positively. Hence, these aspects are followed while discussing M-Learning in the classroom in this thesis.

2.3.2   M-Learning Context

In any information system, the knowledge of the user may depend on two different aspects: the application domain which represents the reality under examination, and the working environment, in other words the context (Bolchini et al., 2009). "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application including the user and applications themselves" (Dey, 2001, p. 5). From an educational viewpoint, the learning context is defined as "the situation under which a learning activity happens and this situation includes the learner and his/her surrounding environment" (Li et al., 2009, p. 912).

M-learning context has been used as a pre and/or post activity in conjunction with other types of learning (Colazzo, Molinari, Ronchetti, & Trifonova, 2003; Rogers et al., 2004), complementing previous classroom learning experiences (Ryu & Parsons, 2009). It is further explained by Wang' six dimensions which includes *identity, learner*, *activity*, *collaboration*, *spatio-temporal*, and *facility* (Wang, 2004). The first four of

these dimensions are used to define situational contexts of M-learning while the last two are associated with the environmental context (Parsons et al., 2007).

The following explanation is given by Ryu and Parsons (2009) about M-learning contexts. The authors described that *Identity* is one of the important situational contextual factors in which a mobile learning system can provide the right learning content at the right time depending on the identification of the user (learner or teacher). Another contextual factor, *learner,* needs to be considered while designing mobile learning applications because each learner has some different characteristics that relate to their learning experiences. For example, highly self-motivated learners would probably enhance their learning experiences by utilizing all the features provided by the system. Some studies such as (Shen et al., 2009; Tsianos et al., 2009) show that M-learning can have different learning effects based on learners' cognitive abilities and their dependence on the context where learning takes place.

The other two situational M-learning contexts are *learning activities* and *collaboration*. The former is the most promising feature of M-learning context as it covers not only individual learning but also collaborative learning experiences that can hold much promise for mobile learning activities. The latter can take place in number of different ways; within a class or via a remote connection with a shared learning environment. Nevertheless, the environmental contexts including *spatio-temporal* and *facility* are effective contextual factors in mobile applications. *Spatio-temporal* is used to define an awareness of time and/or space where mobile learning takes place while *facility* can impact on the design of M-learning interfaces by providing rich learning experiences to learners (Parsons et al., 2007). In this study, *activity* (science learning activity) within a science laboratory is taken as the M-learning context for experimentation.

2.3.3   Mobile Learning Activities in the Classroom

There has been significant interest and tremendous growth in the use of mobile technologies in education. This rapid development towards mobile technology deployment at school level, offer students new opportunities for increasing engagement, motivation and learning (Lin et al., 2012). In fact, mobile devices are revolutionizing school education and transforming the conventional classroom into interactive classroom systems that have the potential to enhance students' learning experiences (Scornavacca et al., 2009). For designing mobile learning activities for formal education, five educational affordances of mobile technologies are identified for classroom practitioners, including (i) access to multimedia (ii) connect with peers and others (iii) create representations to demonstrate thinking and knowledge (iv) capture video or photograph, and (v) support data processing and analysis (Churchill & Churchill, 2008). These educational affordances can satisfy the needs of diverse students by providing personalized learning experiences within classroom settings (Kong, 2012).

In comparison with desktop machines, it is suggested that these handheld devices are cheaper and more easily used in the classroom than desktop computers (Soloway et al., 2001). They may also increase the sense of privacy as compared to desktop machines (Vahey, Tatar, & Roschelle, 2007). Further, when students use these devices, they are able to personalize their learning experiences in many more ways than would be allowed by paper and pencil or desktop computers (Looi et al., 2009). Mobile technologies are also equipped with built-in cameras and sound recording functions that facilitate immediate recording functionality for note taking (Lai et al., 2007). They have other features including computing power and wireless capability, which can make learning expedient, immediate, authentic, accessible, efficient and convenient (Curtis et al., 2002; Ogata & Yano, 2004). Consequently, the use of mobile technologies

may increasingly become a convincing choice of technology for classroom learning experiences for various purposes such as communication and assessment using short message service (SMS) text messaging (Scornavacca et al., 2009), English vocabulary learning (Chen & Hsu, 2008; Looi et al., 2009), music learning (Zhou, Percival, Wang, Wang, & Zhao, 2011) and science inquiry learning (Yarnall, Shechtman, & Pennel, 2006; Zhang et al., 2010). Some of these are discussed in this section.

There have been several mobile projects in the literature regarding the use of SMS text messaging in the classrooms. For example, in TXT-2-LRN (text-to-learn) (Scornavacca et al., 2009), students were equipped with SMS-enabled mobile phones in the classroom by which they could send messages to their teachers during lectures. In this project, two classroom dynamics were designed: *Open Channel*, in which students are allowed to send questions or comments to the teacher without interrupting the class and *M-Quiz*, when the teacher presents a slide containing a question with four possible options, then students can use their mobile phones to send an appropriate answer in response. In a similar vein, MOLT (MObile Learning Tool) (Cavus & Ibrahim, 2009) was designed and evaluated with 1st year undergraduate students in order to provide an opportunity to learn some new English words using text-based SMS messages on their mobile phones from the teacher. In another SMS-text based messaging project PLS TXT UR Thoughts (Markett, Arnedillo-Sanchez, Weber, & Tangney, 2006), students were invited to send SMS text messages to their teachers via mobile devices while they were delivering lectures to them. The teachers can view the messages and verbally answer their queries afterwards. However, these SMS-based learning activities were designed for only student-teacher communication purposes rather than emphasizing the broader use of mobile devices in learning.

Some other projects were designed for broader mobile learning activities in the classroom. MOGCLASS (Musical mObile Group for Classroom Learning And Study in Schools) (Zhou et al., 2011) was a project in which a collaborative multimodal music

environment was designed and evaluated. This project was based on networked mobile devices. The application of that project supports students' music experiences by enabling creative and engaging music lessons that make the classroom engaging and effective (Zhou et al., 2011). In another research project, Looi et al. (2009) developed a mobile learning application which was based on a English curriculum unit on learning prepositions used in elementary grade (primary) 2 classrooms. The application of this project was developed with an objective to build a participatory learning classroom in which a teacher and students can participate using their mobile devices. However, none of these projects highlighted the entire significance of mobile learning experiences because they were only evaluated in terms of technological usability.

There is a growing interest from science educators and researchers in developing curricula that specifically consider the affordances of mobile technologies in classroom learning activities. In MILE (Mobile Inquiry Learning Experience) (Zhang et al., 2010), a mobile learning environment was designed for primary school science learning activities in which students are required to use their mobile devices to understand the given topic related to characteristics and classification of living things, particularly *fungi* by watching videos, looking at pictures and reading other relevant information files found in this application. Another project, WHIRL (Yarnall et al., 2006), was designed for consistent feedback on primary school students' progress in building conceptual knowledge and inquiry skills. For these purposes, different tools are provided to students for learning tasks such as conceptual modelling, understanding of biological and physical processes, promoting student questioning and improving accuracy and precision in data collection.

Similarly, in Looi et al. (2011), a learning environment GoKnow MLE (mobile learning environment) was used for primary school students to ensure a delivery of science curriculum that facilitates and scaffolds student-centred learning activities within

classroom. Using GoKnow MLE, learners are involved in different kinds of tasks such as accessing learning material, a lesson overview, objectives of the lesson and what is expected from them in learning about a topic, the 'body system' in particular. Apart from this, learners also participated in inquiry learning activities by playing a cooperative game to identify the parts and functions of five body systems. In this collaborative activity, they helped each other to identify the parts correctly, and the teacher played an important role as critic to ensure whether the students have identified the correct body parts and systems.

This thesis shares similar goal to the last three projects mentioned above, to explore mobile learning experiences within authentic science classroom inquiry. However, there are some major differences noted: the target audience for the above projects were primary school students while this thesis focuses on high school students. Further, these projects were designed to facilitate the delivery of pre-defined learning content to students. In contrast, this thesis provides adaptive suggestions as assistance to scaffold student inquiry learning activities. As a matter of fact, in the previous literature, there is a lack of exploration of mobile applications in terms of providing guidance in facilitating science learning (Hmelo-Silver & Barrows, 2006). In addition, whether the given assistance can provide significant gains in students' learning performance needs to be further evaluated (Hmelo-Silver et al., 2007). Hence, this thesis explores students' mobile learning experiences in a science classroom learning activity and also evaluates their learning performances after providing assistance during the learning activity.

2.3.4 Designing Mobile Learning Activities

The design of mobile learning activities is based on a number of tasks, including the design of technologies, media and interactions for supporting seamless flow of learning across contexts, and using mobile technologies in education for developing

innovative practices (Sharples, Arnedillo-Sanchez, Milrad, & Vavoula, 2009). However, activities always take place in a certain situation with a particular context (Engestrom, 1987). Thus, context can play a crucial role both in learning and in the design of mobile technologies by improving the richness of communication in human-computer interaction and make it possible to create more useful technological devices (Uden, 2007).

There are many techniques and tools that have been developed to support taking the context into account in the design of computer technologies. These include, task analysis (Dix, Finlay, Abowd, & Beale, 1998), participatory design (Bodker, Knudsen, Kyung, Ehn, & Madsen, 1988), instructional design theory (Reigeluth, 1999) and contextual design (Holtzblatt & Beyer, 1993) to name but a few. However, Kaptelinin, Nardi and Macaulay (1999) criticised these techniques because they only follow a bottom-up approach instead complementing this by a top-down approach. They further recommended activity theory as an ideal framework for describing the structure, development and activity in context. From a mobile learning perspective, Uden (2007) suggested activity theory as a powerful tool to model and understand the design of a mobile learning environment that is usable and contextual.

2.3.4.1 Activity theory

Activity theory (AT) originated in the former Soviet Union as a cultural, historical psychology by Vygotsky (1978) and Leont'ev (1981). It is a theoretical framework for analysing human activities as processes while interconnecting both individual and social levels at the same time (Kuutti, 1996). AT has been used as an analytical tool for many different fields such as human-computer interaction (Kuutti, 1996), information systems (Bodker, 1991), computer-supported collaborative learning (Bodker, 1997; Mwanza-Simwami, 2001), communities of practice (Engestrom, 1993) and mobile

learning (Mwanza-Simwami, 2009; Uden, 2007; Zurita & Nussbaum, 2007), among others.

There are some fundamental principles of AT that constitute a general conceptual system (Kaptelinin & Nardi, 1997), which includes: the hierarchical structure of activity, object-orientedness, internalization/externalization, tool mediation, and development. According to the first principle, AT describes human activity in a hierarchical structure consisting of three levels (Zheng, Li, & Zheng, 2010): operations, actions and activity. That means, each activity has goal-oriented direction and conscious actions while each action is implemented through automatic operations. On the other hand, the principle of 'object-orientedness' defines the term 'object' as socially and culturally determined properties rather confining it to only physical properties. According to the third principle, AT distinguishes internal and external as two different activities: 'internalization' is the transformation of external activities into internal ones while 'externalization' deals with the conversion of internal activities into external ones. The fourth principle defines AT as a mediating activity with the involvement of some tools. A Tool can be physical such as computers or wirelessly connected mobile devices or intellectual like rules or roles displayed on mobile devices. Physical tools are designed to handle objects while intellectual tools are used to manipulate actions in one way or another (Zurita & Nussbaum, 2007). Finally, the last principle, 'development', emphasizes not only an object of study but also a general research methodology for evaluating formative assessments of the study participants. An organized application of any of these principles leads eventually to engaging all the other ones (Kaptelinin & Nardi, 1997).

Engestrom outlined three generations of AT (Engestrom, 1999). In the first, AT follows Vygotsky's concept of mediation (Vygotsky, 1978) that focuses on the notion of artifact-mediated and object-oriented actions. The triangle of the first generation is based on subjects, objects and mediating means (tools) in which subjects can be

individuals engaged in an activity. While an activity can be performed by subjects using tools to achieve objects (objectives) (Kuutti, 1996). However, in the second generation, AT extends the triangular individual activity to a broader human activity system by including three other important elements, including rules, community, and division of labour. Community can be defined as the inclusion of one or more people sharing the same object with the subject. Rules are denoted as the regulation of the actions and interactions within an activity while division of labour tells how activities are divided between community members (Uden, 2007).

The third generation of AT aims at developing conceptual tools to comprehend dialogue, multiple perspectives and a group of interacting activity systems (Zheng et al., 2010). The former two generations of AT are usually discussed within a single activity system while this generation deals with the interactions between two activity systems. By following this generation, Sharples and colleagues redefined Engestrom's model (1987) in the form of a framework to analyse the activity system of mobile learning (Sharples et al., 2005). This framework consists of two layers, namely semiotic and technological. The semiotic layer represents learning as a semiotic system in which learners' actions are supported by cultural tools and signs. In contrast, the technological layer of this framework describes learning as an engagement with technology such as computers or mobile devices (Sharples et al., 2005). Moreover, the terms 'rules', 'community' and 'division of labour' are replaced with 'control', 'context' and 'communication' respectively. Since this thesis proposes a new mobile learning application (tool), in designing and evaluating learning as an engagement with technology, only the technological layer of the framework (Sharples et al., 2005) is considered in this research.

2.3.4.2 Use of activity theory in mobile learning

Learning is basically situated and socially mediated by culturally defined tools (Engestrom, 1987; Lave & Wegner, 1991). The applications of AT provide a conceptual framework for any learning environments that can support conceptualizations to the following: simplify the nature of learning activities, inform how learners can socially participate in a technology-supported learning environments, and design tools to support learners in various contexts (Gifford & Enyedy, 1999). Further, three main advantages are defined for learning environments: (i) providing the application specifications, (ii) supporting extendable and adaptable design and (iii) analysing social and cultural practices to provide a common vocabulary to describe what students learn in context (Mwanza-Simwami, 2001).

There are some benefits of using AT in a learning environment, particularly in mobile learning, such as; learners are not isolated users at a desktop or in an office. They use mobile services within society and that society can have an impact on the learners' activities (Kaenampornpan & O'Neill, 2004). Similarly, mobile learning applications are not designed in isolation but in the context of use, as embedded in the meaningful activity. Thus, with the help of AT, mobile learning designers are able to identify important features of human activities in a hierarchical structure (Uden, 2007).

Another advantage of applying AT to mobile learning is concerned with the interface of the application (Uden, 2007). The interface of the mobile learning device is changing with the advancement of technologies and according to the needs of current users and their use contexts (Tarasewich, 2003). However, from an AT perspective, the interface and the computer artefact, such as the mobile device, are mediators of learning activities (Bodker & Petersen, 2000). Hence, AT seems to provide appropriate abstractions and concepts to design activities for mobile learning.

AT also provides a powerful medium for supporting effective mobile learning because it not only analyses learning processes and outcomes for the design of mobile learning but also attempts to improve the learner interaction by exploiting information relating to learners, devices and environments through the notion of context-awareness (Uden, 2007).

In the literature, AT was expressed as a descriptive tool for describing human activities rather than explaining any method for putting AT ideas into practice (Kuutti, 1996; Kaptelinin & Nardi, 1997). Nevertheless, Mwanza-Simwami (2001) proposed a method, namely Activity-Oriented Design methods (AODM), which is used to operationalise the theoretical concepts of any underlying activity system, together with the provision of clear evidence of the mapping between theory and the design product. From a mobile learning perspective, AODM presents four methodological tools to support different system design phases such as processes for gathering and analysing design requirements, generating research questions and mapping operational processes (Mwanza-Simwami, 2009). This thesis follows these methodological tools for investigating the early phases of the design of the proposed application that deals with science inquiry learning activities. A further description of these tools is provided later in section 3.2.

2.4 Inquiry-Based Learning (IBL)

Inquiry learning or Inquiry-based learning (IBL) has been described in the literature from a variety of perspectives by researchers, educators and practitioners over the years (De Jong, 2006; Hmelo-Silver et al., 2007; Van Joolingen & Zacharia, 2009; Lim, 2004). Some define it as the hands-on-experience of investigating a problem. Others relate it with the discovery approach or development of inquiry skills. There are some

others who emphasize IBL as a medium to promote high-order thinking skills and self-directed learning (Looi, 1998).

Van Joolingen & Zacharia (2009, p. 21) described IBL from two broad views due to its twofold nature: 'inquiry by means' and 'inquiry by ends'. According to the first view, IBL is considered as an instructional approach or pedagogy (Hwang & Chang, 2011; Lim, 2004). The other view defines IBL as an educational activity that 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 (De Jong, 2006; Hmelo-Silver et al., 2007; Kuhn, Black, Keselman, & Kaplan, 2000).This thesis follows this view because in this study, students were involved in a scientific inquiry with hands-on-experience of real-time data collection and analysis processes that help them to generate hypotheses and their explanations.

Apart from these examples, IBL can be seen in close relation to problem-based learning (PBL) (Evenson & Hmelo-Silver, 2000; Kolodner et al., 2003), or discovery learning (Gijlers & De Jong, 2005). For instance, discovery learning is described as narrower term by Edelson et al. (1999): "In our conception of learning from inquiry, students can discover scientific principles through their own inquiry activities, but discovery is not the only mechanism for learning from inquiry" (p. 394). However, in practice, PBL and IBL are often considered as synonyms by many authors (Bell, Urhahne, Schanze, & Ploetzner, 2010; Hmelo-Silver et al., 2007; Kirschner, Sweller, & Clark, 2006). The primary differences found between these terms are related to their origins. The term PBL has used in medical education for solving problems via hypothetical-deductive process (Barrows & Tamblyn, 1980) while IBL has its origins in the practice of scientific inquiry where learners are involved in these activities: posing questions, collecting and analysing data, developing hypotheses and evidence-based explanations (Kuhn et al., 2000).

2.4.1 Scientific Inquiry

The National Science Education Standards noted that scientific inquiry is essentially a question-driven, open-ended process in which learners need to study the natural world and propose explanations based on the evidence (National Research Council, 1996). Quintana et al. (2004) provided a more elaborated definition in which they define scientific inquiry "as the process of posing questions and investigating them with empirical data, either through direct manipulation of variables via experiments or by constructing comparisons using existing data sets" (p. 341). Bell et al. (2010) explained with an example that 'data' mentioned in this definition does not necessarily refer only to quantitative data but also to qualitative data. For instance, in a Co-Lab inquiry project (Van Joolingen, De Jong, Lazonder, Savelsbergh, & Manlove, 2005), learners use quantitative parameters of a leaking water tank to understand and model its outflow behaviour, while qualitative parameters including observation, classification and interpretation of animal behaviour is supported in another project Animal Landlord (Smith & Reiser, 1998).

In a scientific inquiry learning activity, learners are encouraged to develop understanding and knowledge about the scientific phenomena that they observe in the physical world and also find out how to perform this type of inquiry like scientists (Van Joolingen & Zacharia, 2009). In addition, it fosters learners' motivation towards science and supports affective learning (Chuang et al., 2009). Therefore, this trait of inquiry activity becomes one of the most challenging and exciting ventures of today's' schools (Bell et al., 2010). The literature related to school science inquiry shows that learners can be engaged in IBL environments to generate better scientific explanations about working domains, understand learning content more easily and effectively, collaborate with peers, and evaluate their own work better than in non-inquiry-based

learning settings (Kolodner et al., 2003; Metz,2004). In this way, learners can become active rather than passive recipients of domain knowledge.

Despite the promise that IBL appears to propose for science education, inquiry-based instruction is another important medium for learners to learn scientific concepts while performing inquiry investigations that could not be ignored (Eslinger, White, Frederiksen, & Brobst, 2008). It is therefore defined as "the creation of a classroom where students are engaged in essentially open-ended, student-centred, hands-on-activities" (Colburn, 2000, p. 42). The four-level continuum (Banchi & Bell, 2008) contains *confirmation*, *structured*, *guided* and *open* inquiry levels in an inquiry-based learning activity to support learners in determining relationships between variables, or generalizing from data collection. Banchi and Bell (2008) further explained these levels: In a *confirmation inquiry*, learners are provided with questions and procedures to understand a previously introduced concept by carrying out investigations. Similarly, in a *structured inquiry*, questions and procedures are defined to learners but they have to generate their own explanations about the collected data. In contrast, a *guided inquiry* contains only questions and learners need to design their own procedures along with data collection and investigations. In an *open inquiry*, learners act like a scientist, deriving questions, making procedures, collecting data, explaining the natural phenomena and communicating results. This level requires the most scientific reasoning and cognitive load from the learners.

A confirmation inquiry experience and an *open inquiry* have totally opposite perspectives. In the former, learners are asked to find out the known scientific principles, while in the latter, they have no directions from teachers nor are they supported by any tools during investigations. *Open inquiry* may have many advantages in helping learners to derive some meaningful learning from inquiry but on the other hand, the free exploration of complex investigations may create a heavy load on learners' working memory that is an unfavourable condition for learning (Kirschner et

al., 2006; Sweller, 2004; Winn, 2003). However, the other two inquiry levels, namely *structured* and *guided,* are supported either by the teachers or the tools used for investigations. The main difference between these two inquiries is only about the description of the procedure used while performing investigations. A procedure is mentioned with a problem by teachers in a structured inquiry whereas in a guided inquiry, learners need to find out their own procedures to answer the problem under investigation (Windschitl, 2002). However, *guided inquiry* in the classroom is far more intellectually challenging for learners as compared to the other two inquires: *structured* and *confirmation*. Therefore, for providing guided IBL environments to learners, it is necessary to offer extensive scaffolding that can engage learners in conceptualizing scientific concepts, managing inquiry investigations, and articulating their critical thinking in order to facilitate learning (Hmelo-Silver et al., 2007; Quintana et al., 2004).

2.4.2 Scaffolding in Scientific Inquiry

In the area of educational research, scaffolding is considered as an instructional technique in which learners become increasingly proficient problem-solvers by using guidance from mentors who scaffold through coaching, task structuring, and suggestions, without giving learners the final answers straight away (Quintana et al., 2004). In TEL environments, technology scaffolds behave as a mentor in order to support learners' critical thinking skills for specific tasks, and thereby facilitate classroom learning (Sharma & Hannafin, 2007).

In a scientific inquiry, technology scaffolds not only guide learners how to do a specific task but also help them to understand why this task should be done in that way (Hmelo-Silver, 2006). Such inquiry tools can support the cognitive regulation of learners (Chuang et al., 2009). Cognitive regulation refers to an iterative process in which learners are engaged in problem-solving activities to direct and adjust their

learning after utilizing the given feedback mechanisms (Pintrich, 2000). Most cognitive regulation models are based on the three phases of planning, monitoring and evaluating (Manlove, Lazonder, & De Jong, 2006). The planning phase is an important phase in which learners are engaged in problem orientation, goal setting and strategic planning for completing their tasks. In the monitoring phase, learners assess their current learning states about the goals which were established in the planning phase. While in the evaluation activities, learners reflect on the quality of their planning and what they achieved in the end (Manlove, Lazonder, & De Jong, 2007).

These phases resemble inquiry learning processes (De Jong, 2006; Van Joolingen & Zacharia, 2009) in which learners are typically involved in such IBL activities as: *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. However, the pedagogical advantages of such inquiry learning processes are often challenged by learners' understandings about the underlying domain in technology-assisted learning environments (Mulder et al., 2011). This is due to the lack of support where such tools fail to provide appropriate scaffolding to help learners to perform inquiry investigations or give guidance to assist them comprehend the specified domain knowledge.

2.4.3   Scaffolding Design Framework

There is extensive research ongoing in IBL environments exploring the design of software tools to scaffold learners (Chen, Tan, Looi, Zhang, & Seow, 2008; Chuang et al., 2009; Li & Lim, 2008), and researchers and educators have developed theory-driven and empirically based design guidelines for providing effective scaffolding

strategies to support learning (Hmelo-Silver & Guzdial, 1996; Linn, 2000; Quintana et al., 2004; Reiser, 2004; Scardamalia & Bereiter, 1991).

There are some scaffolding frameworks found in the literature such as Linn's scaffolded framework 'Knowledge Integration Environment' (KIE), which stresses the integration of scientific understanding with prior common sense knowledge (Linn, 2000) while Scardamalia and Bereiter's (1991) intentional learning framework promotes learners' understandings through structured discourse. However, Reiser's (2004) framework focuses further by mentioning two mechanisms of scaffolding in software tools: (i) assistance in structuring the task of problem solving and (ii) increasing the utility of the problem-solving experience for learning. On the other hand, Hmelo-Silver and Guzdial (1996) uses black-box and glass-box scaffolding to suggest how scaffolding can be useful in supporting learning and performance in science learning activities.

All of the above-defined frameworks are based on different theoretical perspectives and propose a particular set of design principles which can be suitable for only specific contexts. However, Quintana et al. (2004) offer a common theoretical framework to define and evaluate scaffolding design approaches for software tools. In addition, this framework is based on prior research efforts such as the scaffolded knowledge integration framework (Linn, 2000), principles of learner-centred design (Quintana, Soloway, & Krajcik, 2003) and problem-based learning (Kolodner et al., 2003).

Quintana et al. (2004)'s framework also considers all the following scientific reasoning processes: S*ense making* is one of the inquiry components in which learners engage in testing hypotheses and interpreting the data. In *Process management*, learners are involved in strategizing decisions for controlling the inquiry process, while *articulation and reflection* is the process of constructing, evaluating and reflecting on what has been learned. The other frameworks discussed previously did not follow these

scientific reasoning processes comprehensively. For instance, Hmelo-Silver and Guzdial (1996), and Scardamalia and Bereiter (1991) mainly focused on *articulation and reflection* while neglecting *sense making* and *process management*. In contrast, Reiser (2004) and Linn (2000) described these scientific reasoning processes to some extent but they did not consider principles of learner-centred design in their defined frameworks (Quintana et al., 2003). These reasoning processes are important components in this research because learners were required to be involved in all these processes while conducting science inquiry investigations. Thus, this thesis follows Quintana et al. (2004) as a scaffolding design framework for providing IBL environments for students.

2.4.3.1 Quintana et al. (2004)'s scaffolding guidelines for scientific inquiry

Quintana et al. (2004) defined a design framework that can help application designers to scaffold IBL activities in a science inquiry domain. The given guidelines for designing inquiry-based scaffolding tools are as follows:

♦ Guideline 1: Use representations and language that bridge learner's understandings.

♦ Guideline 2: Organize tools and artefacts around the semantics of the discipline.

♦ Guideline 3: Provide user representations that learners can inspect in different ways to reveal important properties of underlying data.

♦ Guideline 4: Provide structure for complex tasks and functionality.

♦ Guideline 5: Embed expert guidance about scientific practices.

♦ Guideline 6: Automatically handle nonsalient, routine tasks.

♦ Guideline 7: Facilitate ongoing articulation and reflection during the investigation.

The first three guidelines are related to *sense making*, an inquiry component in which learners are engaged with testing hypotheses and interpreting data. These guidelines are used not only to provide representations to help learners comprehend the underlying domain-specific knowledge but also bring learners' critical thinking skills into action, which makes them to articulate their ideas about the given phenomena.

The next three guidelines of this scaffolding design framework are based on the *process management* inquiry component. These guidelines suggest that tools should structure learners' activities in such a way that learners can get proper guidance in accordance with their scientific inquiry investigations. The provided guidance from the tools can reduce learners' cognitive load when they are dealing with complex tasks. The final scaffolding guideline defines *reflection and articulation* to facilitate learning during inquiry investigations. It involves support that encourages learners to articulate and reflect on their ideas in ways that are scientifically productive.

This scaffolding framework intends to provide three fundamental benefits (Quintana et al., 2004). The first use of this framework is to develop an integrated theory of pedagogical support for complex learning environments, particularly, science inquiry-based. Secondly, a mechanism is described in this framework that provides the building blocks for an empirical knowledge base about successful design approaches for scaffolding. It is also a useful guiding tool for designing educational tools, though this framework does not tell a designer which specific guideline to select for which problem domain. These design decisions should be based on the kinds of tasks and obstacles tackled by the application designers (Quintana et al., 2004). For example, Animal Landlord (Smith & Reiser, 1998), Model-It (Metcalf, Karjcik, & Soloway, 2000), Symphony (Quintana, Eng, Carra, Wu, & Soloway, 1999), and Web-Based Inquiry

Science Environment (WISE) (Slotta, 2004) are some examples that follow guidelines according to their design requirements. The design of the application 'ThinknLearn' discussed in this thesis is also based on these guidelines.

2.5   Reasoning in Scientific Inquiry

The research conducted in cognitive and developmental psychology under the label 'scientific reasoning' is best conceptualised as an activity in which learners not only use their conceptual knowledge of particular scientific phenomena but also address the critical thinking skills and strategies that transcend the applied domain-specific knowledge (Zimmerman, 2000). Technology-assisted learning environments can be a powerful tool to enhance learners' reasoning skills and provide meaningful learning in IBL activities (Hmelo-Silver & Barrows, 2006). In the literature related to scientific reasoning, C.S.Peirce (1839-1914) was a pioneer who defined logic as the theory of correct reasoning, of what reasoning ought to be. He further explained that the logic of scientific inquiry is divisible into three modes of inference: (1) deduction or explicative inference; (2) induction or evaluative inference; and (3) abduction or innovative inference (Raholm, 2010). These modes are explained further in this section.

2.5.1   Deduction

Deductive arguments have traditionally been considered as the method of choice for reasoning, especially for reasoning in natural sciences (Laudan, 1981). In deduction, reasoning is presented in two contexts; a transition from a general form of reasoning to a specific one, and this specific conceptual form is embodied in the way the scientists deduce predictions from their hypotheses (Blachowicz, 2009). It is also referred to as 'if-then-reasoning' because "hypotheses are normally expressed in the form of testable if–then statements: If some set of conditions is present and observed, then a certain kind of behaviour will occur" (Narine, 2010, p. 28). For example, there is

a hypothesis which states that 'stick A is the longest of three sticks'. To prove this, we measure that stick A is longer than stick B and stick B is longer than stick C. Using that knowledge, we can deduce that stick A is longer than stick C and then reach a conclusion that stick A is the longest. This trait of reasoning begins with the hypotheses and then deduces results from these hypotheses. This complete if-then pattern is recognised as hypothetico-deductive reasoning (Lawson, 2005).

In school science, hypothetico-deductive reasoning has dominated over the years. In this form of reasoning, learners are required to construct theories about a particular science domain and then validate these theories by observational and experimental data (Grandy & Duschl, 2007). This is regarded as a method of proof that preserves truth (Patokorpi, 2009). It means that if deduction starts from true premises, the logical form guarantees that the conclusion will be true. However, this can not be true every time for all types of scientific inquiries (Patokorpi, 2009). Therefore, this method has been strongly criticized by both philosophers and psychologists (Haig, 2005; Patokorpi, 2009; Rozeboom, 1999; Walton, 2004). According to them, scientific explanations do not always proceed in a deductive manner because it is not confirmed that the generalization of one thing can be applicable to a specific problem. For instance, if many green parrots in the garden eat apples and it can be hypothesized that green parrots eat apples. Then, it still cannot be specified for the other green parrot that was not observed yet. Although, there remains a logical possibility that this new observing parrot would eat an apple but this assumption cannot be made for sure.

2.5.2   Induction

Induction is another scientific method in which ideas are required to be processed by learners (Grandy & Duschl, 2007). However, the main difference between deduction and induction is that the former method speaks to the discovery from general statements of specific ones, whereas the latter method is used to reason from

observed particulars to general propositions (Fischer & Gregor, 2011; Lawson, 2005). An inductive research approach starts with gathering data by empirical observations, free from prior ideas or hypotheses as to how the observations should be explained. Scientific explanations in inductive form of inquiry follow a facts-before-theory sequence; find the way to understand the observed phenomena that can give explanations for theory construction (Haig, 2005). Induction is a method of proof, which preserves less truth as compare to deduction because it does not start from true premises and the logical form cannot guarantee that the conclusion will be true (Patokorpi, 2009).

In science education, induction is also a common method of reasoning in which learners are presented with a specific challenge, such as experimental data to interpret, a case study to analyse, or a complex real-world problem to solve (Prince & Felder, 2007). Despite its importance in school science IBL, induction has received considerable criticism from those who seek to promote a hypothetico-deductive conception of scientific inquiry (Haig, 2005). It is argued that induction is not an appropriate reasoning method in scientific inquiry for obtaining evidence because this type of reasoning generalizes a theory or an idea from small set of observations, which never completely prove that the consequences drawn from the obtaining evidence are absolutely valid (Blachowicz, 2009). For example, if it can be hypothesized that green parrots eat apples and observed that all the parrots in the garden eat apples. Then it does not true that all observed parrots in the garden should be green.

2.5.3   Abduction

Abduction is a form of reasoning that is used in generating one hypothesis from a range of hypotheses based on observations (Coltheart, Menzies, & Sutton, 2010). Hence, it is considered as a backward reasoning from explanations to a cause, so searching for an idea is central (Oh, 2010). There are three distinct perspectives related

to the concept of abduction (Patokorpi, 2009); scientific research or inquiry is one of these in which it is used to establish some new theory or idea (hypothesis). Unlike deduction, it does not preserve any truth about testing hypotheses. Therefore, abduction describes what might be plausible. The second perspective to abduction is a model of machine reasoning (logic programming), which has been applied to computer systems that must work with incomplete knowledge. In programming logic, abduction is conceptualised as a logic that can make computer machines think and act more like humans do (Satoh, Inoue, Iwanuma, & Sakama, 2000). This type of logic is more concerned with comparing hypotheses for formal-logical accuracy rather than the actual mental process of reasoning. Last but not least, abduction is considered as a form of everyday reasoning or practical reasoning because in rapidly changing real-life scenarios, our knowledge relies mostly on guessing or hypotheses with incomplete evidence (Patokorpi, 2009) such as medical diagnostics and earth science problems (Oh, 2010; Raholm, 2010).

Abduction is different from induction and deduction because it enables researchers to reach beyond a pure representation of facts based on observations (Raholm, 2010). For instance, it is observed the fact that all the parrots in the garden eat apples and all of them are green parrots. Then, we can hypothesize from this observed phenomena that green parrots may eat apples. Apart from this, an example in the next section will explain the differences between these forms of reasoning in more detail. Within many fields of study, researchers are using abduction as a form of reasoning including medical diagnostics, scientific theory formulation, accident investigation, language understanding, jury deliberation and school scientific inquiry problems (Ross, 2010). However, in school science, the need for an abductive inquiry approach has been sparsely explored in the literature (Oh, 2011). Therefore, science educators and researchers have recently begun to study the process of hypothesis generation in the context of abductive science inquiry investigation.

2.5.4   An Example

The following example, taken from the collected papers of C.S. Peirce (1931-1958) cited in (Raholm, 2010), will show the relationships between the three forms of reasoning more clearly. In this example, the Case (Hypothesis), Result (Observation) and Rule (Condition) are defined to show the differences in order.

Deduction:

Rule–All the beans from this bag are white

Case– These beans are from this bag.

Result–These beans are white.

Induction:

Case–These beans are from this bag.

Result–These beans are white.

Rule–All the beans from this bag are white.

Abduction:

Rule–All the beans from this bag are white.

Result– These beans are white.

Case–These beans are from this bag.

This reasoning process is different from both deduction and induction: the former draws a Result from a Rule and a Case; the latter generalizes a Rule from a Case and a Result (Haig, 2005; Walton, 2004). However, in abduction, the Rule and Result are used together to find a Case. It is further elaborated by Peirce (cited in Mahootian &

Eastman, 2009): Deduction proves that something *must be*; Induction demonstrates that something *actually* is functioning; Abduction merely suggests that something *may be*. This further suggests that deduction can draw a prediction which can be tested by induction, and abduction is used to understand the complete phenomena.

This example shows that there is an opportunity to explore this trait of abduction in inquiry problems where learners are challenged to formulate scientific hypotheses and explain natural phenomena (Kleinhans, Buskes, & De Regt, 2005; Oh, 2011).

2.6 Mobile Technologies in Science Inquiries

Most of the literature regarding the adoption of mobile technologies in science education tends to provide significant opportunities for genuinely supported learning experiences about the sciences. The history of science educational activities has primarily focused on science curriculum development and implementation (Forbes & Davis, 2008). However, the affordances of handheld devices make it possible to build learning environments that can enable learning activities for science students (Looi et al., 2011). From the school education viewpoint, a number of mobile learning science applications have been discussed in the literature. These applications reflect the diversity of learning experiences to either classroom, outside the classroom or mixed settings. Some of them are discussed in this section and also summarized in Table 2.2.

2.6.1 Mobile science inquiry in mixed settings

Over the years, many different science learning projects have been developed under mixed settings. Amongst them, MOBIlearn[4] was a large scale European-led research and development project that ran for almost 3 years (2002-2005) in ten countries. Its aim was to develop, implement and evaluate a reusable architecture for delivering

---

[4] www.mobillearn.org

mobile learning experiences (Kukulska-Hulme et al., 2009). The MOBIlearn system was implemented with three scenarios: Museum, First aid (Lonsdale et al., 2004) and Campus-based learning environment (Da Bormida, Lefrere, & Taylor, 2003). The successful demonstration of these scenarios showed that learners could interact with these mobile technologies in a number of different settings and the systems could provide information and guidance according to the needs of mobile learners. HandLearn (Avraamidou, 2008) is another research project that was designed to support inquiry-based science investigations in formal (classroom) and informal (park) learning environments. This project was aimed to; (i) develop curriculum material based on learning theories with science perspectives (ii) investigate the role of handheld devices in science learning and (iii) produce material for teacher professional development.

In similar recent examples, LET's GO! (Learning Ecology through Technologies from Science for Global Outcomes (Maldonado & Pea, 2010; Spikol, Milrad, Maldonado, & Pea, 2009; Vogel, Spikol, Kurti, & Milrad, 2010), a collaborative research project between Stanford Centre for Innovations in Learning, USA and Centre for Learning and Knowledge Technologies (CeLeKT), Sweden, provided educational activities and tools to help K-12 students participate in collaborative science learning involving local environmental data in the domain of ecology. Moreover, the data can be gathered, analysed, reflected on, and reported through mobile and sensor technologies that engage learners in exploring, experimenting with in and outside the classroom activities for deeper domain understanding. nQuire (Sharples et al., 2011) was also implemented in both settings: classroom and outside. For that purpose, aconstraint-based toolkit was designed in that project for supporting the continuation of mobile science learning activities between classroom and non-formal settings. Further, this application can run on both mobile and desktop computers to guide learners by providing an interactive visual representation of scientific practice.

Table 2.2 Summary of the mobile science inquiry-based learning projects

Project Name	Learning Setting	Devices Used	Learners' level / Age	Learning Task	Style of Inquiry	Use of Mobile Device
MOBIlearn	Mixed	Mobile	School students	Museum	Inductive	Guidance & text messages
LET'S GO!	Mixed	Mobile, Sensor & Camera	Aged 16-18 yrs	Water & soil quality	Deductive	Data collection
nQuire	Mixed	Mobile, PC & Camera	Aged 14 yrs	Healthy eating	Deductive	Guidance
Ambient Wood Project	Outside classroom	PDA, Probe & Camera	Aged 11-12 yrs	Habitants in woodland	Inductive	Guidance
Savannah	Outside classroom	PDA	Aged 11-12 yrs	Animal behaviours	Inductive	Guidance
My Mobile Mission (M3)	Outside classroom	Mobile	Aged 11 yrs	Sustainable energy	Deductive	Sending clues via SMS
BIOKID Sequence	Classroom	PDA	$5^{th} - 8^{th}$ Grades	Biodiversity curriculum	Inductive	Data collection
WHIRL	Classroom	Mobile	4- 11 Grades	Science topics	Deductive	Guidance

Regardless of the fact that these science learning projects have been used for different purposes, research findings generally point out promising outcomes associated with the use of mobile technologies in mixed settings (within and outside the classroom) (Avraamidou, 2008).

2.6.2 Mobile science inquiry in outside classroom settings

For outside classroom learning activities, the Ambient Wood Project (Randell, Phelps, & Rogers, 2003; Rogers et al., 2005) is one of the examples of mobile science projects in which a playful learning experience was designed that encourages learners to explore and hypothesize about different habitats found in woodlands. Learners can be equipped with a variety of mobile devices and visualization tools to access and share contextually relevant digital information with their own observations of the physical environment.

In a similar vein, Savannah (Facer et al., 2004) was carried out jointly by Futurelab, HP Laboratory (Bristol), the BBC National History Unit and the Mixed-Reality Laboratory of Nottingham University. It is one of the examples of outside science learning application that promotes game-playing and has a strong element of self-motivation and collaborative approaches to conceptual understanding of animal behaviour. Another project, M3 (My Mobile Mission) (Wyeth et al., 2008) was implemented for outdoor treasure hunt activities using mobile devices as mediator. In this project, learners were needed to solve clues by exploring the local environmental data about sustainable energy.

The focal point of all these outside classroom projects is that learning may be supported in new ways by combining the real word with digitally re-presented information. In addition, learners can experience natural phenomena and explore

concepts and relationships by interacting with physical and digital artefacts (Rogers et al., 2005; Sharples et al., 2005).

2.6.3 Mobile science inquiry in classroom settings

In one of the classroom settings projects, the BioKIDS Sequence (Parr, Jones, & Songer, 2004) was a learning experience for 5th and 6th grade science students in south-eastern Michigan, USA. In this project, PDAs were used to collect scientific data, monitor habitats and identify species using tools. This project presented a case for meaningful use of technology to support scientific reasoning as students need to analyse data and generate scientific explanations based on their data. Further, this project (Songer, Huber, & Lee, 2003) showed that students gain significant improvement in developing complex reasoning with the help of such technology-enhanced learning tools.

Project WHIRL (Yarnall et al., 2006) was another science research project based in classroom settings, funded by the National Science Foundation and conducted with teachers and administrators in the Beaufort Country School District in South California. This project demonstrated that these mobile technologies are used easily with science classrooms in order to support more frequent assessment practices. These assessment activities include students' previous knowledge about a particular domain; tracking students' learning content progress, identifying and diagnosing students' misunderstandings and evaluating learning performance in their school tasks.

The ultimate goal of these science learning projects was to reveal the pedagogical potential of mobile technologies to enhance science learning with variety of educational settings including classroom, outside classroom, and mixed settings. All of these projects were generally followed by a hypothetico-deductive or inductive style of inquiry investigation in which learners are required to process ideas (or hypotheses) (Grandy & Duschl, 2007) as presented in Table 2.2. In contrast, abductive science

inquiry emphasizes the development of hypotheses from observed phenomena (Oh, 2010, 2011). In the mobile learning technologies literature, this kind of inquiry has not been previously exploited (Grandy & Duschl, 2007; Oh, 2011). Therefore, this provides an opportunity to explore some new approaches in school science inquiries using mobile technologies.

2.7 Abductive Inquiry in School Sciences

In science education, one of the important tasks is to provide explanations of natural phenomena. An abductive inquiry is also implemented in a similar way that leads learners towards new explanations on the basis of background theories and observations (Colheart et al., 2010; Raholm, 2010). However, in this type of inquiry, learners are not certain about the conclusions but they get some possible explanations of a given problem, and those potentially possible explanations guide learners to formulate hypotheses (Eriksson & Lindstorm, 1997). As a matter of fact, this is the essence of abduction, that it starts with the incomprehensive nature of explanation and ends with the creation of satisfactory new knowledge by connecting phenomena and concepts expressed as hypotheses (Raholm, 2010).

2.7.1   Pedagogical Ambitions in Scientific Explanations

Scientific explanations have two important aspects in science (Peker & Wallace, 2011): first, they provide a unified picture of how various scientific phenomena fit together; second, they help to comprehend how things work in the world. According to the National Research Council (2000, p.19), "To formulate and revise scientific explanations using logic and evidence are among the fundamental abilities necessary to do scientific inquiry". Scientific explanations are usually composed of three components: *claim*, *evidence* and *reasoning* (Gil & Ben-Zvi, 2011). A *claim* is a statement or conclusion concerning the actual problem. *Evidence* is scientific data that

supports the claim, whether taken from other resources or deriving from an investigation. *Reasoning* provides some justification for considering suitable evidence from the data in support of the claim. It is the combination of these three components that can help learners to understand scientific knowledge in a meaningful way (McNeill & Krajcik, 2007).

It is suggested in cognitive science literature that scientific explanation is highly recommended as a tool for developing learners' cognitive development (Krupa, Selman, & Jacquette, 1985). Further, critical thinking plays a vital role in providing a foundation for such learning environments where learners need to think as rational, mature thinkers who will be able to understand and to appropriately use knowledge in analysing problems in some meaningful way (Kordaki & Dardoumis, 2009). This critical thinking habit not only helps learners to differentiate knowledge from mere opinions while conducting science inquiry investigations but also guides them to generate hypotheses that explain the natural phenomena (Shen, 2010). Several studies show that if learners construct their own scientific explanations, they are more likely to be able to critique these explanations and hence augment their own conceptual understanding (Coll, France, & Taylor, 2005; Hart, 2008; Shen & Confrey, 2007).

In the area of educational research, Southerland, Abrams, Cummins and Anzelmo (2001) investigated the nature of students' biological explanations between second, fifth, eight and twelfth grade learners. They found that students have both tentative and shifted explanations; Tentative explanations are those in which learners have doubt about the plausibility of their explanations, while in shifting explanations they give different explanations for the same phenomenon when they are asked about it at different times. In another classroom setting, Khan's (2007) study describes a GEM (generate, evaluate and modify) cyclic approach for formulating scientific hypotheses. The outcome of that study revealed that both modelling and inquiry help learners to comprehend abstract concepts about the topic (molecular structures). These studies

mainly focus on learners' hypotheses generation processes and their explanations. However, they do not stress learners' critical thinking during such abductive form of inquiries.

Oh (2011) discussed different characteristic features of abductive IBL activities in the domain of earth sciences. Four groups of undergraduate students participated and the results of that study showed that students have the capability to make scientific hypotheses when appropriate resources are provided to them. In another similar study (Peker & Wallace, 2011), learners were asked to explain why fungi grew better in a warm environment than a cold one, and had to generate a hypothesis that could best explain the situation. That study further showed that learners' explanations were primarily based on first-hand knowledge gained in the science laboratories but they faced difficulties in explaining phenomena that involved complex cause-effect relationships. Given these difficulties, researchers and science educators made the case for the need for instructional scaffolding in improving the quality of learners' explanations during science inquiry investigations (McNeill, Lizotte, Krajicik, & Marx, 2006; Peker & Wallace, 2011; Sandoval, 2003).

2.7.2   The Abductive Inquiry Model

As discussed previously, abduction is a creative and evaluative form of reasoning that enables learners to generate plausible hypotheses on the basis of background theories and use their critical thinking skills to explain the observed phenomena (Oh, 2011). Based upon these characteristics of abduction, the Abductive Inquiry Model (AIM) has been adopted in school science IBL environments (Oh, 2008, 2010, 2011).

The AIM consists of four main elements (Oh, 2011): *exploration*, *examination*, *selection* and *explanation* (see Figure 2.3). In the *exploration*, learners investigate the given scientific phenomena by observing data and find ways to explain it scientifically. The

examination phase then follows so that learners find out scientific facts or theories in order to formulate scientific hypotheses. In other words, the main focus of this phase is to examine all possible rules which are able to provide explanations for the investigating phenomena. During the *selection* phase, learners evaluate all the previously inferred hypotheses and choose those that provide the most plausible explanations. If learners find any flaws or problems in this phase then they may go back to the other previous steps; *exploration* and *examination* for the development of more sophisticated explanations of the observed phenomena. Therefore, these phases are not defined linearly in AIM, but rather are cyclic in nature, and hypotheses are iteratively modified and explained through ongoing development (Oh, 2011). In the final phase, learners recommend complete explanations of the given phenomena using the rules and hypotheses chosen in the earlier phases.
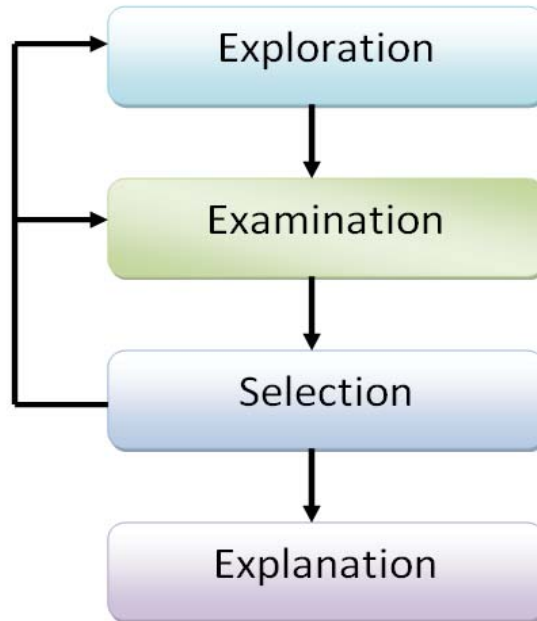
Figure 2.2 The abductive inquiry model (AIM) (Oh, 2011, p. 413)

This abductive inquiry model is a promising approach for the pedagogical purposes of enriching learners' knowledge and engaging them in scientific inquiry practices (Oh, 2010). Nevertheless, this approach is not supported by technology scaffolds (Hmelo-Silver, 2006; Sharma & Hannafin, 2007) that can behave as a guide in order to support learners' critical thinking skills while performing scientific inquiry investigations. Oh's model has been used in this study to design abductive science IBL activities.

2.8 The Role of Ontology in Science Education

Certainly, in the education field, there are many applications available which cover the broad spectrum of ontology-based scaffolding (Ghidini et al., 2007; Jovanovic et al., 2009, Vas et al., 2009). Research on the role of ontologies in education has already shown some of the features expected to be embedded in the next generation of educational tools (Bittencourt, Isotani, Costa, & Mizoguchi, 2008). Such features include: adaptive and personalized learning, better use of pedagogies to enhance learning, storage and retrieval, and effective ways of exchanging information. However, the role of ontology-based scaffolding in inquiry learning applications has been explored in only a few studies (Chu et al., 2011; De Jong et al., 2010; Weinbrenner, Engler, & Hoppe, 2011), which provide us with an opportunity to explore some features of technology-assisted learning in the sciences.

2.8.1 Ontology Based Scaffolding in Scientific Inquiries

In the literature related to education, there is paucity in which ontology-based scaffolding is used in abductive mobile science inquiry investigations. Nevertheless there is some significant related work that should be acknowledged.

The Concept Mapped Project-Based Activity Scaffolding System (CoMPASS) consists of a hypertext system and curriculum modules based on ontology-based scaffolding from

which learners can learn science (Kolodner et al., 2003). CLS (Chu et al., 2011) provides visual concept transfer paths that assist learners to comprehend the relationships between the defined course concepts. In this application, the ontology-based scaffolding is used for structuring learning content for learners to navigate through learning material by following their own personalized paths. In fact, these systems mainly focus on concept mapping that can reduce learners' cognitive load to some extent and facilitate meaningful learning (Chu et al., 2011) but the science learning described in these systems is not undertaken in inquiry-based learning settings.

In a similar vein, the SCY Project (De Jong et al., 2010) is an ongoing collaborative project between some renowned European universities and organizations. This project is funded by the European Community, which intends to offer learners a learning experience that includes both inquiry 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. In each of this inquiry learning process (LASs), learners need to gather and process information engage, design and conduct experiments, make interpretations and abstractions. This leads to the production of 'emerging learning objects' (ELOs) (Hoppe et al., 2005). SCY's ELOs include models, concept maps, artefacts, data sets, hypotheses, tables, summaries, plans, reports and lists of learning goals (De Jong et al., 2010). One of the examples discussed in this project in (Weinbrenner et al., 2011) supports learners in the process of finding the relevant concepts of contents and transforming them into a concept map by using a domain ontology. The specific roles of ontologies are addressed in this project (Weinbrenner, Engler, Bollen, & Hoppe, 2009) including semantic representation for human-human interdisciplinary exchange, serving as meta-level descriptions for repositories, standardization and interlink metadata vocabulary, and facilitation of high level inter-operability between tools and services.

CIEL (Collaborative Inquiry and Experiential Learning) (Van Joolingen, Bollen, Hoppe, & De Jong, 2007) is another European project under the Kaleidoscope Network of Excellence. In this project, the CIEL ontology is used for building semantically interoperable applications for IBL environments that include ELOs such as 'hypothesis', 'experiment' and 'data set'. These ELOs are created to provide meaning to data that are stored. The ontology ensures that the meaning of the object is maintained over the whole learning process.

Although, these projects highlight some reasonable opportunities for science learning at a conceptual level, they do not target mobile learning environments. In addition, none of the above projects emphasize the abductive form of science inquiry investigations.

2.9   Summary

In this chapter, the relevant literature has been reviewed, identifying some key connections across different areas including mobile learning, ontologies and science education as shown in Figure 2.4. The literature reveals that the use of ontology in learning environments is quite a new area of research, which is continually evolving with new approaches and methods.

Beside the fact that ontologies can be applied for knowledge creation and conceptual modelling, other uses also stand out amongst technologies, mainly due to their diverse nature (Pahl & Holohan, 2009). The theoretical aspects described in this chapter present some important issues related to the use of ontologies for scaffolding learning content in mobile science inquiry investigations. The intention of this thesis is to argue for how ontology-based scaffolding design can be further used as a practical approach for the research and development of new learning landscapes for science students with current mobile technologies.
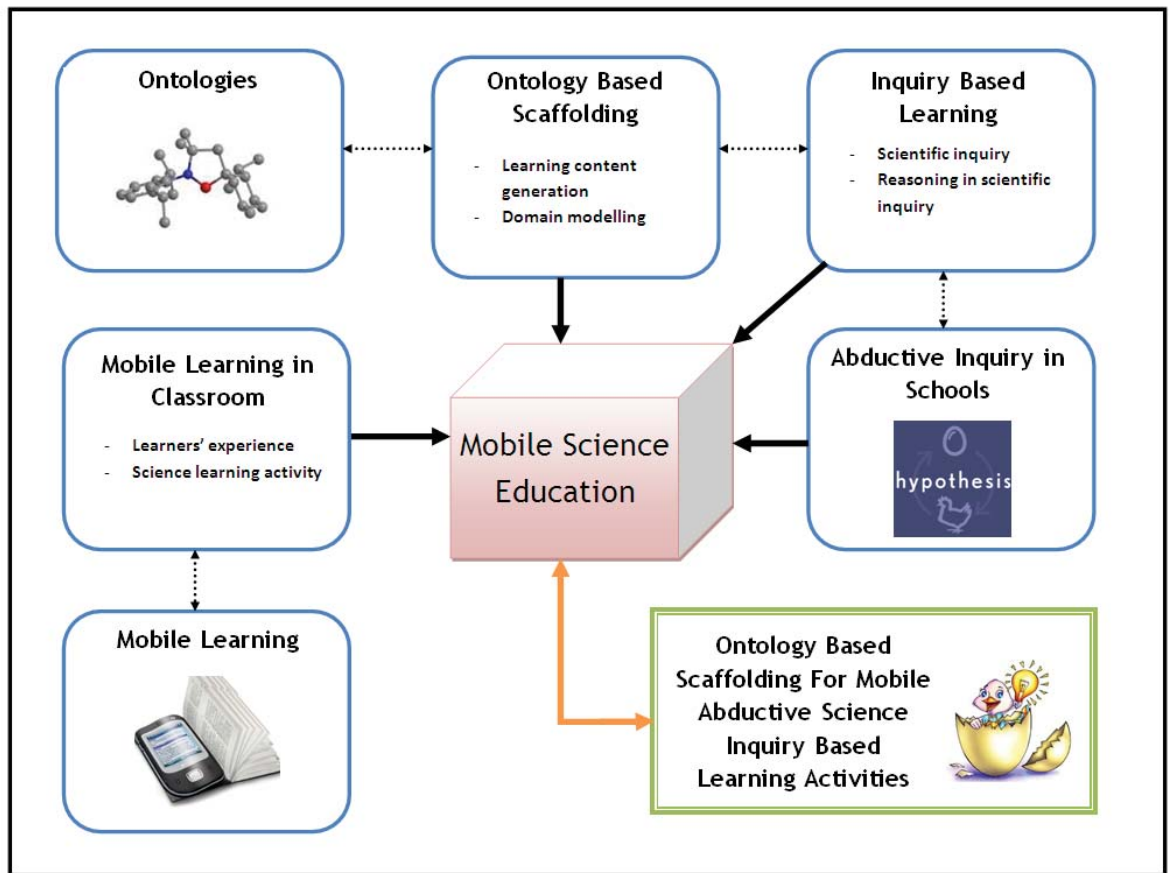
Figure 2.3 Summary of the literature review topics

These mobile technologies offer many different levels of engagement for supporting pedagogical ambitions in school education that transform the conventional form of classroom into interactive classroom systems that have the potential to enhance students' learning experiences (Scornavacca et al., 2009). From the school science perspective, a number of mobile learning science applications have been discussed in the literature (Parr et al., 2004; Randell, et al., 2003; Sharples et al., 2011; Spikol et al., 2009; Yarnall et al., 2006). These applications reflect the diversity of learning experiences that can take place in a variety of classroom and outside learning activities (Avraamidou, 2008). However, the educational advantages of these technologies are less explored in terms of their extensive guidance in facilitating meaningful science

73

classroom learning (Hmelo-Silver & Barrows, 2006). In addition, the given assistance can provide significant gains in students' learning performance need to be further evaluated (Hmelo-Silver et al., 2007).

IBL is an example of a learning activity that can encourage learners to develop knowledge about the scientific phenomena that they observe in the physical world (Van Joolingen & Zacharia, 2009). However, the pedagogical advantages of such learning activities are often challenged by the learner's understanding of a particular domain at a conceptual level (Mulder et al., 2011). In a scientific inquiry, technology scaffolds behave as a mentor to guide learners about how to do a specific task, and thereby facilitate classroom learning (Hmelo-Silver, 2006; Sharma & Hannafin, 2007). For this purpose, scaffolding design guidelines (Quintana et al., 2004) can be applied to help learners comprehend the domain-specific knowledge, and may enhance their reasoning skills during such IBL activities.

In school sciences, scientific explanations generally proceed in a deductive or inductive way. In contrast, abductive inquiry in which searching for an idea (hypothesis) is central has not been previously considered (Grandy & Duschl, 2007; Oh, 2010). Therefore, the Abductive inquiry Model (Oh, 2011) has been used in this thesis to investigate such kind of inquiry with an ontology-driven learning application.

In the previous literature, only a few studies (Van Joolingen, Bollen et al., 2007; De Jong et al., 2010; Chu et al., 2011) suggest IBL activities by using ontologies. This provides some new opportunities to explore technology-assisted learning in the sciences. Thus, this research not only demonstrates to educators how ontology-based scaffolding can be implemented practically for abductive mobile science inquiry but also as a guiding tool for learners to construct some meaningful learning.

Research Methodology

This chapter describes the methods applied in this research, which starts with an introduction to design science and then discusses the rationale for using a design science research methodology (DSRM) for conducting this research. DSRM is further supported by activity oriented design methods (AODM) that relate to the activity system of the proposed application, and AODM tools are covered in the next section of this chapter. The following section elaborates evaluation methods that include the M3 evaluation framework and data collection methods for evaluating the designed application. At the end, a summary of this chapter is presented.

3.1 A Design Science Exploration

Design science is fundamentally a problem-solving paradigm in information science research. This brings together two important components: a design process and evaluation of design elements (Collins, Joseph, & Bielaczyc, 2004). A design process mainly focuses on a sequence of activities that constructs an innovative product (the design artifact). The evaluation of the design artifact then offers feedback information which assists in improving both the quality of the product and the design process (Hevner, March, Park, & Ram, 2004). This build-and-evaluate loop is iterated a number of times, until the final design artifact is completed (Markus, Majchrzak, & Gasser, 2002). The research described in this thesis falls under the category of design science

because the basic proposal for carrying out such research requires an IT artifact that may help in exploring ontology-supported mobile learning in the context of abductive science inquiries. For that purpose, an ontology-driven mobile web application has been designed and evaluated.

3.1.1 Methods for Design Science Research

There has been consensus on the common understanding of design science research in information science that involves learning through the act of building (Hevner et al., 2004; Keuchler & Vaishnavi, 2008; March & Storey, 2008). It is suggested in (Keuchler & Vaishnavi, 2008) that the design of the artifact defines what is to be built and the method used for specifying how such an artifact is to be built.

There is a substantial body of research in the field of designing methods for design science research in information science and engineering disciplines. In Information science, Nunamaker, Chen and Purdin (1990) proposed a multi-methodological approach that includes theory building, systems development, experimentation and observations. In Walls, Widmeyer and El Sawy (2004), an information science design theory was defined that resembles traditional social science-based theory building and testing. Both these methods emphasized theoretical perspectives of the research problems rather any practical ones. In addition, they did not consider communication as an important activity of the research design that can help in disseminating the resulting knowledge to the research community. Further, Walls et al. (2004) did not focus on the experimentation or demonstration of the artifact before evaluating it.

Hevner et al. (2004) proposed seven guidelines for understanding a research problem and designing a research artifact. These guidelines were: (i) design an artifact (ii) problem relevance (iii) design evaluation (iv) research contributions (v) research rigor (vi) design as a search process and (vii) communication of research. These guidelines

mainly focused on the nature of the iterative research process. However, this did not consider experimentation of the artifact before evaluating it in the real world. Similarly, in the computing science domain, Takeda, Veerkamp, Tomiyama, and Yoshikawam (1996) proposed a design cycle for intelligent design systems which consists of five sub-processes including awareness of the problem, suggestion, development, evaluation and conclusion. Further, this model extended the reasoning process in the design research cycle (Keuchler & Vaishnavi, 2008). However, neither of these models targeted demonstration and communication as important activities for designing artefacts and promoting their utility and novelty to researchers and other relevant audiences.

In engineering, Archer (1984) presented a design process model that focuses on data collection, analysis, synthesis, development and communication. In a similar vein, Eekels and Roozenburg (1991) defined an iterative design cycle that consists of the following elements: practical problem, analysis, synthesis, simulation, evaluation and conclusion. Both these models were developed for solving practical problems only. However, Cole, Purao, Rossi and Sein (2005) outlined a basic model that deals with the integration of design science with action research. The defined activities in this method were: identification of the problems, build and evaluate. None of these models except Eekels and Roozenburg (1991) discussed experimentation of the artifact as an important activity before evaluation. Cole et al. (2005), and Eekels and Roozenburg (1991) did not emphasize communicating the resulting knowledge to target audiences.

All of these above discussed methods were mainly based on specific research contexts and to the practical needs of design practitioners. However, a design science research methodology (DSRM) (Peffers et al., 2008) offers a commonly accepted method for carrying out design science research. This method consists of the following six activities that cover all the previous activities found in the literature, including problem

identification and motivation, objectives of a solution, design and development, demonstration, evaluation, and communication.

In addition, a methodology should incorporate three major elements: *principles*, *practices* and *procedures* (Peffers et al., 2008). The *principles* behind conducting design science research are to create and evaluate information technology (IT) artefacts that may include models, constructs, methods and instantiations for solving research problems (Hevner et al., 2004). For *practices,* a methodology element requires the development of IT artefacts on the basis of a research process that comes up with a solution by using existing theories or literature of a defined problem (Fulcher & Hills, 1996; Hevner et al., 2004). *Procedures* is another important element of a methodology, which provides a generally accepted process for doing design science research (Peffers et al., 2008). Further, these IT artefacts are evaluated with respect to their effectiveness and efficiency to improve performance in the development and use of information systems in many domains (March & Storey, 2008).

Prior research introduced *principles* that define design science research and its goals (Fulcher & Hills, 1996; Hevner et al., 2004), as well as *practice*s that provide guidance for conducting (Archer, 1984; Eekel & Roozenburg, 1991; Fulcher & Hills, 1996; Hevner et al., 2004; Takeda et al., 1996) and justifying it (Nunamaker et al., 1990; Walls et al., 2004). None of the prior literature discusses a common *procedure* that provides a generally accepted process for conducting design science research except as defined in DSRM (Peffers et al., 2008). Hence, this research adopts DSRM for addressing the research challenges drawn from the literature.

3.1.2 DSRM process model

The DSRM process model accomplishes two things: it may provide a road map for researchers who want to use design as a research mechanism for information science research; it may help researchers by legitimizing their research using understood and accepted processes (Peffers et al., 2008). This process model used a consensus-building approach, which ensures that this model is based on common process elements, discussed earlier in the literature related to design science research (Peffers et al., 2008). This model consists of six activities in a nominal sequence as depicted in Figure 3.1.
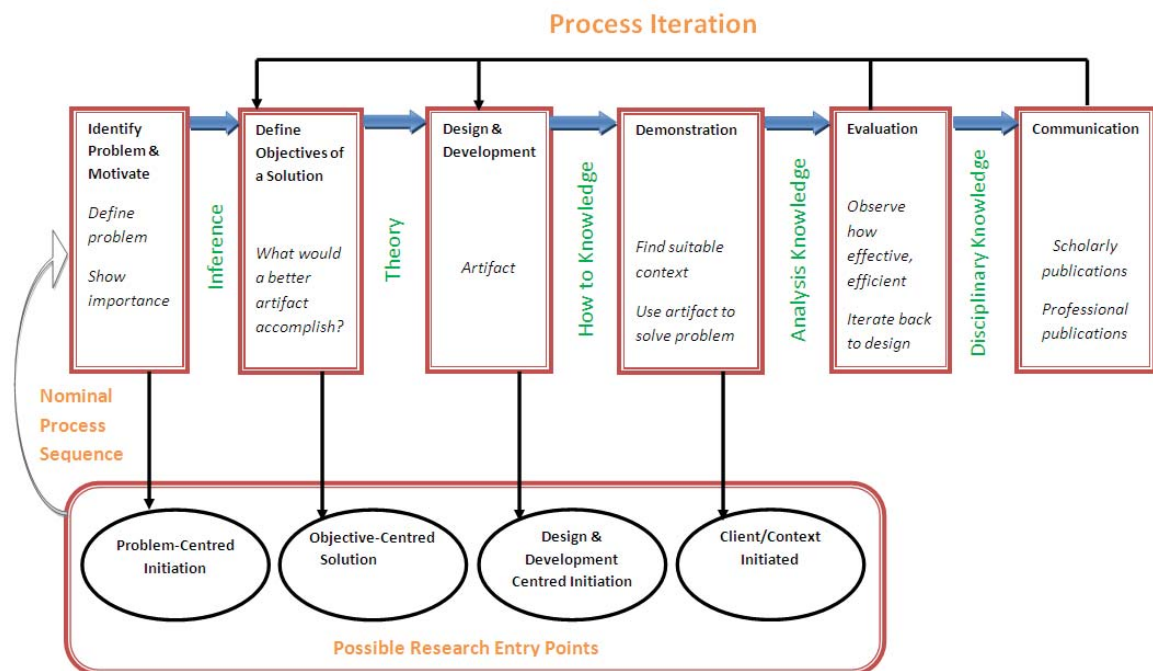
Figure 3.1 DSRM process model (Peffers et al., 2008, p.54)

3.1.2.1   Activities

The activities of the DSRM process model are: problem identification and motivation, definition of the objectives for a solution, design and development, demonstration,

evaluation, and communication (see Figure 3.1). While considering these activities, there is no compulsion for researchers that they would always follow to a sequential order from activity 1 through activity 6. Instead, they may actually start at almost any step and move outward (Peffers et al., 2008).

3.1.2.1.1   Activity – 1: Problem identification and motivation

In this activity, a design research problem is identified and justifies the motivation behind developing an artifact that can effectively provide a solution. Justifying the value of a solution provides two things. One, it motivates the researcher and the audience of the research to pursue the solution and to accept the results. Two, it helps to understand the reasoning associated with the researcher's understanding of the problem (Peffers et al., 2008).

3.1.2.1.2   Activity – 2: Define the objectives for a solution

This activity is used to infer the objectives of a solution from the problem domain, considered as 'thought experiments' to explore the feasibility of each approach (Vaishnavi & Keuchler, 2007). The objectives in this activity can be qualitative, in which a description about the new artifact is expected to support a solution of a given problem, or quantitative, in which terms of how a desirable solution would be better than recently designed ones, if there are any (Peffers et al., 2008).

3.1.2.1.3   Activity – 3: Design and development

A design research artifact can be any designed object in which a research contribution is embedded in the design (Peffers et al., 2008). This activity involves designing and developing an artifact that deals with the desired functionality of a given research problem. The design and development process in design science research is differentiated from software engineering in terms of the nature of the problem and

solution (Hevner et al., 2004). In software engineering, an existing knowledge base is used for the application design of the given organizational problems while design science research addresses important unsolved problems in unique or innovative ways or solved problems in more effective or efficient way (Hevner et al., 2004).

3.1.2.1.4   Activity – 4: Demonstration

This activity involves the use of the artifact to solve one or more instances of the problem by experimentation, case study, proof, simulation, or other appropriate activity (Peffers et al., 2008).

3.1.2.1.5   Activity – 5: Evaluation

In this activity, observations and measurements are calculated to see how well the artifact supports a solution to a given research problem. This activity compares the objectives of a solution to actual observed results from the use of the artifact in the demonstration (Peffers et al., 2008). At the end of this activity, the researchers can decide whether to iterate back to the design and development activity for the effectiveness of the artifact or to continue on to the last activity of this model.

3.1.2.1.6   Activity – 6: Communication

This activity is used to communicate the research problem and its significance to researchers and other target audiences such as practicing professionals. In addition, the utility, novelty and efficacy of a designed artifact are also shared among research communities (Peffers et al., 2008). It not only enables practitioners to take advantage of the benefits offered by the given solution to a problem but also enables researchers to build a cumulative knowledge base for further extension and evaluation (Hevner et al., 2004).

3.1.2.2   Research entry points

In the DSRM process model, researchers can start from any activity to solve the solution according to their research requirements. Peffers et al., (2008) defined four possible research entry points: *problem-centred initiation*, *objective-centred solution*, *design and development centred initiation*, and *client/context initiated* as shown in Figure 3.1.

3.1.2.2.1   Problem-centred initiation

In this approach, researchers proceed in the given sequence of the DSRM process model (see Figure 3.1), if the idea for the research resulted from the observation of a problem or from suggested future research in a paper from a prior project.

3.1.2.2.2   Objective-centred solution

This entry point is initiated from the activity 2 of this DSRM process model in which researchers need to address the problem by developing artefacts.

3.1.2.2.3   Design and development centred initiation

This approach starts with the activity 3 that defines the artifact without formally thinking through the explicit domain in which it may be used.

3.1.2.2.4   Client/context initiated

In this approach, a solution may be provided after observing its practical use in the actual context. This approach can be started from the fourth activity of this model.

3.1.3 DSRM and Other Used Methods

This DSRM process model is iterative in nature until it accomplishes a solution to the underlying research problem. Therefore, in this research, the process model is used

iteratively in designing and evaluating the proposed application. There are some other methods used, which support the DSRM process model in this research as depicted in Figure 3.2. AODM (Activity oriented design methods) (Mwanza-Simwami, 2009) tools are used for generating research questions and the identification of the number of research design iterations. Scaffolding design framework (Quintana et al., 2004) was applied for designing science inquiry learning activities (see Section 4.1.2.3.3). For evaluation purposes, the M3 evaluation framework (Vavoula et al., 2009) was applied to investigate the different aspects of the designed solution. In addition, quantitative and qualitative data collection methods were used in this research for the evaluation of the designed solution. The subsequent sections describe these methods in details.
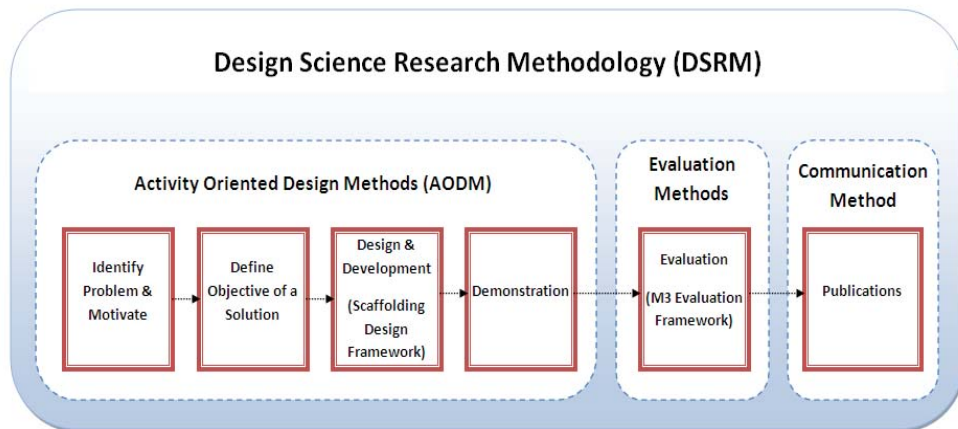
Figure 3.2 Different methods used in this research

3.2 Activity-Oriented Design Methods (AODM)

AODM is an analytical and practical approach for applying key concepts of activity theory to human computer interaction research and practice, which presents four methodological tools to support the processes of data gathering, analysis and communicating design insights (Mwanza-Simwami, 2001).

Activity theory is the theorectical framework that underpins the development and use of AODM, which describes human activities as processes that can be used to achieve targeted objectives (Leonte'v, 1981). The central theorising in activity theory leads to the concept of tool mediation, which can be developed for human activities and use both physical tools like mobile phones and conceptual tools such as human language and software applications (Mwanza-Simwami, 2009). This concept is based on the understandings that the tools can help learners not only to mediate their activities faciliate the performance of actions but can also reveal and transform the individual's mind.

These tools offer three main advantages for mobile learning projects (Mwanza-Simwami, 2009) which include: (i) investigation of the relationship between learner motives and technology usage, (ii) inter-connectedness of learning episodes in mobile learning through the decomposition of learner activity models and (iii) facilitation of a holistic approach to investigating mediators of learner activities by studying tools in use. This research involves mobile abductive science inquiries in which learners can perform inquiry investigations by using mobile devices whilst at the same time they need to think and learn from the given application. Thus, AODM tools are appropriate and relevant to this study because they are used for investigating the relationships between learners' experiences and the proposed application. In addition, this research follows DSRM, which is an iterative process, so each of these iterations is basically the result of the decomposition of the activity system.

AODM tools have been successfully used in several mobile application design and evaluation projects. Lab @Future Project (Baudin et al., 2004; Mwanza-Simwami & Engestrom, 2003) is one in which these tools were applied for designing and evaluating technology-supported learning in European high schools. These tools were also used to support systems requirements gathering in another large scale European-led research and development project, namely the MOBIlearn Project (Evans & Taylor, 2004;

84

Lonsdale et al., 2004). The main purpose for using these tools in that project was to investigate the design and use of mobile technologies for supporting learning. In another learning project in the field of Computer Supported Collaborative Learning (CSCL), these tools were used to comprehend collaborative knowledge building practices between course instructors and students (Greenhow & Belbas, 2007).

In all these discussed projects, Engetrom's model (1987) was used while applying AODM tools. These projects follow this perspective: learning in a mobile age, in which learners' actions are supported by cultural tools. However, the other perspective deals with the evaluation of learning as an engagement with technology (Sharples et al., 2005). Thus, this thesis adopts a framework (Sharples et al., 2005) for evaluating technology-assisted mobile learning environments. This thesis not only uses AODM tools for supporting the early research phases, specifically the generation of research questions, but also the identification of the number of iterations required for demonstration purposes. This identification has been achieved by mapping between from generated research questions to the number of iterations used in a design science process using DSRM. These tools are defined in the following sections.

3.2.1 AODM Tool 1: Eight-Step Model

The Eight-Step model (Mwanza-Simwami, 2009) explains the various components of Engestrom's model (Engestrom, 1987) of human activity in terms of the situation being examined. This involves working through the eight steps shown in Table 3.1 to gather and analyse data that will provide initial information about the activity and the context in which it is carried out.

By using this Eight-Step model, designers or researchers need to identify the appropriate answers to the questions that lead towards the construction of the activity system of the discussed problem domain. Thus, for using this model in this thesis,

there is a need to identify the answers to the questions asked during each step. Therefore, this model has been adapted in this thesis by including an 'Answers' column, which incorporates the answers asked during each step of the activities performed in this research. The given table (see Table 3.2) adapts the original Eight-Step model (Mwanza-Simwami, 2009) by answering all the questions according to the research activity.

Table 3.1 Eight-step model (Mwanza-Simwami, 2009)

The Eight-Step Model		
Identify the:		**Questions to ask**
Step 1	Activity of Interest	What sort of activity am I interested in?
Step 2	Objective	Why is the activity taking place?
Step 3	Subject	Who is involved in carrying out this activity?
Step 4	Tool	By what means are the subjects performing this activity?
Step 5	Control	Are there any cultural norms, rules or regulations governing the performance of this activity?
Step 6	Communication	Who is responsible for what, when carrying out this activity and how are the roles organized
Step 7	Context	What is the environment in which this activity is carried out?
Step 8	Outcome	What is the desired outcome from carrying out this activity?

Engestrom's model is an extended version of Vygotsky's original model (Vygotsky, 1978) of human activity by adding other key components of activity theory including 'rules and regulations', 'community' and 'division of labour'. However, Sharples and colleagues redefined Engestrom's model in the form of a framework to analyse technology-assisted mobile learning that shows a dialectical relationship between technology and semiotic layers (Sharples et al., 2005).

These layers present either a semiotic framework for educational theorists to analyse learning activity in the mobile age, in which learners' actions are supported by cultural tools and signs, or a technological framework for application developers and engineers to propose requirements for the design and evaluation of new mobile learning systems (Sharples et al., 2005). In this technological layer, learning is defined as an engagement with technology, in which tools such as computers and mobile phones are embedded with functionality in order to communicate with learners (Sharples et al., 2005).

These layers have dialectical relationship because the semiotics of the learning terms of knowledge, language and resources at one side while these functionalise are embedded in specific devices may provide different learning experiences on the other. Thus, the technology shapes learner behaviour, and that behaviour in turn affects the way that learners perceive technology (Taylor,Sharples, O'Malley, Vavoula, & Waycott, 2006). Therefore, this cyclic and dialectical process is the only way to capture the complexity of learning in the mobile environment. As far as this research is concerned, IBL activities are designed and investigated for the design and evaluation of a new mobile learning application 'ThinknLearn'. Hence, only the technological layer is being followed in the activity system of this application as depicted in Figure 3.3.

Table 3.2 Adapted Eight-step model (Mwanza-Simwami, 2009)

The Eight-Step Model			
Identify the:		**Questions to ask**	**Answers**
Step 1	Activity of Interest	What sort of activity am I interested in?	Learning activity (first aid learning or science inquiry-based learning)
Step 2	Objective	Why is the activity taking place?	Accessing learning content (learning about heat transfer)
Step 3	Subject	Who is involved in carrying out this activity?	Learner (Mobile learner)
Step 4	Tool	By what means are the subjects performing this activity?	Ontology-based scaffolding application (ThinknLearn)
Step 5	Control	Are there any cultural norms, rules or regulations governing the performance of this activity?	School ethics (Curriculum)
Step 6	Communication	Who is responsible for what, when carrying out this activity and how are the roles organized	Mode of interaction and support of co-workers (Teacher/Student/ Researcher)
Step 7	Context	What is the environment in which this activity is carried out?	Abductive science inquiry-based learning environment/ Learning space
Step 8	Outcome	What is the desired outcome from carrying out this activity?	Reinforced knowledge & skills
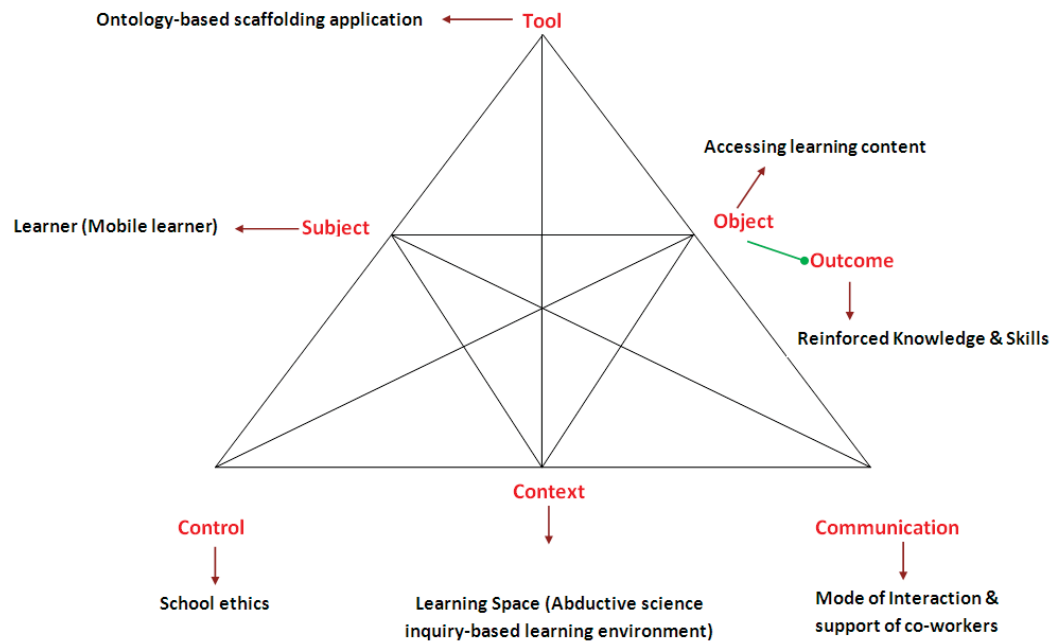
Figure 3.3 Technological layer of the activity system (adapted from Sharples et al., 2005)

3.2.2 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 (Mwanza-Simwami, 2009). This enables the researcher to investigate a more focused analysis of human activity. In this tool, operational guidelines (Mwanza-Simwami, 2009) are followed that facilitate:

♦ the decomposition of the main activity system into sub-activity triangles by levelling abstractions during activity analysis.

♦ the reduction of cognitive complexity by generating sub-activity triangles that are united through the shared object of the main activity system.

♦ the analysis, conducted within and between the various components of the main activity system so as to identify contradictions.

♦ the research questions, generated by using sub-activity triangles when performing detailed analysis of activities.

This research does not address issues related to the collaboration and human computer-interaction activities. Thus, these two components (Communication, Control) are not considered in this research while producing sub-activity triangles. The other remaining components of the given activity system (Subject, Tool, Object, Context) can be used to generate four sub-activity triangles: (i) (Subject, Tool, Object); (ii) (Subject, Tool, Context); (iii) (Subject, Object, Context); and (iv) (Context, Tool, Object). In contrast, this research focuses on the proposed application (Tool) with respect to its learning space (Context). Therefore, only two sub-activity triangles are chosen in which both 'Tool' and 'Context' components are being used to mediate activity. However, the first sub-activity triangle (Context, Tool, Object) are used twice in this research because for analysing the use of tool in a general learning space before using in a specific learning environment (abductive science environment) as shown in Figure 3.4.

3.2.3 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 (Mwanza-Simwami, 2009). In this thesis, three sub-research questions were generated (see Figure 3.5), which corresponded to the sub-activity triangles as shown in Figure 3.4.

These sub-research questions can be used to analyse user interactions with the given tool being used to mediate activity in this research. In a broader way, these questions can also be used to explore the main research question of this thesis; *how can an*

90

ontology-based scaffolding application provide learning content in mobile abductive science inquiry-based learning environments?
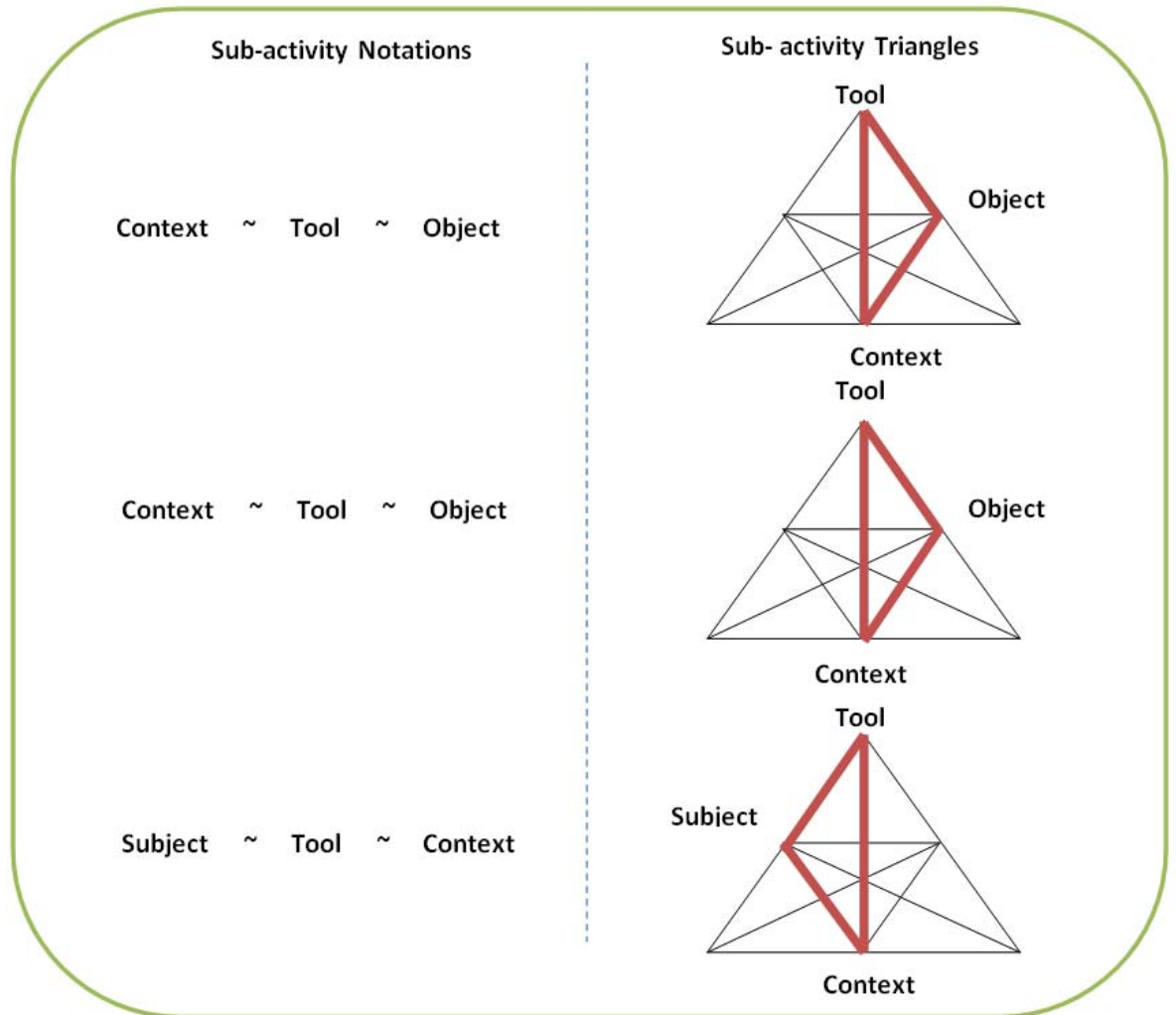
Figure 3.4 Sub-activity notations and triangles

91
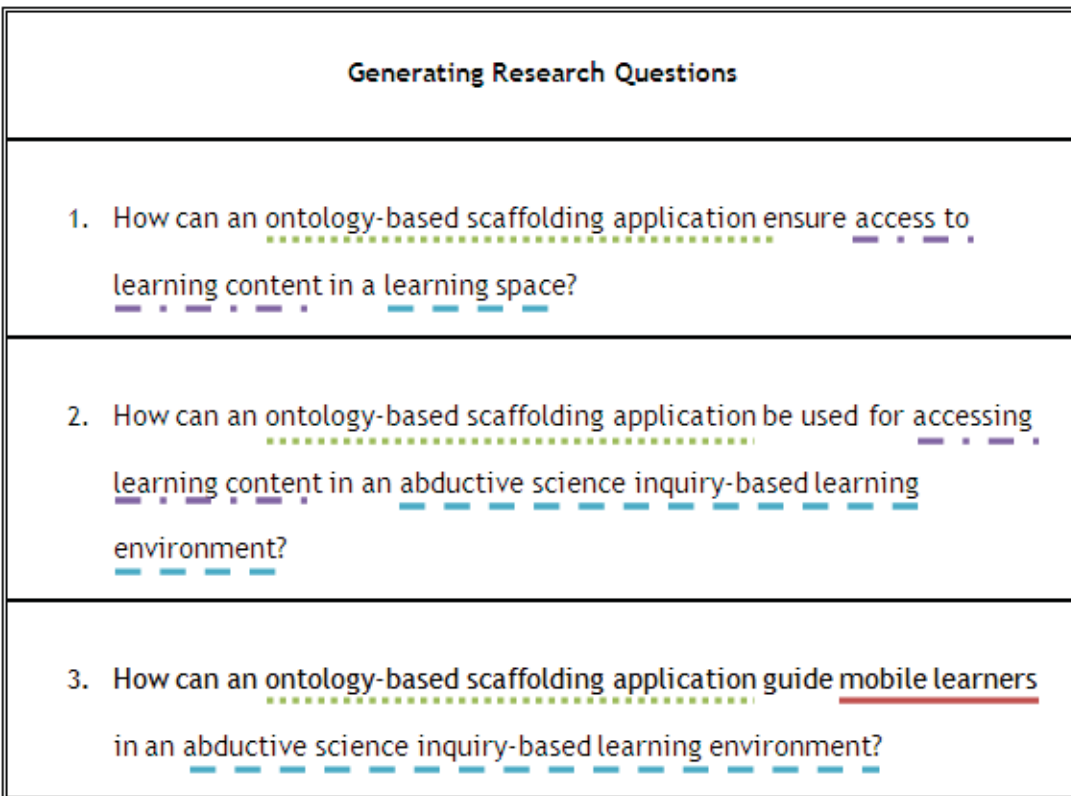
Figure 3.5 Research questions generated by using sub-activity triangles

3.2.4 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 (Mwanza-Simwami, 2009). It is further used to interpret study findings within research communities. In this thesis, the identified sub-research questions are further mapped into four research design iterations as depicted

in Figure 3.6. These iterations are designed and evaluated to investigate the main research challenge drawn from the literature.
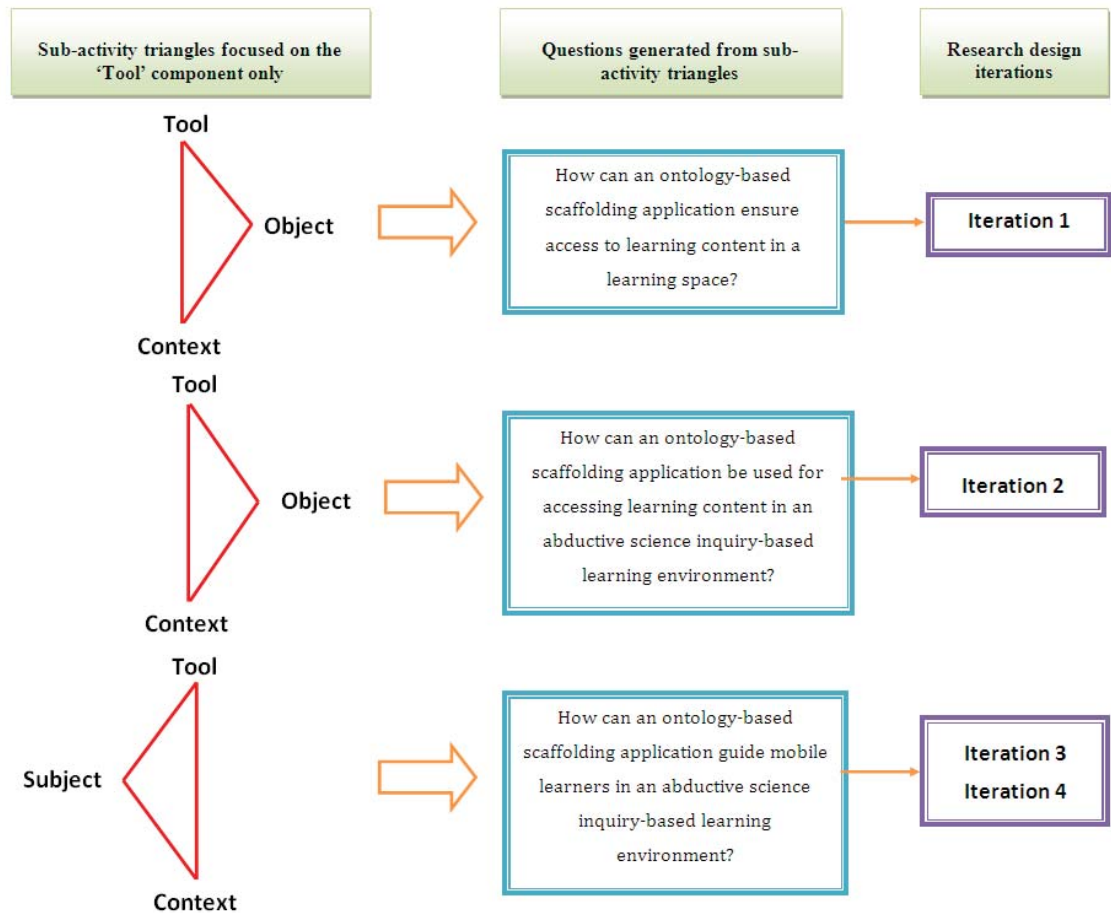
Figure 3.6 Mapping AODM operational processes with research design iterations

Using the 'Context-Tool-Object' sub-activity triangle, a research question is generated which addresses the issues about the use of ontology-based scaffolding in an application for accessing learning contents in a learning space. For that purpose, the first iteration of the research is used to evaluate ontology-based scaffolding applications in multiple ways: course content and MCQs.

93

From the 'Context-Tool-Object' sub-activity triangle, a research question is identified which explores an ontology-based scaffolding application for conducting activities in a learning space that is specific to an abductive science IBL environment. The second iteration of this research develops an application for answering this question.

The third sub-activity triangle, the 'Subject-Tool-Context' elaborates a research question which examines the abductive science IBL application with mobile learners in a classroom context. For that reason, the third iteration of this research evaluates the proposed application with a small number of participants, considered as the pilot study, while the last iteration explores the impact of the application on learning performance, referred to as the final experiment of this study as depicted in Figure 3.6.

3.3 Evaluation Methods

In the lifecycle of application designs, evaluation is an essential activity in which utility, quality, and efficacy need to be rigorously demonstrated via well-executed methods (Hevner et al., 2004). There are two commonly used methods for the evaluation of application designs: formative and summative (Scriven, 1967). The former focuses on the usability issues that need to be solved during the prototype stage before a final design can be completed. In contrast, the latter is used to evaluate the effectiveness of the final solution for a particular domain (Hartson, Andre, & Willings, 2003).

There is a wide range of evaluation methods and frameworks found in the literature which deal with formative and/or summative evaluation of mobile learning. Some of the well-known evaluation frameworks are discussed here. For instance, Bates and Poole (2003) proposed a method that evaluates the effectiveness of the use of technology for teaching in higher education. This framework consists of eight criteria including the appropriateness of the technology for students, ease of use and reliability, costs, teaching and learning approaches, interactivity, organizational issues,

novelty and speed. In a similar vein, Economides and Nikolaou (2008) presented a framework for evaluating mobile devices in relation to mobile learning. According to them, there are three important device characteristics that need to be evaluated; usability, technical and functional.

Motiwalla (2007) defined a mobile learning evaluation framework that follows two main objectives: (a) monitor the usage of mobile applications in classroom settings and get feedback about the use of the application (b) determine the student opinions about the value and role of the application. Unlike many frameworks that specifically target the technological usability of the devices in mobile learning, Motiwalla (2007) not only covers usability aspects but also deals with the learning experience of the students during mobile learning. However none of these frameworks considered summative evaluations in terms of students' performance while they were involved in a particular mobile learning activity.

A task-centred approach was defined by Taylor et al. (2006) to evaluate a mobile learning environment for both technological usability and learning effectiveness. Similarly, Corlett, Sharples, Bull and Chan (2005) not only investigated technological usability but also the usability of the hardware devices used when evaluating mobile applications. In addition, they also evaluated the perceived impact of the applications on learning along with the students' attitudes towards the use of PDAs and their provided applications. Both these frameworks follow formative and summative evaluations but they do not consider the wider organizational and socio-cultural context of learning.

In contrast, a three-level framework for evaluating mobile learning was proposed by Vavoula and Sharples (2009), which not only considers formative and summative evaluations but also the wider context of learning towards the organizational level. This framework comprises these three levels: a micro level dealing with usability, a

meso level concerned with the learning experience, and a macro level related to the integration within existing educational and organizational contexts. This thesis uses two levels of this framework for evaluating the proposed application 'ThinknLearn' for the following reasons: (i) it is one of the frameworks that was previously used in mobile science inquiry learning activities (ii) it supports both formative and summative evaluations, and (iii) this study follows DSRM in which activities are carried out in iterations. This framework also follows a system development process that can be iterative in nature.

3.3.1 The M3 Evaluation Framework

The M3 evaluation framework deals with the evaluation at the development process starts with the early stages of design to a final assessment of the deployed technology in use (Vavoula & Sharples, 2009). This framework was defined for the evaluation of MyArtSpace, a web-based service on mobile phones for IBL that allows learners to collect information during a school museum trip (Sharples, Lonsdale, Meek, Rudman, & Vavoula, 2007). The evaluation activities undertaken by using this framework can inform stakeholders with the outcomes of each evaluation activity either guiding the next phase of the system development or feeding into an iteration of an earlier phase (Vavoula & Sharples, 2009).

M3 consists of three levels of granularity (Vavoula & Sharples, 2009): *Micro,* which examines the individual activities of technology users and assesses the utility of the application; *Meso,* which investigates the learning experience as a whole, and learning breakthroughs and breakdowns; and *Macro,* which examines the impact of the new technology on established learning practices as presented in Table 3.3. However, in the case of this research, only *Micro* and *Meso* levels are considered. The reason for not considering the *Macro* level is because this level involves the emergence of new practices and its longer term impact. However, this study deals with the emergence of

new abductive science inquiry practice in school science education, which is not currently followed as educational practice in schools. Thus, at this stage of the research, this level of evaluation is not yet possible.

Table 3.3 The M3 evaluation framework (adapted from Vavoula et al., 2009)

Micro Level: Usability Issues	Meso Level: Educational Issues	Macro Level: Organizational Issues
- Technology usability (Usability and mobile quality aspects) - Individual and group learning activities	- Mobile learning experience as a whole - Learners' assessments (Pre-post and retention tests)	- Longer term of impact on the educational practices - Emergence of new practices

3.3.1.1 Micro level

This level investigates the individual activities of the technology users and assesses the usability and utility of the educational tool. In this research, high school students were involved in the following activities: **Measuring temperature**, in which students were provided with three different coloured tins to measure the temperature of each tin after a particular time interval. **Observing tins**, in which students observed different properties of tins, such as finding out which coloured tin loses heat energy the fastest. **Data entry**, in which students were required to enter temperature values for each tin observed at a particular time interval. **Answering MCQs**, in which students were asked to answer MCQs related to the observations taken during the science experiment. **Constructing hypotheses**, in which students were asked to construct hypotheses about the given knowledge and the observations made during the science experiment. **Answering questionnaires**, in which students were required to rate the usability,

mobile quality aspects and the use of the proposed application 'ThinknLearn' by using a five-point Likert scale. **Participating in group discussion**, in which students were asked to answer three questions related to their overall learning experiences about the application.

The first five activities were conducted by the students to perform science experiments. However, the last two activities were used to evaluate the technological usability of the application experienced by the students while conducting the first five activities. For usability evaluation purposes, the following ISO 9126 usability metrics were used in this research: *understandability*, *learnability* and *operability* (ISO, 2003). These metrics evaluated the application in terms of its use to achieve a typical task (hypothesis generation). In addition, for exploring the quality of learners' experiences in a mobile learning context, three mobile quality metrics were also applied: *metaphor*, *interactivity* and *learning content* (Parsons & Ryu, 2006). These aspects were used in order to identify the quality of the learning experience during the mobile learning activities. For assessing these aspects, different data collection methods including questionnaires and interviews were employed for evaluating the application in multiple ways.

3.3.1.2   Meso level

In this level, the learning experience as a whole was evaluated in terms of learners' critical thinking skills and their learning outcomes. In the case of the designed application, evaluation at this level involved exploration of a successful connection between school abductive science inquiry and mobile learning technology. This level also revealed learners' understanding of the topic and their critical thinking skills during hypothesis generation.

At this level, students were divided into two groups, experimental and control groups. Tests were used as a data collection method for evaluating the learning breakthroughs

and breakdowns while the learning activity was taking place. Control group students performed science experiments without the use of the application 'ThinknLearn' while experimental group students were assisted through the application. Apart from this difference, both groups were involved in identical activities: **Pre-test**, in which students were asked to answer four questions before performing their science experiments. These questions were related to domain knowledge about the science experiment. **Post-test**, in which students were required to answer the same questions asked at the pre-test activity after conducting the science experiments. However, in this activity, one open-ended question was added, addressing the constructed hypothesis and its explanation about the given domain. **Retention test**, in which all previous participants were asked to answer the same questions that were asked in the pre-test activity after a span of two months. This test was used to measure how the students retained their knowledge after two months. Thus, no science experiments were performed in this activity.

Afterwards, the learning performances of both groups of students were evaluated by the scores they got during these tests: pre, post and retention. In addition, the overall learning performances of both groups were compared. Two other comparisons were also observed at this level: (i) pre and post test scores of each group students (ii) post and retention test scores between each group of students.

3.3.2   Data Collection Methods

Data collection is a fundamental aspect of any type of research study. There are six major methods for data collection that includes questionnaires, interviews, focus groups, tests, observation and secondary data (Johnson & Turner, 2003). These methods are used in various research approaches including qualitative, quantitative and mixed methods to ensure the trustworthiness of the research findings (Borrego, Douglas, & Amelink, 2009).

The term *trustworthiness* is often used to describe the extent to which the findings of a research study can be trusted by readers due to the use of various data collection methods in terms of its reliability and validity (Leydens, Moskal, & Pavelich, 2004).In many cases, the mixing of qualitative and quantitative methods (mixed methods) (Creswell, Plano Clark, Gutmann, & Hanson, 2003; Johnson & Onwuegbuzie, 2004) may result in the most accurate and complete description of the phenomenon under investigation (Johnson & Turner, 2003). This mixing is also known as *triangulation* (Jick, 1979) that compares the results from either two or more different methods of data collection (Mays & Pope, 2000). Thus, triangulation is typically considered to be a strategy for improving the validity of research and may be used to establish trustworthiness (Leydens et al., 2004).

The effectiveness of triangulation depends on the basis that the weaknesses of a single method may be compensated by the counter-balancing strengths to other method (Amaratunga, Baldry, Sarshar, & Newton, 2002). Thus, there is a strong suggestion within the research community that both quantitative and qualitative complement each other and may be blended in research of many kinds (Amaratunga et al., 2002; Fellows & Liu, 1997; Rossman & Wilson, 1991).

Over the years, triangulation has been adopted for evaluating mobile application designs as this not only captures multiple perspectives of the learning experiences of mobile learners but is also useful for validating the collected data (Vavoula & Sharples, 2009). Hence, this research adopts triangulation as a data collection methodology to students' learning achievements with or without using the designed application 'ThinknLearn', as well as the perceptions about the use of the application in an abductive science inquiry activity. For that purpose, a quantitative questionnaire (completely structured and closed-ended), qualitative semi-structured group discussions and mixed tests (mixture of open and closed-type items) are used in this research as illustrated in Figure 3.7.
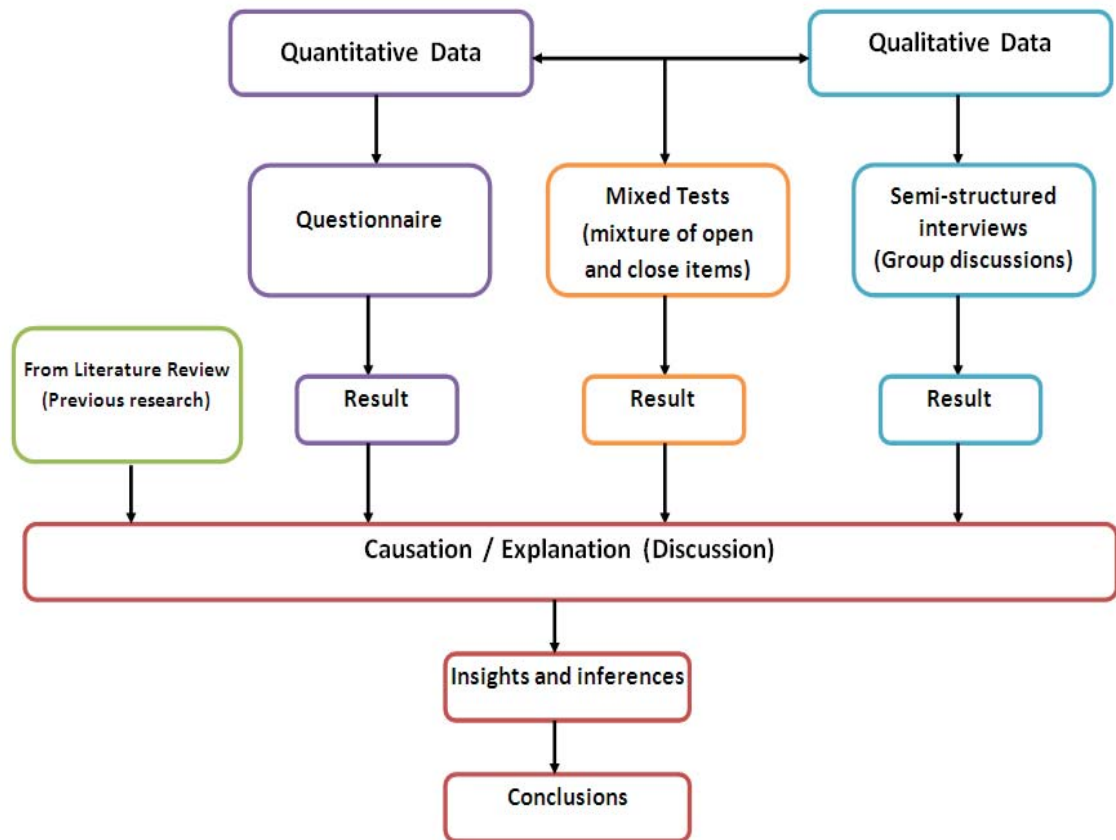
Figure 3.7 Triangulation of data collection methods (adapted from Fellows & Liu, 1997)

3.3.2.1   Questionnaires

The use of questionnaires is one of the major methods of data collection in many research designs due to its following strengths, (i) moderately high measurement validity for well-constructed and well-tested questionnaires (ii) quick turnaround (iii) low dross rates for closed-ended questions (iv) ease of data analysis for closed-ended questions (Johnson & Turner, 2003). In contrast, there are always some factors, which can be used as threats to the questionnaires such as faulty interpretation of results, faulty questionnaire design, sampling and non-response errors, respondent unreliability, ignorance, processing and statistical analysis, and error in coding (Bryman, 2008; Oppenheim, 1992). However, this research minimizes the effect of these threats as possible as it could.

In the previous literature related to mobile learning, this method was used in number of studies in order to evaluate learners' perceptions about the application including usability aspects (Huang, Lin, & Cheng, 2010; Motiwalla, 2007; Thornton & Houser, 2005; Uzunboylu, Cavus, & Ercag, 2009; Wang, Shen, Novak & Pan, 2009). In a similar vein, this method was used in this research for evaluating the utility and usability of the application 'ThinknLearn', as required by *Micro* level of the M3 evaluation framework (Vavoula & Sharples, 2009).

For that purpose, a quantitative questionnaire (see Appendix IV), based on a completely structured and close-ended questions were administered. The 9 questions in the questionnaire attempted to investigate student's opinions on different aspects of the mobile science inquiry 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). These questions also covered usability and mobile quality aspects of the application. All participants filled out the same questionnaire after completing their learning activities. These questions or items provide the possible responses from which the participants must select. A 5-point Likert scale was used to collect all the responses from the participants. However, no questions related to participants' personal characteristics were asked in the questionnaires. For the reliability of the questionnaire before using in the final experiment, scale reliability was tested from the pilot data of this research design.

3.3.2.2   Interviews (Group discussions)

Interviews, is the other method of data collection in which interviewer establishes connection and asks a series of questions to interviewee (Johnson & Turner, 2003). In interviews, interviewer must always remain non-judgemental to the responses given by the interviewee to reduce the potential biasness effect of the interviewer. In

addition to that, if interviewer wants clarity of some questions then he/she may ask interviewee to give information in details. This is one of the advantages of interviews over questionnaires where interviewer probing is not possible (Johnson & Turner, 2003). However, this method is usually more expensive and time-consuming as compare to questionnaires. In addition, the responses obtained during interviews are required to clarify the meaning of the findings due to its qualitative nature (Amaratunga et al., 2002). Apart from these, there are some threats to this method including data are based on personal interactions (Silverman, 2006), incomplete understanding of participant's point of view (Lankshear & Knobel, 2004) and results can be difficult to replicate or generalise relatively due to small sample sizes (Bryman, 2008).

This method was used along with questionnaires for evaluating learners' opinions about mobile learning applications in the literature (Huang et al., 2010; Motiwalla, 2007; Thornton & Houser, 2005; Wang et al., 2009). Similarly, in this research, this method was used for investigating students' learning perceptions about their learning experiences during abductive science inquiry investigations using 'ThinknLearn'. A set of semi-structured group discussion questions were asked within group of students because the given science experiment was conducted by them in groups. Three main questions (see Appendix V) were asked to students regarding the opinions on the effectiveness, ease of use and learning experience of the application while performing their science experiments. An initial draft of the semi-structured interview questions had been circulated between two academic teachers and eight science educators for their critical comments on the content and clarity, before finalizing the group discussion instrument.

3.3.2.3   Tests

Tests are commonly used in quantitative research to measure different traits of research participants such as attitude, personality, self-perception, aptitude, and learning performance (Johnson & Turner, 2003). Pre-test and post-test designs are prevalent in research in which the comparison and/or measurement of the change between control and experimental groups are resulted (Dimitrov & Rumrill, 2003). These pre-test and post-test designs were applied in number of studies for evaluating learners' achievements during mobile learning experiments (Huang et al., 2010; Kong, 2012; Sandberg et al., 2011; Thornton & Houser, 2005).

In this research, pre-test and post-test design was used to evaluate students' learning achievements after performing learning activities. A set of identical pre-test and post-test questions (close-ended) were constructed to measure student's conceptual knowledge of the given topic. The test paper consisted of four multiple choice questions (see Appendices VI-VIII) were given to students. However, an open-ended question (see Appendices VII-VIII) about the hypothesis was asked only in the post-test to identify what students were obtained at the end of this learning activity. So, in this way, both qualitative and quantitative data can provide strengths to validate learning assessments. Additionally, retention tests were also carried out with the same learners to explore how much they retained their domain knowledge after a span of two months. For that purpose, only close-ended questions were posed.

This triangulation of data collection methods not only provide the foundation for evaluating the application 'ThinknLearn' with multiple perspectives of the learning experiences of mobile learners but also validate the collected data from different sources.

3.4 Summary

This section summarizes research methods used for addressing the research challenges drawn from the literature. In this thesis, research methods are applied to the design and the evaluation of an application which may help us in exploring technology-assisted abductive science activities.

For conducting this research, the design DSRM (Peffers et al., 2008) has been adopted as it provides a commonly accepted method for successfully carrying out design science research in information science. This research methodology describes a process model that consists of six activities (Peffers et al., 2008). These activities are iterative in nature until they reach a desired solution. However, there is no compulsion to initiate the research design from any activity that is any research entry point (Peffers et al., 2008).

The discovery of research questions and the number of design iterations needed to address the main research problem were identified by AODM tools (Mwanza-Simwami, 2009). For defining an activity model of the designed application, only the technological layer of the redefined Engestrom' model (Sharples et al., 2005) was adopted because this research focuses on technology-assisted learning. Further, two sub-activity triangles were generated by using the 'Tool' and 'Context' components of the activity model for the proposed application. These led to sub-challenges of the research which further mapped into four design research iterations.

The M3 Evaluation framework (Vavoula et al., 2009) was applied for the evaluation of the application 'ThinknLearn'. This framework is based on three levels: *Micro*, *Meso* and *Macro*. However, Macro level evaluation is not appropriate at this stage of the research because this level requires evaluating the longer term impact of the new technology or application in practice. In Micro level evaluation, the usability and the

mobile quality aspects of the application were investigated while the impact of the application on learners' learning performance and critical thinking skills were evaluated at the Meso level.

This research uses a mixed methods approach (Creswell et al., 2003; Johnson & Onwuegbuzie, 2004) in which data was collected through the combination of qualitative and quantitative methods; a quantitative questionnaire and qualitative semi-structured group discussions. Moreover, pre-post and retention tests were also conducted with the learners to measure their learning outcomes.

Implementation

This chapter explains the implementation of an application using ontology-based scaffolding, which covers four research design iterations implemented for addressing the research challenges discussed in this thesis. The design science research process consists of motivation, objectives, design and development, demonstration, evaluation and communication. All these activities are discussed in each of these iterations.

The motivation activity indicates the purpose behind the design of a particular iteration while the conceptual model is also defined in this activity to illustrate the main objectives. The functional along with the technical architectures are defined in the design and development activity. Domain ontologies are also described in this activity. Apart from these components, this activity also defines how scaffolding design framework guidelines have been used to design the application 'ThinknLearn' in the last three iterations. However, the demonstration activity explains the objectives in the form of artefacts while the evaluation activity describes how artefacts of these iterations are evaluated. At the end, how each of these research iterations is communicated with the target audience is discussed in the communication activity.

4.1 Research Design Iterations

In this research, an innovative application is created by using the DSRM process model (Peffers et al., 2008) in four research design iterations as depicted in Figure 4.1.

107
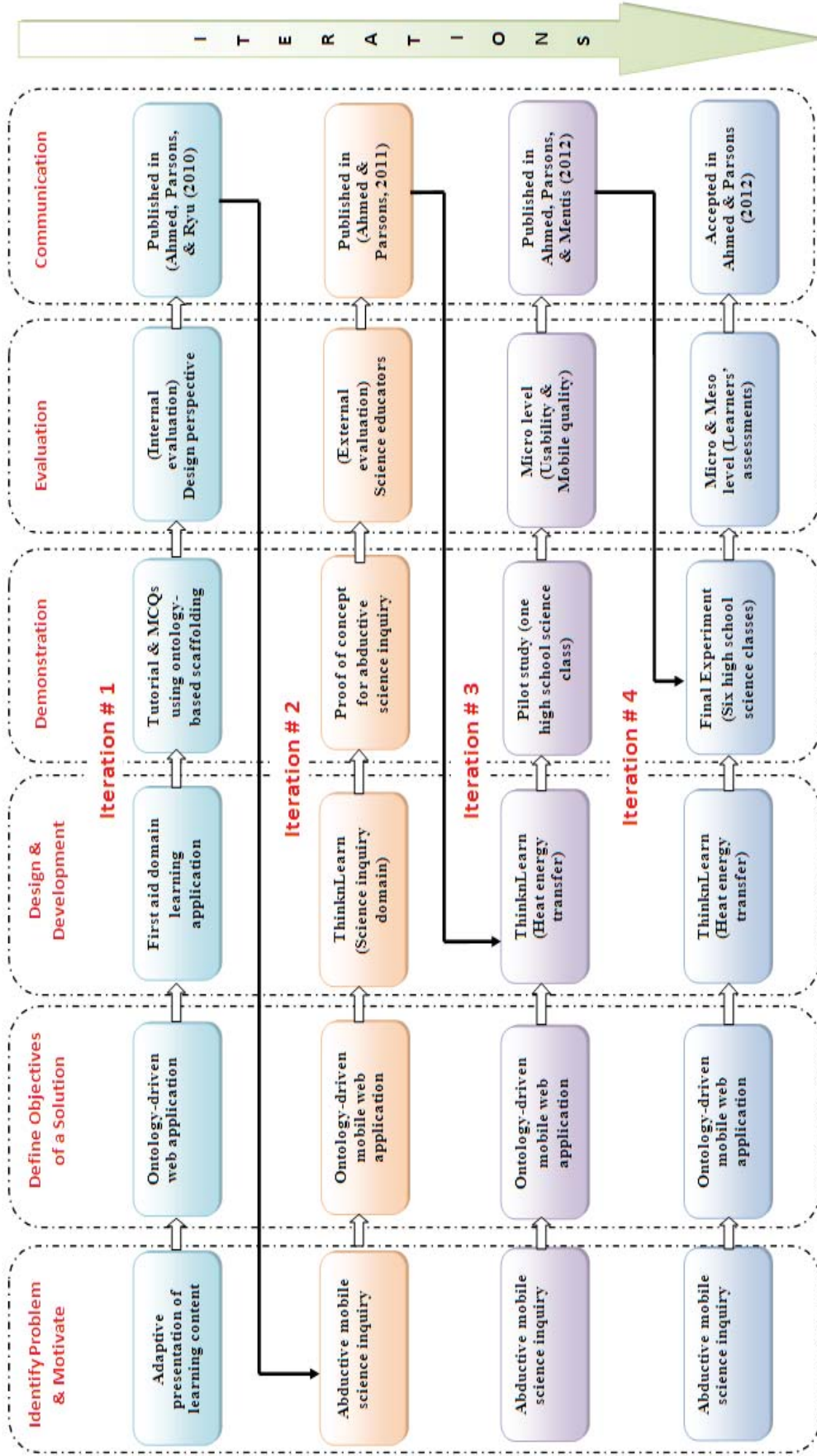
Figure 4.1 Research design iterations (Peffers et al., 2008)

The first iteration revolves around the use of ontology-based scaffolding for presenting learning content while an abductive form of investigation in mobile science inquiry is explored in the last three iterations. However, the basic motivation for considering all these iterations remains intact with the research challenges defined in this thesis. In the following sections, the research design iterations are discussed in detail.

4.1.1 Iteration # 1: Adaptive Presentation of Learning Content

This iteration was designed to investigate the use of ontology-based scaffolding for providing adaptive presentation of learning content. For that purpose, it follows a problem-centred approach (Peffers et al., 2008) which proceeds in a sequence of six activities as described in the following sections.

4.1.1.1 Activity 1: Problem identification and motivation

The motivation behind this iteration was to explore how a domain ontology representation can be presented as a tutorial (plain text) and as multiple choice questions (MCQs) in a learning application. Previously, there are a number of studies in the literature, which discuss either one of these aspects; representation of domain ontologies and MCQs (Ghidini et al., 2007; Holohan et al., 2005; Jovanovic et al., 2009; Vas, 2007; Vas et al., 2009). However, none of them targeted both forms of representation in an application. Thus, there is a need to explore the use of ontology-based scaffolding for presenting learning content into both ways in a learning context.

For presenting such learning content, the commonly understood and practical domain of first aid was considered as an experimental domain for this iteration. This domain was chosen because the importance of the first aid domain knowledge was highlighted in many previous studies (Engeland, Roysamb, Smedslund, & Soggard, 2002; Kelly & Tangney, 2005; Lonsdale et al., 2004; Lubrano et al., 2005); the first aiders, can get advice just-in-time from such scaffolded learning application according to the severity

of the injuries and contexts, for example, in the field (Lonsdale et al., 2004), which can recognize conditions from signs and symptoms and also get the opportunity to apply diagnostic skills to real life scenarios (Kelly & Tangney, 2005). Hence, this was the motivation to explore adaptive presentation of learning content using ontology-based scaffolding in this commonly used domain of the literature.

4.1.1.2 Activity 2: Objective of the solution

The objective was to develop an ontology-driven first aid web application for the adaptive presentation of learning content that enables learners to test their knowledge and learn from the tutorial. This application has provided a web environment that allows learners to view tutorials and MCQs covering different aspects of first aid domain knowledge, generated by using domain ontology. Nevertheless, the only purpose of this solution was to identify how ontology-driven application can be implemented in a learning domain.

4.1.1.3 Activity 3: Design and development

The design of the artifact supports the development of an ontology-driven web application. The conceptual model of this application discussed here illustrates the objectives of this iteration. In addition, functional and technical architectures along with domain ontology are covered in this section.

4.1.1.3.1 Conceptual model

The conceptual model of this iteration defines an abstract viewpoint of the research objectives required that deals with the development of an ontology-driven application for presenting learning content in multiple ways as depicted in Figure 4.2.

This application deals with the content level adaptation (adaptive presentation) (Brusilovsky, 2001) that represents learning content in two different ways: tutorial and

MCQs. Generation of MCQs is regarded as an assessment method for measuring learners' knowledge while the knowledge represented in the form of tutorials can assist learners to learn about a specific domain.
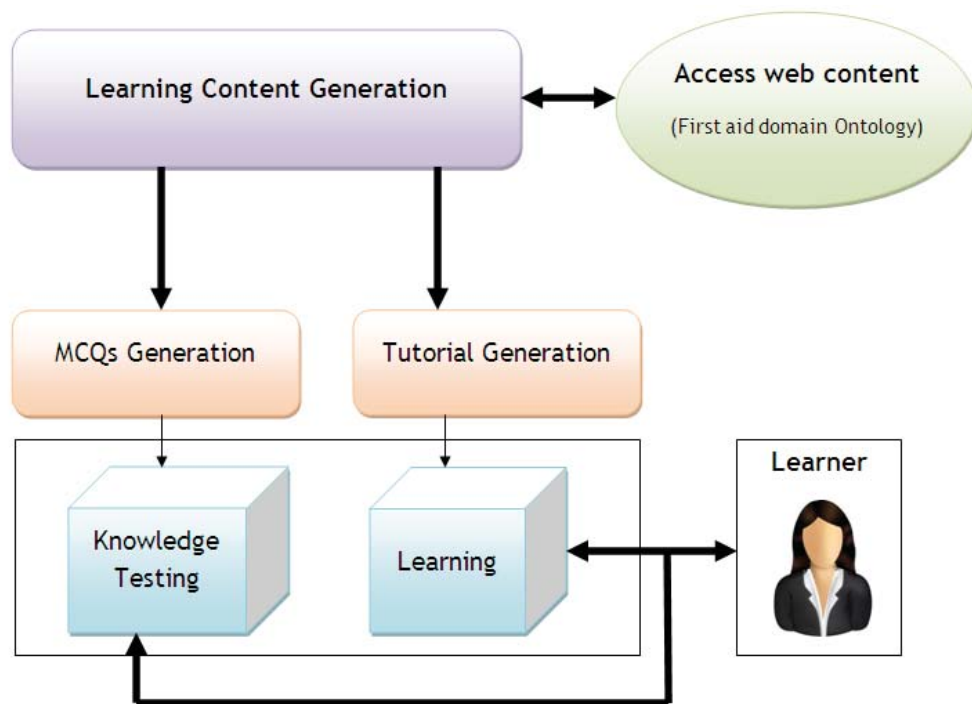
Figure 4.2 Conceptual model of iteration 1

4.1.1.3.2 First aid domain ontology

The first aid domain ontology used here, covers a small sample of only two important aspects of first aid knowledge domain: *bleeding* and *burning* as depicted in Figure 4.3. This ontology and also other ontologies discussed in this thesis are defined using Protégé 4.0[5], an open source ontology editor and knowledge base framework.

---

[5] http://protege.stanford.edu/
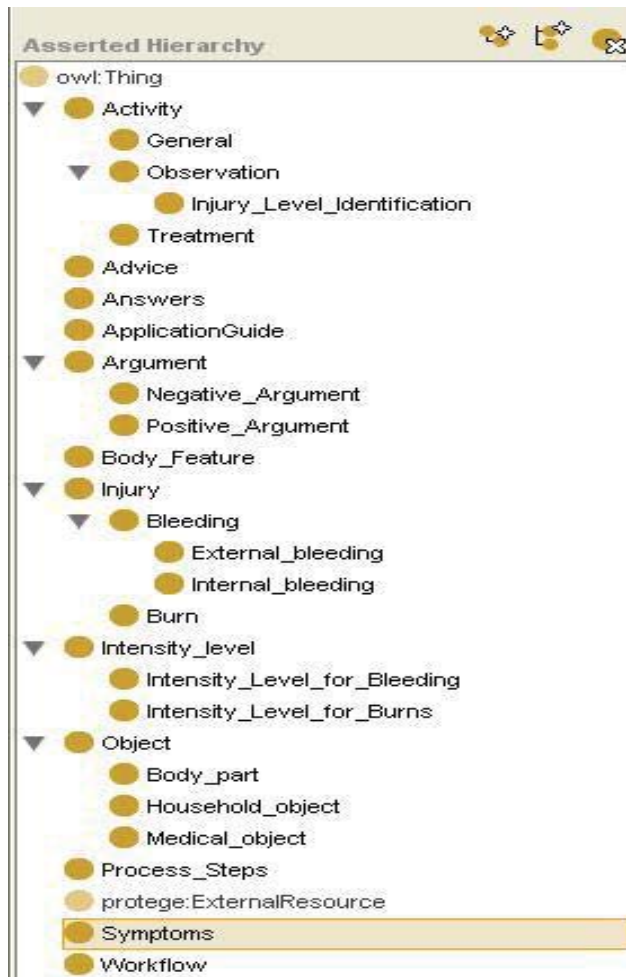
Figure 4.3 First aid domain ontology

The structure of this domain ontology is based on several important classes or concepts including 'Injury', 'Symptoms', 'Activity', 'Object' and 'Advice'. For instance, the 'Activity' concept defines the explanation about what type of activity is required by a first aider in an emergency situation. This 'Activity' concept is divided into sub activities 'General', 'Observation' and 'Treatment'. In the 'Observation' activity, a first aider needs to identify the type of injury. After observational activity, either the 'General' or 'Treatment' activity will trigger. In the case of the former, the first aider calls for help while in the latter, the first aider provides immediate treatment before

112

the other professional assistance arrives. Similarly, the other concepts and sub-concepts are mentioned in this domain ontology for providing learning content.

4.1.1.3.3 Functional architecture

The functional architecture (see Figure 4.4) describes the functions supported in this application. The functions are divided into two categories: core system functions and reporting functions (Draganidis et al., 2008). Core system functions include the ontology management function that is responsible for loading and reading data from the domain ontology. Further, it is also used to retrieve specific individuals of the classes (concepts) and sub classes (sub concepts) defined in the ontology. There are other sub-functions that extract data and object properties of the particular individuals using defined concepts and sub concepts of the ontology. The content management function is the other core system function that is defined for generating learning content such as questions and answers (MCQs) and tutorials. First, the knowledge represented in the ontology is converted into the form of tutorials about the underlying domain (first aid). Then for MCQs generation, related and unrelated concepts from the same ontology are used to construct challenging answers covering closely related false answers (distracters).

Reporting functions provide a number of view functions, such as 'View MCQs' and 'View Tutorial'. The former produces a series of MCQs regarding the topic covered in the domain while the latter presents a specific topic of the domain by using data and object properties defined in the ontology.
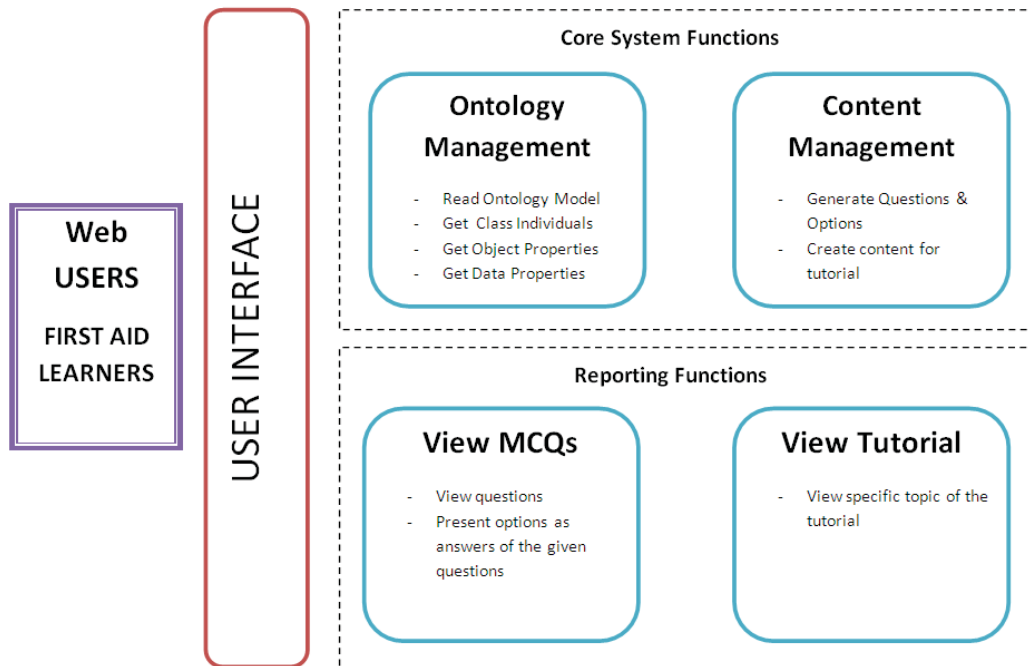
Figure 4.4 Functional architecture of iteration 1

4.1.1.3.4 Technical architecture

In this section, an overview of the technical architecture of the application is described which is influenced by the approach used in (Draganidis et al., 2008), as shown in Figure 4.5. This technical architecture has a few differences from the architecture used in (Draganidis et al., 2008); inclusion of OWL (Web Ontology Language) and the Pellet[6] instead of using RDF (Resource Description Framework) and RDQL[7] respectively.

The reasons are: OWL is an extended version of RDF which has more facilities for expressing meaning and semantics than XML, RDF and RDF-S and also has an ability to represent machine interpretable content on the web (McGuinness & Van Harmelen, 2004). Apart from this, OWL has a World Wide Web Consortium Recommendation for building ontologies. On the other hand, Pellet is a reasoner, a core component of

---

ontology-based data management applications and has also become a popular and practical tool for working with ontologies defined in OWL-DL (the Description Logics) (Sirin et al., 2007) while RDQL is only a query language used for extracting information from RDF graphs. However, Pellet includes a query engine that can efficiently answer queries expressed either in SPARQL[8] or RDQL that leads to the inferred knowledge extracted from the ontology (Sirin et al., 2007). So the use of this Pellet reasoner can provide the freedom to either use SPARQL or RDQL for extracting information from the ontology.
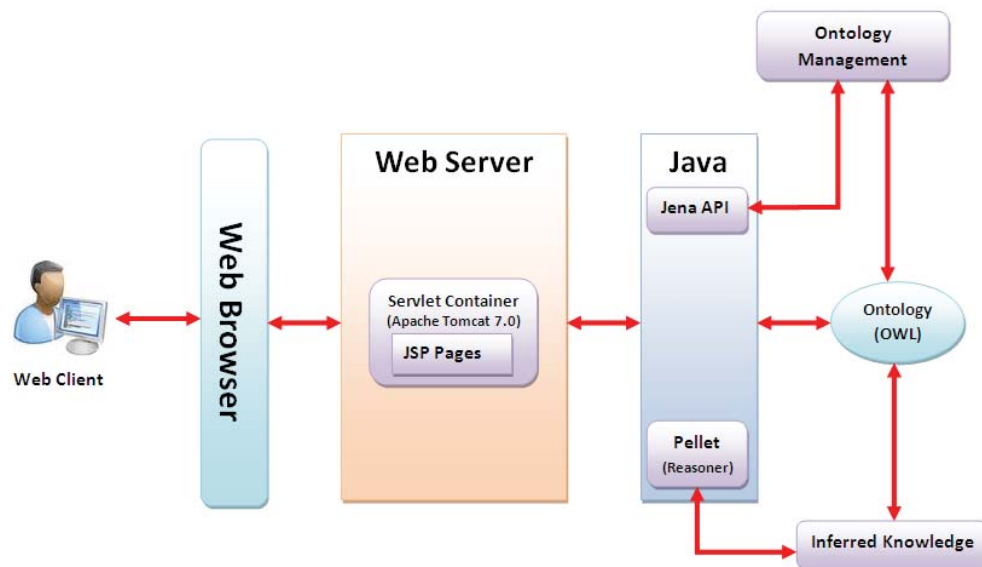
Figure 4.5 Technical architecture of iteration 1 (adapted from Draganidis et al., 2008)

In this architecture, the back-end is implemented in Java and access to the ontology is provided through the Jena API[9], a Java framework for building ontology-driven applications. The Jena API provides a programmatic environment for RDF, RDF-S (Schema) and OWL. Further, Pellet is used to infer relevant knowledge from the ontology defined in OWL.

---

[8] http://www.w3.org/TR/rdf-sparql-query/
[9] http://jena.sourceforge.net

In this web application, clients can interact with the server (Apache Tomcat Server 7.0) using an HTTP request to a Java Servlet as shown in Figure 4.5. Java Server Pages (JSPs) are used in this application so that learners can access reporting functions such as 'View Tutorial' and 'View MCQs'. These JSPs are returned to the browser being used by the web clients.
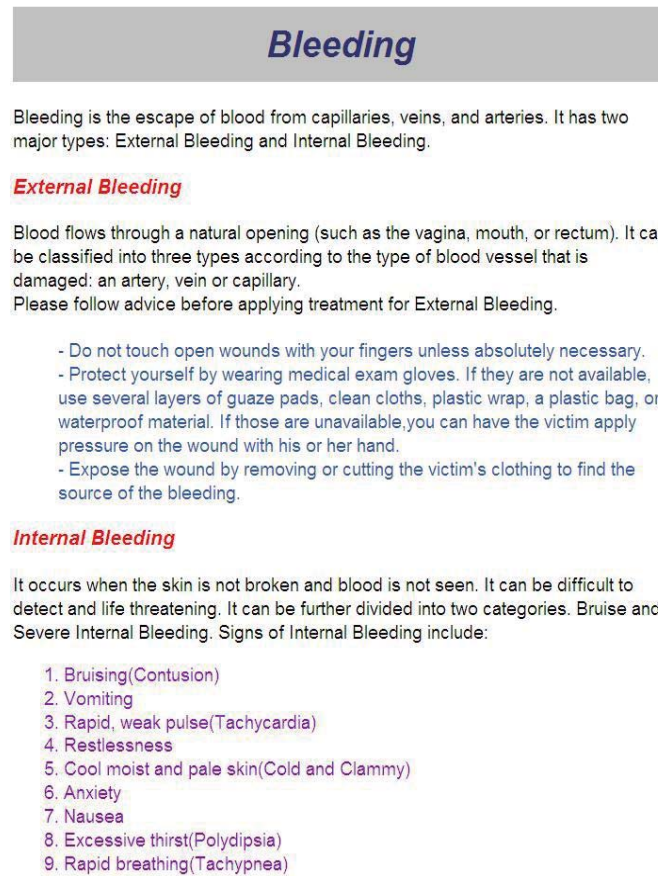
Using this adapted technical architecture (see Figure 4.5), a first aid web learning application was developed in this iteration to represent learning content in two different ways: tutorial (plain text) and MCQs. The former representation is used to describe the knowledge of the first aid domain to learners while the latter representation can provide an opportunity to evaluate learning performance. The information for these representations can be extracted through the use of data and object type properties defined in the ontology.

4.1.1.4   Activity 4: Demonstration

For the demonstration purposes, an excerpt from a tutorial is displayed in Figure 4.6 which covers the main topic of 'Bleeding'. It represents sub-types of bleeding including 'External Bleeding' and 'Internal Bleeding'. In addition, signs (symptoms) for internal bleeding and advice for external bleeding are mentioned. In an ontology, data type properties are related to data type values (numerical or string) whereas object data properties are used to define relationships between concepts or individuals (instances) and data type properties (Antoniou & Van Harmelen, 2009).

In this particular example, the following data type properties are defined; 'Default_Label', 'Definition' and 'rdfs:label', all of them are defined as type 'String' in this ontology. The 'Definition' data type property is used to describe a concept or sub-concepts discussed in this ontology. In a similar way, 'Default_Label' defines labels for a particular concept while 'rdfs:label' is used to store the alternative name of any

particular concept. For example, 'Bruising' is extracted from the ontology as 'Default_Label' of one of the signs for internal bleeding and 'Contusion' is the alternative name defined for 'Bruising' using the 'rdfs:label' data type property. In a similar way, object properties are used to explain relationships between concepts defined in the ontology. For instance, the 'has_advice' object type property is defined that explains relationships between 'Injury' and 'Advice' concepts by presenting advice for external bleeding in this specific example as shown in Figure 4.6. The Jena API and Pellet reasoner are used together to extract specific information for representing learning content. Thus, the whole tutorial is generated using data and object type properties of the resources (instances or concepts) defined in the ontology.

Bleeding

Bleeding is the escape of blood from capillaries, veins, and arteries. It has two major types: External Bleeding and Internal Bleeding.

External Bleeding

Blood flows through a natural opening (such as the vagina, mouth, or rectum). It can be classified into three types according to the type of blood vessel that is damaged: an artery, vein or capillary.
Please follow advice before applying treatment for External Bleeding.

- Do not touch open wounds with your fingers unless absolutely necessary.
- Protect yourself by wearing medical exam gloves. If they are not available, use several layers of guaze pads, clean cloths, plastic wrap, a plastic bag, or waterproof material. If those are unavailable,you can have the victim apply pressure on the wound with his or her hand.
- Expose the wound by removing or cutting the victim's clothing to find the source of the bleeding.

Internal Bleeding

It occurs when the skin is not broken and blood is not seen. It can be difficult to detect and life threatening. It can be further divided into two categories. Bruise and Severe Internal Bleeding. Signs of Internal Bleeding include:

1. Bruising(Contusion)
2. Vomiting
3. Rapid, weak pulse(Tachycardia)
4. Restlessness
5. Cool moist and pale skin(Cold and Clammy)
6. Anxiety
7. Nausea
8. Excessive thirst(Polydipsia)
9. Rapid breathing(Tachypnea)

Figure 4.6 An excerpt from a tutorial

117

The same information that is encapsulated in the first aid ontology is also used to construct MCQs. For developing questions and answers, data and object type properties again come into action. Further, property-based strategies (Papasalouros et al., 2011) are used to generate correct answers and distracters. However, in this particular example, only *label questions* are defined. These *label questions* are asked about the alternative names defined for a particular injury, symptoms or treatments. These questions are generated to ask first aid learners in order to test their domain knowledge. A few *label questions* (see Figure 4.7) are used here to demonstrate how the same domain knowledge can be reused in MCQs.

Figure 4.7 MCQs related to alternative names of injuries and symptoms

118

In this particular example, only those questions are generated, which ask about the alternative names of either injury or symptoms. A random function is used in the application that retrieves a particular injury or symptom from a pool of these resources defined in the ontology to generate a question about it. In contrast, the challenging task is to provide distracters (closely-related answers) as options in those MCQs. For that purpose, alternative names of the same kind are grouped together as answers (options) for a specific question. The ontology uses its defined inter-related relationships and infers relevant resources that belong to that resource asked in the given question.

The concepts 'Burn' and 'Intensity_Level' are defined through the object type property 'could_be_result_of' in this ontology. In this particular learning domain, four degrees of burns, namely first, second, third and fourth degrees are described. All these degrees have alternative names. For instance, 'Third Degree Burn' is also known as 'Full Thickness Injury'. In MCQs, the correct alternative name is included in the given options with three other alternative names (distracters). For example, 'Third Degree Burn' has three wrong answers ('Superficial Burn', 'Partial Thickness Burn' and 'Full Thickness Burn'). The application selects these incorrect answers by using a random function for each given question from a pool of similar types. In this way, dynamic MCQs are generated that may challenge learners in answering questions. As a consequence, this iteration explores the use of ontology-based scaffolding for presenting learning content into multiple ways.

4.1.1.5 Activity 5: Evaluation

This application was internally evaluated by a group of researchers from a design perspective so the application did not ask for any user input but instead displays learning content in the form of MCQs and a tutorial. The following positives were achieved from this evaluation:

One of the positives was a successful demonstration of the presentation of learning content in multiple ways. The other positives including the use of ontology-based scaffolding in an application, use of property-based strategies (Papasalouros et al., 2011) for generating correct answers and distracters in MCQs, and the implementation of the adapted technical architecture from this (Draganidis et al., 2008) in an ontology-driven application.

Conversely, some negative issues were identified from this evaluation; first, the domain (first aid) was not appropriate for a practical demonstration in school contexts, because this domain has some limitations to design such learning environments where learners can interact with the observational data and obtain content according to their learning contexts. Hence, it was required to recognize a new exciting and interesting domain for this purpose. Second, this is a web application without any adaptivity features by which learners can able to access dynamic content using different range of mobile devices. Last but not least, this domain has lacked a suitable pedagogical approach in which learners may use their critical thinking skills to understand and use knowledge in analysing problems in some meaningful ways.

4.1.1.6 Activity 6: Communication

After designing and evaluating this iteration, this work was communicated to the research community by publication in (Ahmed, Parsons & Ryu, 2010).

4.1.2 Iteration # 2: Mobile Science Inquiry-based Learning

From the evaluation of the previous iteration, a few issues were pointed out. This iteration was designed to resolve these issues. Opting for a suitable pedagogical approach, science inquiry-based learning was chosen. This is one of the most challenging and exciting ventures of today's' schools because of these following reasons; this domain of learning can foster motivation and interest in science, can also

be helpful to learners to perform inquiry steps like scientists, can help learners to understand scientific processes (Bell et al., 2010). Previous literature related to education shows that learners can engage in IBL environments to generate better scientific explanations about working domains, understand learning content more easily and effectively (Kolodner et al., 2003; Metz,2004). In addition, learners can become active rather than passive recipients of domain knowledge.

In science education, there are many environmental science learning projects found in the literature; LET'S GO! (Spikol et al., 2009), Ambient Wood Project (Rogers et al., 2005), and BioKIDS Sequence (Parr et al., 2004), in which learners are required to observe the natural phenomena. Hence, for selecting a domain for science inquiry, an environmental topic related to plant and soil was taken as an example scenario for this iteration to demonstrate this application to science educators. For the web adaptivity issue, the Wireless Universal Resource File (WURFL)[10] and the Wireless Abstraction library (WALL) are introduced in the technical architecture. Thus, this iteration was extended the use of ontology-based scaffolding in mobile science IBL environments. For this reason, the nature of the research problem was modified and due to this, it also followed a problem-centred approach (Peffers et al., 2008) which proceeds in a sequential order from activity 1 through activity 6 as described in the following sections.

4.1.2.1   Activity 1: Problem identification and motivation

The motivation behind this research iteration was to demonstrate to science educators the use of ontology-based scaffolding in a science inquiry domain, specifically to abductive science inquiry (Oh, 2010, 2011). The main reasons for considering this abductive form of science inquiry investigation were:

---

[10] http://wurfl.sourceforge.net/

In school sciences, learners usually follow a hypothetico-deductive model (Grandy & Duschl, 2007) in which they are required to process ideas (hypotheses). This type of model follows a step-wise scientific method based on formulating hypotheses and validating them with experimental results. A less common approach is abductive science inquiry, which emphasizes the development of scientific hypotheses that are observed from the natural environment (Oh, 2010). In the previous literature related to education, this kind of inquiry has not been widely considered (Grandy & Duschl, 2007; Oh, 2010). On the other hand, support for designing inquiry learning activities by using ontology-based scaffolding has been explored in some recent studies, such as the Concept map Learning System (CLS) (Chu et al., 2011) and the Science Created by You (SCY) project (De Jong et al., 2010). However none of these projects have been targeted for mobile learning environments. Thus, this was the motivation to explore some new approaches to technology-assisted learning in the sciences.

4.1.2.2 Activity 2: Objective of the solution

The objective of this iteration was extended from the use of ontology-based scaffolding in a web application to an ontology-driven mobile web application for abductive science inquiry domain. The rationale for developing a mobile web application was to provide learning content to learners in situ where they are involved in their learning activities. Hence, the purpose for designing such application was to exhibit to science educators the way that an abductive mobile application can be used in a science inquiry domain.

4.1.2.3 Activity 3: Design and development

For the application design and development purposes, the conceptual model is discussed in this section that shows how this application was designed for addressing the research problem identified after evaluating the first iteration. A science content

122

domain ontology is described along with the functional and technical architecture which are used for designing the application. In addition, a scaffolding design framework (Quintana et al., 2004) is also discussed here, that defines how ontology-based scaffolding can be provided in such science inquiry investigations.

4.1.2.3.1 Conceptual model

The conceptual model of this iteration defines an abstract viewpoint of the research objectives required that deals with the development of an ontology-driven mobile web application for abductive science inquiry investigations as depicted in Figure 4.8.

In this conceptual model, the four main components are defined including *Knowledge Testing*, *Learning*, *Prediction & Selection*, and *Observation & Measurement*. The *Knowledge Testing* component is used for assessing learners' knowledge by asking MCQs about a given topic. These MCQs are generated through the underlying domain ontology. The *Learning* component is designed for giving suggestions that help learners to comprehend the discussed topic. These two components are taken from the previous iteration with slight differences. Here, the *Learning* component provides suggestions according to the nature of the problem (science inquiry) instead of presenting tutorials about the underlying domain. *Prediction & Selection* is a new component which guides learners for hypothesis generation and selection after learning about the topic. In the *Observation & Measurement* component, mobile learners can interact with an environment to observe and measure natural phenomena. These main components are connected with a domain ontology through learning content generation components including MCQs, Suggestions and Hypothesis generation as depicted in Figure 4.8.
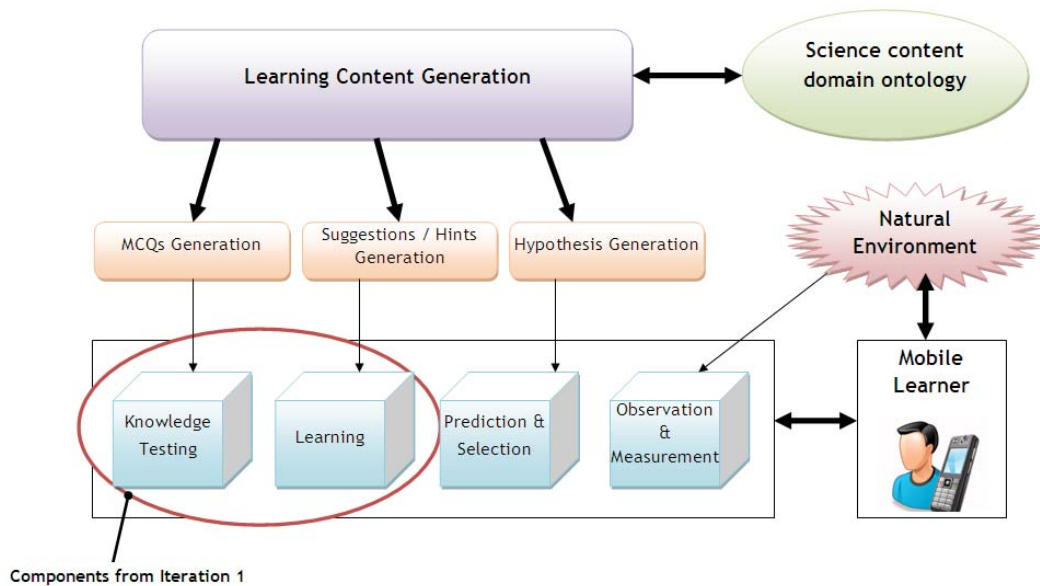
Figure 4.8 Conceptual model of iteration 2

4.1.2.3.2 A Science content domain ontology

This research iteration requires a science content domain for implementing an ontology-driven mobile web application. For that purpose, a domain ontology is discussed that covers some basic science related concepts (see Figure 4.9). As an example domain, this ontology covers an example scenario that deals with the relationships between soil pH, soil type, plant type and some other inter-related concepts. These concepts are directly linked with the two main aspects of a science domain: 'Soil' and 'Plant'. The reasons for choosing this particular domain were: in the current literature related to science education; there are number of studies using in a similar context to some extent (Giemza, Kuntke, & Hoppe, 2010; Huang et al., 2010; Looi et al., 2011; Vogel et al., 2010). Secondly, this is a very common and relevant domain that can be exhibited to science educators as a proof of concept.

124
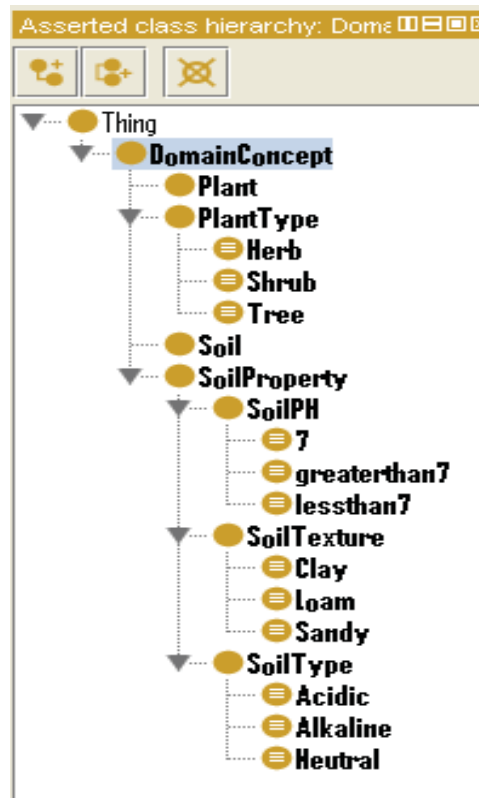
Figure 4.9 A science content domain ontology

In this particular reference scenario, learners need to formulate scientific hypotheses from the collected data. During the collection process, measures of soil pH and soil texture are required while the type of the plant that grows in that soil needs to be observed. There are three main soil texture types including *Sandy*, *Clay*, and *Silt (Loam)* described in this ontology while the value of soil pH can be measured into three categories: *7*, *greaterthan7* and *lessthan7* as shown in Figure 4.9. In this ontology, soil type is also defined as a concept which includes three sub-concepts: *Acidic*, *Alkaline* and *Neutral*. Moreover, only three plant types are considered in this example: *Herb*, *Shrub* and *Tree*. These concepts and sub-concepts are inter-connected in such a way to produce some meaningful information. The given information assists learners to comprehend the underlying domain and then enable them to construct scientific hypotheses about that given domain.

4.1.2.3.3 Using scaffolding design framework

This research iteration deals with the science inquiry domain and therefore a scaffolding design framework defined in (Quintana et al., 2004) was applied that can help us in designing such science IBL applications. This design framework is based on the following seven guidelines, adopted for this research.

- ◆ Guideline 1: Use representations and language that bridge learner's understandings.

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

- ◆ Guideline 2: Organize tools and artefacts around the semantics of the discipline.

  The application uses the same terminologies of the domain concepts as defined in the topic of interest.

- ◆ Guideline 3: Provide user 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.

- ◆ Guideline 4: Provide structure for complex tasks and functionality.

  A domain 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.

126

◆ Guideline 5: 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 inquiry investigations.

◆ Guideline 6: Automatically handle non-salient routine tasks.

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

◆ Guideline 7: Facilitate ongoing articulation and reflection during the investigation.

In this abductive science inquiry 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 critical thinking skills.

4.1.2.3.4 Functional architecture

The functional architecture (see Figure 4.10) illustrates the core system functions and the reporting functions used in this iteration. There are three core system functions: ontology management, input management and content management. The input management function records the inputs from the users which include the observational data, hypothesis selection and answers to the questions related to the observational data.
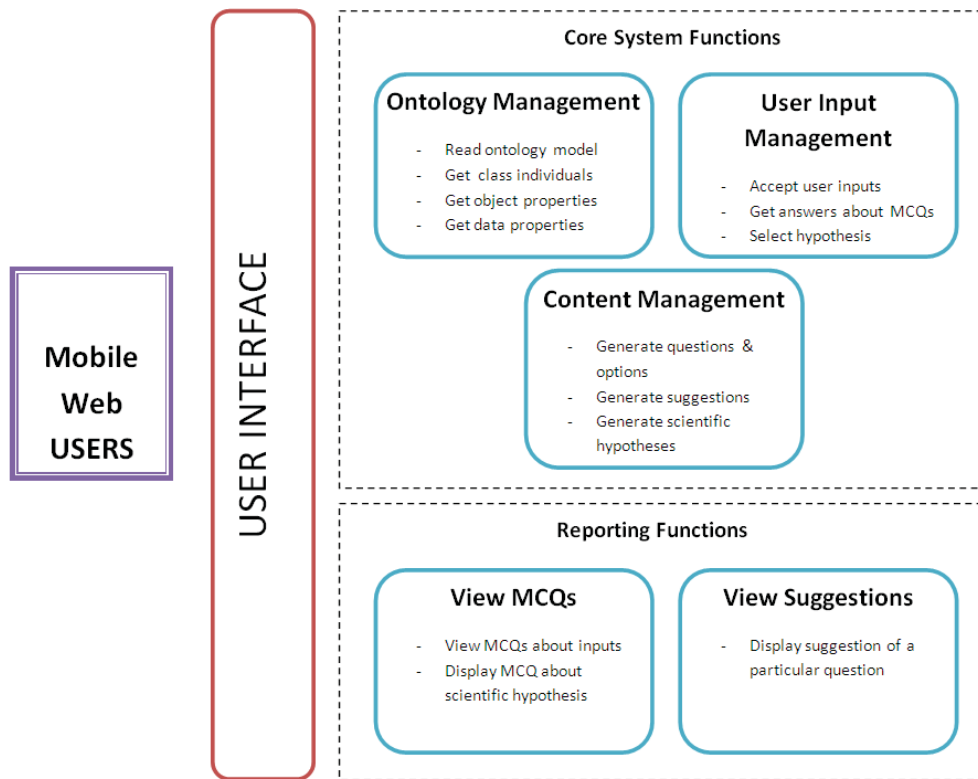
Figure 4.10 Functional architecture of iteration 2

The other functions; ontology management and content management have the same functionalities described in the first iteration. In contrast, in content management, these two sub-functions namely 'Generate suggestions' and 'Generate scientific hypotheses' were not in the preceding iteration. The function 'View MCQs' displays MCQs about the inputs and the scientific hypotheses of a particular domain. 'View Suggestions' is used to give suggestions relevant to the questions about the observational data. Further, this architecture supports science inquiry learning activities in physical environments where learners can experience the affordances of mobile technologies in situ. Thus, this iteration focuses on the use of mobile devices for accessing learning contents as compared to the preceding iteration.

4.1.2.3.5 Technical architecture

The technical architecture outlined in Figure 4.11 is a modified version of the previous architecture described earlier (see Figure 4.5). The basic differences between these two architectures are as follows:
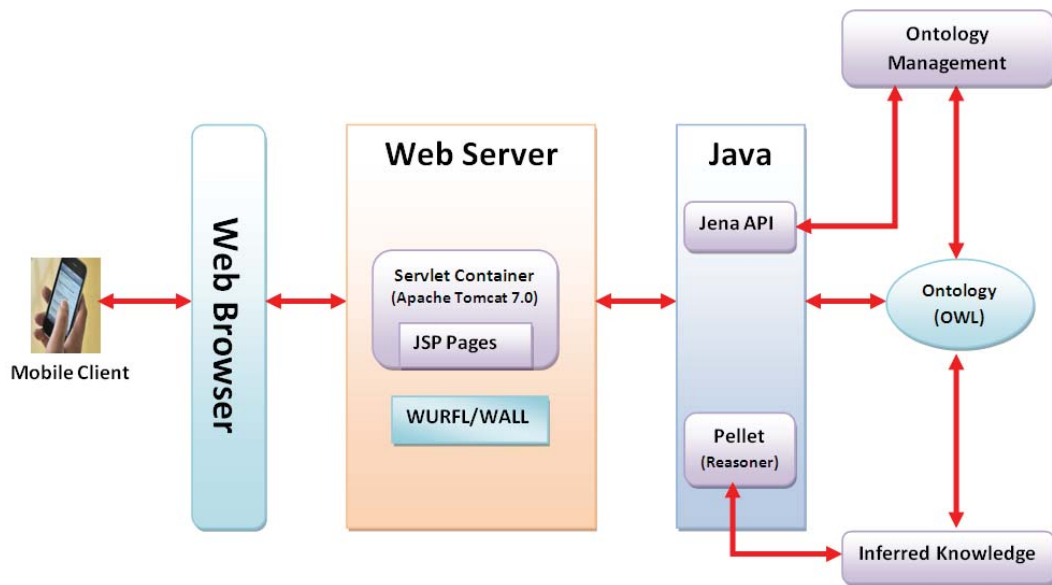
Figure 4.11 A modified version of the previous technical architecture

The previous architecture was defined for web users and was not specifically designed to fulfil the requirements for presenting learning content on different mobile devices, if required. Hence, this modified version is designed to cope with different types of mobile devices having differences in physical form factors such as screen size, resolution, colours supported, layouts, and types of mobile browsers (Parsons, 2008). In order to support all types of mobile browsers that can generate dynamic content in a range of different mark-up languages, the Wireless Universal Resource File (WURFL) and the Wireless Abstraction Library (WALL) are included in this architecture. The WURFL is a large (and continually updated) XML (eXtensible Mark-up language) database of device capabilities while the WALL provides a set of tag libraries which

enable application designers to write server pages for generating different mark-up for different devices (Parsons, 2008).

Using this technical architecture, an application 'ThinknLearn' has been developed to support mobile science inquiry-based learning activities, particularly the generation of scientific hypotheses from the observational data.

4.1.2.4   Activity 4: Demonstration

For demonstration purposes, an example scenario is outlined in which learners need to construct scientific hypotheses from the observational 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 (Soil and Plant) found in this example, as depicted in Figure 4.9.

In this application, mobile 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 type are three key measures to be identified in this application. The designed application 'ThinknLearn' asks for these elements; the soil pH value, the percentages found in the soil texture, and the observed plant type that grows in that soil sample location. The values of soil pH of the samples are taken from 1 to 14 while three main soil texture types: *sand*, *silt (loam)*, and *clay* are measured in percentages as shown in Figure 4.12. In addition, learners have to select one of these plant types; *herb*, *shrub* and *tree*.

Figure 4.12 Measurements and observation screen of 'ThinknLearn'

After submitting the values of these measures, 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. These question-suggestion modules (see Figure 4.13) of the application guide 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.
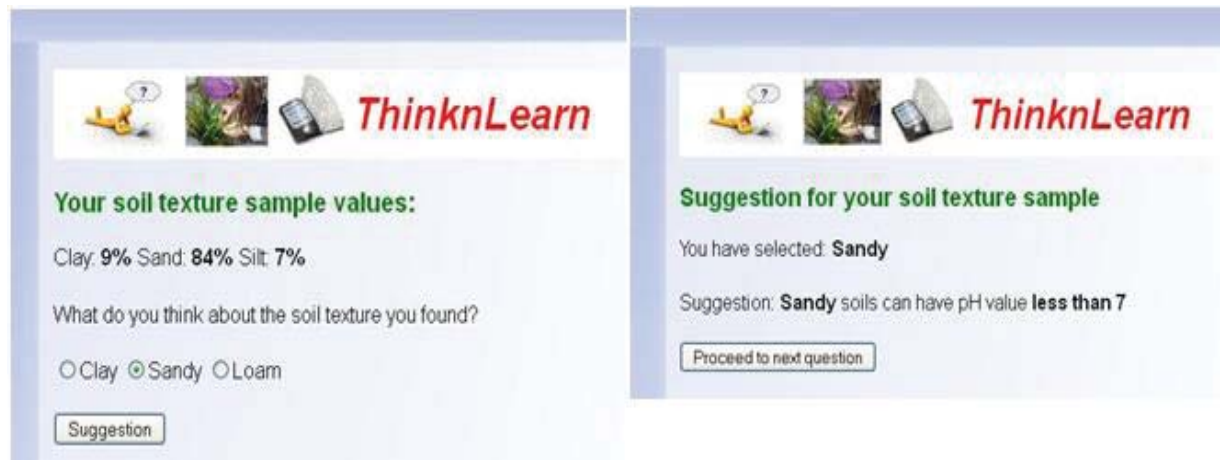
Figure 4.13 Question-Suggestion modules

Afterwards, the application presents a summary of the activities conducted by the learners during this science inquiry learning process as depicted in Figure 4.14. Inputs are placed at the top of the page with all the suggestions given by the ontology. 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 given domain. Observational data 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 inbuilt relationships. From that, the application selects one correct and three incorrect answers (distracters) 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. Additionally, learners can further validate their chosen hypotheses in the real environment which can assist them to draw some explanations about a specific domain.

132
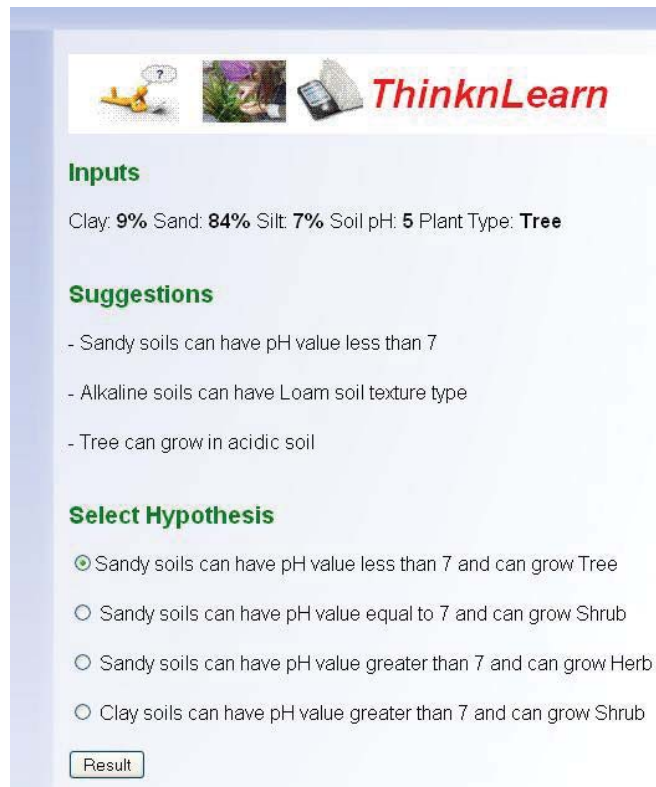
Figure 4.14 Summary and hypothesis selection

4.1.2.5 Activity 5: Evaluation

This application was designed as a proof of concept to science educators regarding ontology-driven mobile web applications for abductive science inquiries. Therefore, in this activity, a group of science educators from diverse science backgrounds (Chemistry, Physics, and Biology) of a local high school was involved in a meeting, held in August, 2011. The following positives were achieved through this iteration: a successful demonstration of hypothesis generation process in the context of abductive form of inquiry investigation, science educators were excited to use this innovative application 'ThinknLearn' in their classes, and the use of WURFL and WALL in the technical architecture which adapts learning content according to different mobile web browsers.

133

On the other hand, a few concerns were raised in the meeting: First, there was no point to use this environmental science example in the application straightaway because it did not cover a school curriculum-based topic. Therefore, it was required to identify a relevant domain for the implementation of such an application in the classroom context. Second, according to the educators, their students were traditionally involved in hypothesis generation activity before collecting the observational data (deductive form of inquiry investigation). Hence, they were not used to following this abductive form of investigation in their science learning activities. Last but not least; the application should be ready before the schedule of their students' practical classes. Thus, they might perform their science experiments for the first time while using such application in their science laboratories.

4.1.2.6 Activity 6: Communication

This proof of concept of the innovative idea was shared amongst the research community by publishing this work in (Ahmed & Parsons, 2011).

4.1.3 Iteration # 3: Abductive Mobile Science Inquiry

This iteration was designed and evaluated to address the concerns raised by science educators in the preceding iteration. During that meeting, science educators agreed with a few science inquiry topics from the New Zealand NCEA Level 1 science curriculum including practical investigation in the biological context (species of any kind), exploration of chemical processes in the context of the environment, and demonstration of knowledge about heat energy transfer. There was a limitation that science educators were only discussing those topics related to NCEA level 1 as they were decided on the involvement of only that level of science students for these kinds of investigations. However, demonstration of knowledge about heat energy transfer was chosen as an experimental context because science educators were interested to

opt for that topic, which can be implemented in the classroom contexts. In addition to that, this topic was considerably easy to demonstrate in a specific time period.

The other concern was related to the implementation of this application within a short span of time. For that reason, it was decided to evaluate this application with a smaller sample size, regarded as the pilot study; before the final design will be implemented and evaluated with large number of students. The motivation and objective for this pilot study remained the same as described in the preceding iteration. Hence, this iteration considered a design and development centred initiation approach (Peffers et al., 2008), which proceeds in a sequential order from activity 3 through activity 6 as described in the following sections.

4.1.3.1   Activity 3: Design and development

This iteration starts with the activity 3 of the DSRM process model (Peffers et al., 2008), that is design and development of the application. Therefore, the conceptual model is discussed in this activity which illustrates an abstract viewpoint about how high school science students can interact with 'ThinknLearn' to generate scientific hypotheses. For implementing an application in a classroom-based learning environment, a heat energy transfer ontology was considered as an example, discussed here in this section. In addition, an abduction example from this application is also discussed here to show how this example can be mapped to the original abduction example from the collected papers of C.S. Peirce (1931-1958) cited in (Raholm, 2010), as mentioned in the Chapter 2 of this thesis. The same functional and technical architectures are used for designing the application as defined in the earlier iteration.

4.1.3.1.1 Conceptual model

In this iteration, one of the science inquiry topics (Heat energy transfer) from the New Zealand NCEA Level 1 science curriculum was taken as an experimental context for performing abductive inquiry investigations with participants. For that purpose, a heat energy transfer ontology was defined for generating learning content as depicted in the conceptual model of this iteration (see Figure 4.15).
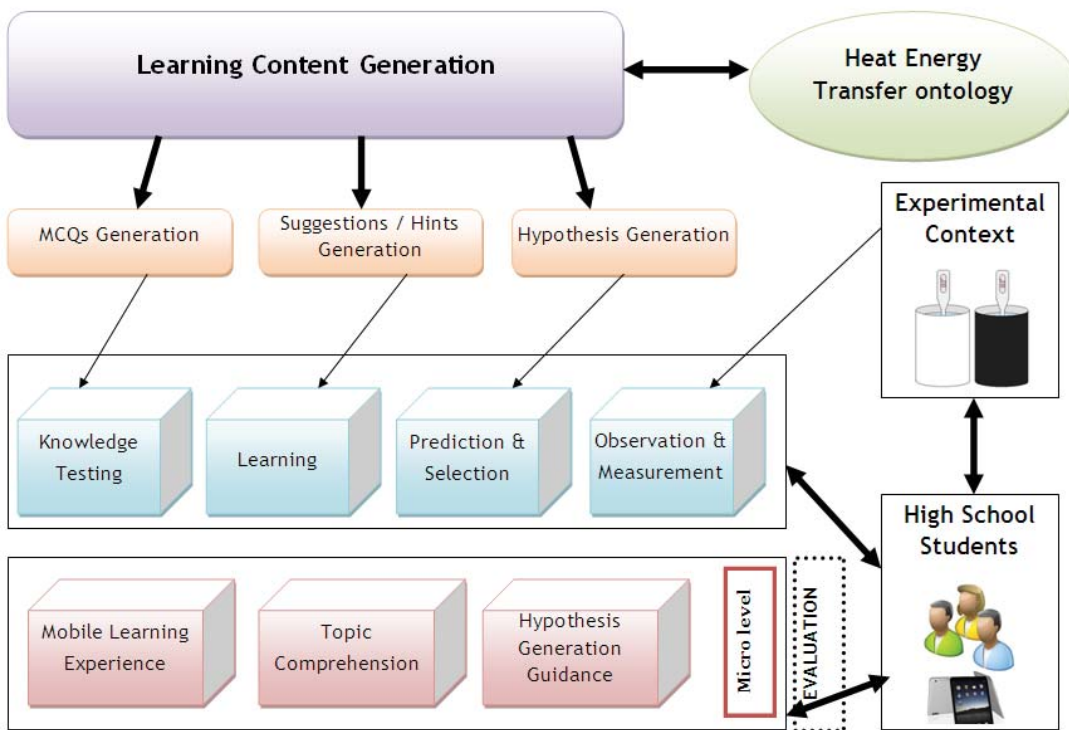
Figure 4.15 Conceptual model of iteration 3

Similar to the previous iteration, learning content are generated; MCQs for testing learners' knowledge about the domain, suggestions for understanding the domain and the pool of hypotheses from which learners can select about the domain.

This conceptual model is different from the prior iteration in terms of the evaluation component. This iteration uses Micro level evaluation (Vavoula et al., 2009) in which

learners (high school students) were asked to investigate this application in terms of its guidance towards hypothesis generation and their comprehension about the topic. Further, these students were also involved in evaluating usability and mobile quality aspects of the application.

4.1.3.1.2 Heat energy transfer - A domain ontology

In this particular iteration, a domain ontology (as shown in Figure 4.16) was developed using one of the standard school science topics (Heat energy transfer). This ontology contains two important aspects of heat energy including the impact on the movement of water particles, and the loss and absorption of heat energy due to different coloured surfaces.
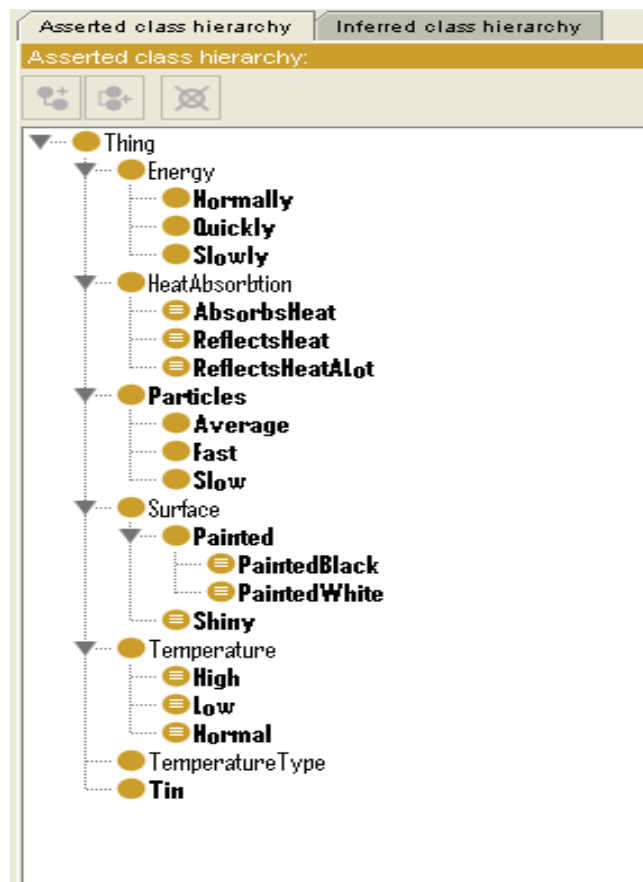
Figure 4.16 Heat energy transfer domain ontology

137

This domain ontology holds some important concepts including 'Particles', 'Surface', 'Tin', and 'Temperature'. The temperature ranges are defined in this ontology as *High*, *Low* and *Normal* while the energy particles can be recorded as *Average*, *Fast* and *Slow*. Further, the loss and absorption of heat energy are categorized into three types: *AbsorbsHeat*, *ReflectsHeat* and *ReflectsHeatALot* as shown in Figure 4.16. These concepts and sub-concepts of the domain ontology are inter-connected in such a way to generate learning content into MCQs and suggestions given to the learners while they are performing their investigations.

4.1.3.1.3   Abduction example from the experimental context

The following abduction example from the experimental context of this application explains the relationships between Case (Hypothesis), Result (Observation) and Rule (Condition or Suggestion), as described in the collected papers of C.S. Peirce (1931-1958) cited in (Raholm, 2010). Here, the ideas relate to black surfaced tins containing hot water losing heat more quickly than white or shiny surfaced tins.

Abduction:

Rule–The water particles in a black surfaced tin vibrate faster than in the other tins.

Result– A black surfaced tin cools more quickly.

Case– A black surfaced tin absorbs more heat energy than the other tins.

According to this example, the falling temperature of black surfaced tin can be recorded by learners in a science laboratory to observe the phenomena (Result) that a black surfaced tin cools more quickly as compared to other tins. Similarly, they may also know about the condition (Rule) from the theory which they were taught in the classroom earlier or by obtained suggestions after the use of 'ThinknLearn'. In this way,

learners may learn about the Result and Rule of this particular example which may lead them to generate a hypothesis (Case) about the observed phenomena.

4.1.3.2   Activity 4: Demonstration

In this activity, the abductive inquiry model (AIM) (Oh, 2011) that defines four elements: *exploration*, *examination*, *selection*, *explanation* was used, which may be utilized for pedagogical purposes of enriching students' knowledge as well as engaging them in scientific inquiry practices (Oh, 2010). This model was not used in the preceding iteration because it was not evaluated with the actual participants (high school students).

In this particular example, three tins with different surface colours were provided in order to compare the way they radiate heat energy. Tin A was painted *White*, tin B *Black* and tin C was *Silver* or *Shiny*. In the *exploration* phase of this example, learners recorded the temperature of each tin at a particular time interval after pouring boiling water in these tins. For the temperature, the range lied between 20-100 ^{0}C while the time recorded between 0-20 minutes. The application asks for the temperature of the given tins with different colour surfaces measured at a particular time. The main task for learners in this phase was to investigate the given scientific phenomena by observing data.

In the previous iteration, only one screen contained all the key measures. However, in this iteration, separate measurement screens are defined for taking inputs of each of these three tins used in this particular example. So that learners may able to access information about each tin separately. One of the measurement screens of the application is displayed (see Figure 4.17) that asks for two inputs from the learners; the temperature of a Shiny tin and the time at which the temperature of that tin may be recorded.

The *examination* phase of this model may help learners to generate scientific hypothesis for this investigating phenomena. After collecting all the values from the *exploration* phase, the application asks a series of MCQs regarding the collected values of these measures one-by-one (see Figure 4.18). This feature makes learners use their observational abilities to answer the given questions. The main reason for not giving correct answers straightaway is to exploit learners' critical thinking skills for comprehending the given domain concepts.

Figure 4.17 Measurement and observation of Silver (Shiny)-surfaced tin

The application does not indicate whether the chosen option is correct or not but it gives suggestions based on the answers chosen by the learners as depicted in Figure 4.19. These context-sensitive suggestions are generated from the domain ontology which may lead learners to think about the various aspects of heat energy related to different coloured surfaces.

140
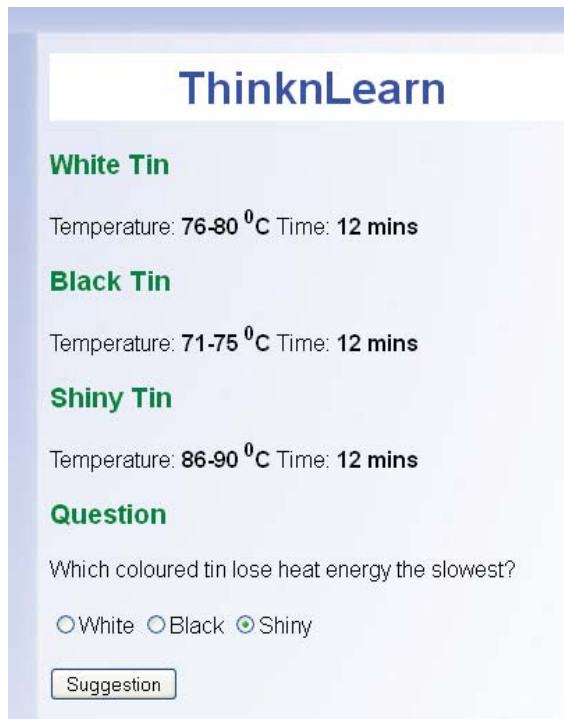
Figure 4.18 MCQ regarding one of the aspects of heat energy

Figure 4.19 Suggestion about the given question

Once these question-suggestion modules completed, the application presents a summary of the activities conducted by the learners during this science inquiry learning activity as depicted in Figure 4.20. Similar to the earlier iteration, this summary page contains all the inputs about the key measures and the given

141

suggestions are identified in the *examination* phase. However, the MCQ regarding the selection of the hypothesis is mentioned on the separate screen in this iteration because of two reasons: first, it may be difficult to show more information in a small mobile screen; second, it may be easier for learners to interact with one component of the application at a time.

Learners are asked to formulate two types of hypotheses, which differ from the one type of hypothesis defined in the prior iteration. One is related to the vibration of 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 inquire 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.

ThinknLearn

Summary - Experiment

White Tin

Temperature: **76-80** ^{0}C Time: **12 mins**

Black Tin

Temperature: **71-75** ^{0}C Time: **12 mins**

Shiny Tin

Temperature: **86-90** ^{0}C Time: **12 mins**
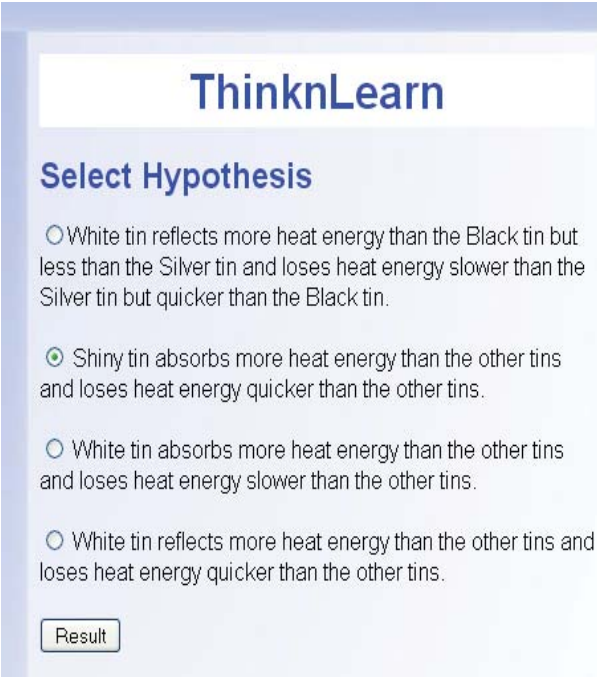
Suggestions

- The water particles in White tin vibrate faster than the warmer tin but slower than the cooler tin.

- A Shiny tin reflects more heat energy than the other tins.

- A Black tin loses heat energy quicker than the other tins.

Generate Hypothesis

Figure 4.20 Experimental summary

142

S*election* is the third phase of this model in which learners are asked to choose one of the possible hypotheses of the observed phenomena. The application extracts all the hypotheses including one correct and other three distracters as illustrated in Figure 4.21. After selecting one of these, learners will get the results about their selections, whether they were right or wrong in selecting a hypothesis about the underlying domain.

In the final phase of the AIM – *explanation* - learners propose complete explanations for the observed phenomena using the given suggestions and hypotheses selected in the preceding steps. These explanations help learners to comprehend the topic which may be further tested by the instructors or teachers to assess learning performance during such inquiry investigations. However, learning assessments of such learners are measured rigorously in the subsequent iteration.

Figure 4.21 Hypothesis selection

143

4.1.3.3   Activity 5: Evaluation

This application was evaluated with a high school science classes to investigate only Micro level evaluation (Vavoula et al., 2009). This evaluation looks at usability and mobile quality aspects of the application. The analyses of the evaluation of this pilot study are discussed in the next chapter of this thesis.

4.1.3.4   Activity 6: Communication

This work has published in (Ahmed, Parsons, & Mentis, 2012) for other target audiences of the relevant research fields.

4.1.4   Iteration # 4: Learning Assessments in Abductive Mobile Science Inquiry

This iteration was considered as the final experiment in the design and evaluation of 'ThinknLearn'. Hence, it was evaluated with more rigor than the pilot study. For that purpose, learning assessments were conducted in this final experiment with a larger sample size. This iteration followed the client/context initiated approach (Peffers et al., 2008), which proceeds in a sequential order from activity 4 through activity 6 to observe the practical use of 'ThinknLearn' in the actual context (science classroom).

4.1.4.1   Activity 4: Demonstration

In this final iteration, the research focused on the learners' assessments about the understanding of a particular domain after using the same application 'ThinknLearn'. Similar to the preceding iteration, the abductive inquiry model (AIM) (Oh, 2011) was exercised by high school students in this final experiment. However, the evaluation part of the iteration included Meso level evaluation (Vavoula et al., 2009) as shown in Figure 4.22. At this level of evaluation, learners' learning performances are assessed in

pre-post and retention tests by dividing students into two evaluating groups: experimental and control.
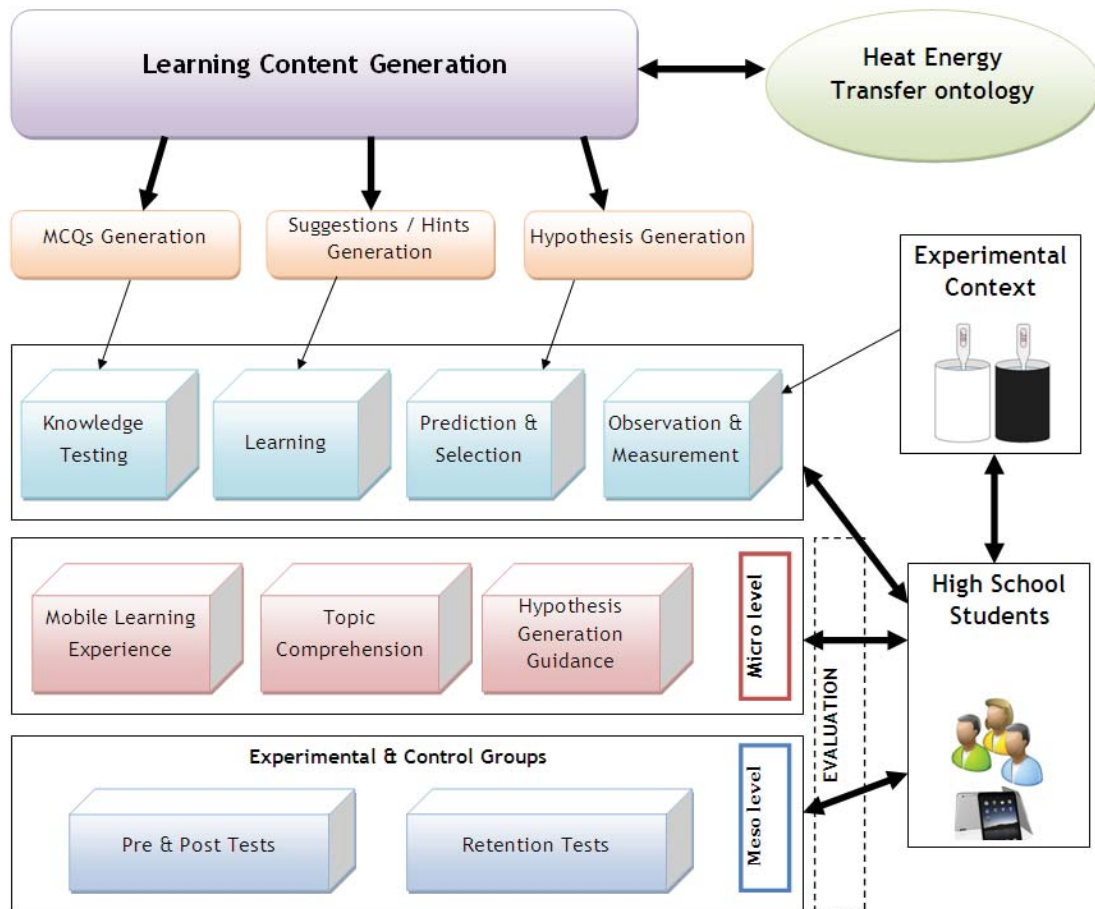
Figure 4.22 Conceptual model of the final iteration

4.1.4.2   Activity 5: Evaluation

In this activity, both Micro and Meso level evaluations (Vavoula et al., 2009) were used. Here, six science high school classes participated while only one science class had taken part in the pilot study evaluation. Similar to the preceding iteration, usability and mobile quality aspects were investigated in the Micro level evaluation of this application. For Meso level evaluation, the evaluation was divided into two parts: pre-

post and retention tests. The pre-post tests were performed to investigate the impact of this application on different experimental and control group of students' learning performance before and after using it. The other dimension of this evaluating component was comparing students' learning performance after a span of two months (retention tests). The analyses of this final experiment are discussed in the next chapter of the thesis.

4.1.4.3   Activity 6: Communication

This work has acknowledged with best paper award (Ahmed & Parsons, 2012) in the research community.

4.2   Summary

This section summarizes the chapter, which implements DSRM process model (Peffers et al., 2008) for tackling research challenges drawn from the literature. In this thesis, four research design iterations were designed and evaluated that lead towards an innovative mobile learning web application 'ThinknLearn'. This application explores ontology-based scaffolding in the context of abductive science inquiry investigations.

In the first of these research design iterations, various uses of ontology-based scaffolding in accessing learning content were explored. However, the subsequent iterations were designed for abductive mobile science IBL activities: One of them was evaluated with science educators; while the next one was evaluated with high school students in terms of Micro level evaluation; the impact of the application on students' learning assessments was investigated in the final iteration. The summary of these research design iterations is illustrated in Figure 4.23.
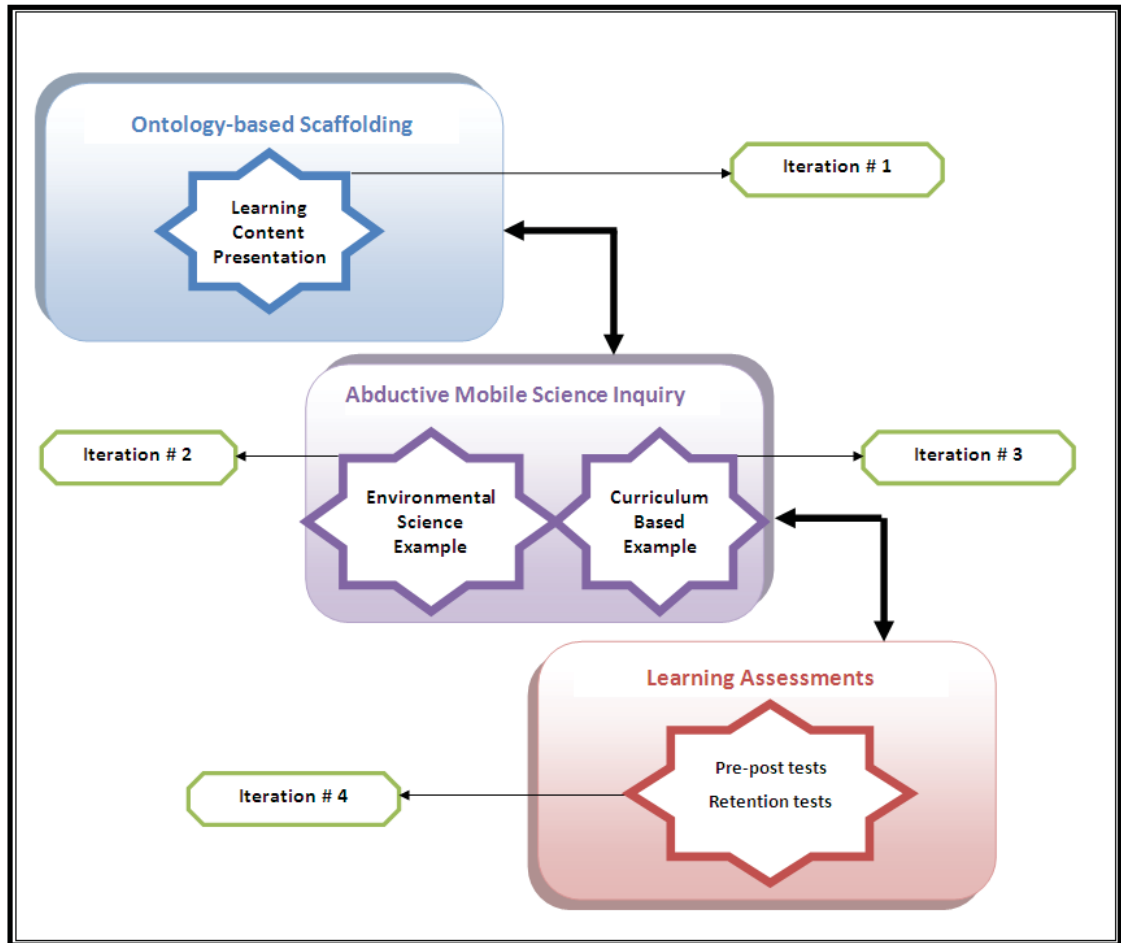
Figure 4.23 Summary of research design iterations

The motivation behind the first iteration was to explore the use of ontology-based scaffolding. This iteration used a first aid domain ontology as an example to present learning content in multiple ways; tutorial and MCQs by applying the technical architecture which uses Jena API and Pellet for extracting information embedded in the domain ontology. This application was internally evaluated by a group of researchers who identified some issues from this evaluation including that the domain (first aid) was not appropriate for the practical demonstration in school contexts, this web application should have adaptivity features so that learners can able to access

dynamic content using different range of mobile devices, and the use of a suitable pedagogical approach for learning activities.

In answering these issues, in the subsequent iteration, science IBL was chosen as an appropriate pedagogical approach because learners can become active rather than passive recipients of domain knowledge while performing such learning activities. More specifically, an abductive science inquiry (Oh, 2010, 2011) was the chosen focus, a less common approach in school sciences which emphasizes the development of scientific hypotheses that are observed from the natural environment (Oh, 2010). This kind of inquiry has been sparsely explored in the literature (Grandy & Duschl, 2007; Oh, 2010). Thus, it provides an opportunity to explore some new approaches in school science learning. This iteration also followed a problem-centred approach (Peffers et al., 2008), similar to the first iteration consisting of six activities.

For web adaptivity, WURFL and the WALL library were used to support all types of mobile browsers that can generate dynamic content to mobile learners (Parsons, 2008). The inclusion of these components in the technical architecture helped to design the mobile web application 'ThinknLearn' by which learning content can be provided to learners in situ where they are involved in their learning activities. Hence, the subsequent iterations dealt with abductive mobile science IBL activities.

In the first of these subsequent iterations, a very common and discussed topic from the science literature was taken as an example (environmental science) to design the application. It was rather a proof a concept to demonstrate to a group of science educators how students can interact in abductive mobile science inquiry investigations. In the evaluation of this application, there were a few concerns raised by science educators. One of these concerns was about the implementation of this application before the students' practical classes so that they can perform their science experiments for the first time while conducting such inquiry learning activities.

148

The other concerns were; the application did not use school science curriculum-based topic and the students were not used to following this abductive form of inquiry investigation before in their science classrooms.

After considering these concerns with science educators in a meeting, in the following iteration (the pilot study), the application 'ThinknLearn' implements one of the topics (Heat energy transfer) from the New Zealand standard school science curriculum. For evaluating the utility of such application, Micro level evaluation (Vavoula et al., 2009) was used to investigate usability and mobile quality aspects with a small sample size of high school students. The motivation behind this iteration remained intact with the use of ontology-based scaffolding in abductive mobile science inquiry investigations as described in the preceding iteration. Therefore, it considered a design and development centred initiation approach (Peffers et al., 2008).

The final iteration of this research work followed the client/context initiated approach (Peffers et al., 2008) to exhibit the practical implementation of the application in the actual context. Thus, the final experiment was conducted with a larger sample size of high school students to evaluate this application. In addition, this iteration also included Meso level along with Micro level evaluation (Vavoula et al., 2009) for evaluating 'ThinknLearn' more rigorously. These evaluations include usability and mobile quality aspects of the application and impact on students' learning performance in pre-post and retention tests. The results and analyses of these evaluations are discussed in the next chapter of this thesis.

Experimental Results and Analyses

This chapter explains the evaluation of the application 'ThinknLearn'. It discusses two experiments, namely the pilot study and the final experiment of the research design. In this chapter, the experimental design, participants, apparatus, procedure and results and analyses are discussed.

5.1 Experiment # 1: Pilot Study

In this pilot study (the 3rd iteration of this research), a specific science example was used as an experimental context to evaluate the designed application with high school science students. The experiment was conducted with one of their science classes for the purpose of evaluating this application in terms of its guidance towards hypotheses generation, and understanding about the particular domain.

5.1.1 Experimental Design

The rationale for this experimental design was to evaluate 'ThinknLearn' in terms of its utility. For that purpose, only the Micro level from a mobile learning evaluation framework (Vavoula & Sharples, 2009) was used in this pilot study. This level investigates the individual learning activities of the technology users and assesses the utility of this educational tool (Vavoula & Sharples, 2009; Vavoula et al., 2009).

The utility covers the use of the proposed application for guiding learners in order to construct scientific hypotheses about the underlying domain, as measured through usability and mobile quality aspects of the application. The usability focuses on the capability of the software product to be understood, learned, used and attract to the user, when used under specified conditions (Bevan, 2001). Three ISO metrics namely *learnability*, *operability* and *understandability* were used (ISO, 2003) for measuring usability aspects of the application. In addition, for exploring the quality of the learning experience in a mobile context, three quality aspects for a mobile learning application were applied; *metaphor*, *interactivity* and *learning content* (Parsons & Ryu, 2006). These aspects are used in order to identify the quality of the learning experience during mobile learning activities.

The experimental design was based on the abductive science IBL investigations, where the participants carried out the structured activities for almost an hour in one session (science class time). The activities involved conducting one of their science class' experiments (Heat energy transfer) in groups, finding the values of the given apparatus, and the use of 'ThinknLearn'. Each group entered the collected data about the given apparatus in 'ThinknLearn', which assisted them in generating scientific hypothesis about a given topic that had already been covered in their classes.

This mobile adaptive web application 'ThinknLearn' was considered as the independent variable while the dependent variables including usability of the designed application and the learners' experience were used as the ratings on 9 questions in the corresponding analyses. For the questionnaire, each question was related to each of these defined usability aspects (ISO, 2003): *learnability*, *operability*, and *understandability*. Apart from these, two questions were stated for each of the quality aspects of mobile learning applications: *metaphor*, *interactivity*, and *learning content* (Parsons & Ryu, 2006). These aspects with their explanations are depicted in Table 5.1 for the evaluation of the application.

151

Table 5.1 Usability and quality aspects for evaluating 'ThinknLearn' (adapted from Chua & Dyson, 2004; Parsons & Ryu, 2006)

Characteristic	Sub-Characteristic	Explanation
Usability aspects	Learnability	Can the learner learn the system easily?
	Operability	Can the learner use the system without much effort?
	Understandability	Does the learner comprehend how to use the system easily?
Quality aspects	Interactivity	Is there an adequate level of interactivity between the learner and the system?
	Learning Content	Does the learner feel that the learning component is of high quality?
	Metaphor	Does the learner have an overall vision of the learning process?

Further in the evaluation process, mixed methods (Creswell et al., 2003; Johnson & Onwuegbuzie, 2004), consisting of a quantitative questionnaire (see Appendix IV) and qualitative semi-structured group discussions (see Appendix V) were used in this pilot study.

Questionnaires were answered and semi-structured group discussions were conducted to evaluate the designed application on the basis of its guidance towards the construction of scientific hypotheses and the learners' experiences after using it. On the other hand, for qualitative semi-structured group discussions three questions were asked to participants that covered different aspects of the evaluation process. These

aspects include mobile learning experience, hypothesis generation and comprehension about a given topic that relates to the usability and the quality aspects of this application.

5.1.2   Participants

A total of 23 out of 28 students divided into eight groups, one of the science classes from Albany Senior High school, Auckland, voluntarily participated in this pilot study. The response rate for the participation in this pilot study was 82.1 percent, which may be considered as a good participating response based on the literature such as Dillman (2000), and Roth and Be Vier (1998) suggest 50% as the minimal level; Fowler (1984) suggests 60% while De Vaus (1986) argues 80% as the minimum response rate. All the participants were NCEA level 1 students in the age range 15-16 years. In this pilot study, most of the participants were equipped with their own mobile devices at the time of the experiment, which indicated that the participants were previously mobile users. The participants' mobile technological background makes them good evaluators of a mobile application that deals with their science learning contents.

For the invitation of the participants, individual consent forms for the evaluation (see Appendix III) were provided. These forms briefly explained the nature of the experiment but did not mention the learning topic. The experiment was undertaken as a learning activity as part of their regular science classes using mobile devices equipped with WiFi. This learning activity involved using a mobile application that was conducted in their science laboratory, so the environment was not a novel factor for the participants. Those under 16 were asked to get a consent form from their parents.

The division of the participants into one of the eight groups was based on their previous science class activities so we were not involved in creating or modifying any groups of participants. The experiment was conducted in the middle of September,

2011 in which the 3rd term of the school was underway and their revision exams were very close. For that reason, the proposed application was tested with participants on a single day (Monday), which investigated only one science class of the school. These limitations in time and availability, did not allow conducting more extensive evaluations in this pilot study.

5.1.3   Apparatus

As depicted in Figure 5.1, three tins with different coloured surfaces including *Black*, *Shiny (Silver)*, and *White* were provided for comparing the way these tins radiate heat energy. A group of participants were required to measure the temperature inside each coloured tin at a particular time and observe the different properties of these tins. A mobile device equipped with WiFi was also provided to each group of the participants, so that they could access the 'ThinknLearn' application.

This application was developed using the same concepts related to the given topic (Heat energy transfer), which were already covered in their classrooms. However, this application helps the participants to comprehend those concepts using their mobile devices. Besides these experimental apparatus, a questionnaire was also given to each of these participants for investigating their individual learning experiences about the application.

Figure 5.1 Apparatus used in the experiment

154

5.1.4   Procedure

The participants were first provided with the instructions by their science teacher. These instructions gave information about the experiment, the purpose of the study, and the data collection process including filling in the questionnaire and semi-structured group discussions.

Each group of the participants was asked to find out the values of each of three tins at a particular time interval. Then, they entered these values into the application 'ThinknLearn'. During the use of this application, participants were required to construct scientific hypotheses about a given domain. Immediately after using this application, all the participants were asked to rate 9 questions individually on a five-point Likert scale (see Figure 5.2). Subsequently, they were also engaged in semi-structured group discussions in which participants were asked to answer three questions related to their overall learning experiences about the application.

Figure 5.2 Participants filling questionnaires

5.1.5   Results and Analyses

Usability plays a vital role in the success of any learning application (Ardito et al., 2006). If a learning application is not usable enough then it impedes the way for facilitating students' learning; the learners would spend more time learning how to use the application than learning the contents (Wong, Nguyen, Chang, & Jayaratna, 2003). Usability features should not only allow learners to efficiently manipulate the interactive application, but should also be appropriate for the intended learning activity (Ardito et al., 2006).

Besides these usability features, quality aspects need to be considered for developing mobile learning applications (Parsons & Ryu, 2006). This section reports on the questionnaire responses that address these aspects for evaluating the application. Further, qualitative responses were also reported, gathered in semi-structured group discussions.

5.1.5.1   Questionnaire responses

The questionnaire was administered to the participants after they had completed the science experiment. The 9 questions in the questionnaire attempted to address different aspects of usability (*learnability*, *understandability*, *operability*) and quality aspects (*metaphor*, *interactivity*, *learning content*). This 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.

   a) *Usability aspects*

As depicted in Table 5.2, the three questionnaire statements (S2, S3, and S4) were intended to investigate the mobile learning application from a usability perspective.

These questionnaire statements addressed the fundamental aspects for usability found in 'ThinknLearn'.

Table 5.2 Quantitative responses of usability aspects in the pilot study

Usability Aspects	No.	Statements	Mean Response ± S.E (Standard Error)
Learnability	S2	This mobile application was easy to use.	4.13 ± 0.13
Operability	S3	Navigation through this application was easy.	4.35 ± 0.15
Understandability	S4	This application guides me to formulate a hypothesis.	3.61 ± 0.20

The responses to statements 'S2' and 'S3' revealed that the participants found this application was easy to use and the navigation was straightforward. Similarly, the ratings on the statement 'S4' also revealed that our respondents perceived that the guidance towards hypothesis generation and the whole learning process was very easy to understand. A one sample t-test against the neutral value 3.00 confirmed these interpretations (t_{22} = 8.67, p< .01 for S2; t_{22} = 9.05, p< .01 for S3; t_{22} = 3.10, p< .01 for S4).

b) Mobile learning quality aspects

The statements listed in Table 5.3 were intended to ascertain if the respondents revealed positive characteristics about their learning experiences using 'ThinknLearn'. This evaluation relates to the quality aspects of the mobile learning application which includes *metaphor*, *interactivity*, and *learning content* (Parsons & Ryu, 2006). Overall,

the questionnaire responses about the quality aspects demonstrated positive attitudes from the participants towards this application.

Table 5.3 Quantitative responses of mobile quality aspects in the pilot study

Quality aspects	No.	Statements	Mean Response ± S.E (Standard Error)
Interactivity	S6	This application helps me understand the relationships between different variables.	3.87 ± 0.16
	S8	This application helps me to improve my reasoning skills.	3.65 ± 0.16
Learning Content	S1	This mobile learning experience was enjoyable.	3.74 ± 0.22
	S9	It is an effective learning application.	4.00 ± 0.21
Metaphor	S5	The given suggestions in the application were relevant.	4.09 ± 0.19
	S7	The given suggestions help me to understand the topic.	3.96 0.19

In the *interactivity* aspect, the participants experienced 'ThinknLearn' as an interactive learning application that not only assisted learners to understand the relationships between different variables covered in this application but also improved learners' reasoning skills while performing abductive inquiry investigations (t_{22} = 5.50, p< .01 for S6; t_{22} = 4.03, p< .01 for S8). In a similar way, the ratings on statements (S1, S9) (t_{22} = 3.36, p< .01 for S1; t_{22} = 4.60, p< .01 for S9) revealed that the learning from this application was an enjoyable experience and overall a high quality learning application for the participants. Similarly, the *metaphor,* another quality aspect of this application showed that the participants experienced an overall vision of the learning processes (t_{22} = 5.80, p< .01 for S5; t_{22} = 4.94, p< .01 for S7). The processes include the relevancy of the given suggestions for constructing scientific hypotheses and the assistance provided by these suggestions to comprehend the given topic.

Consequently, the questionnaire responses of the participants were promising, which suggests that 'ThinknLearn' has embodied considerable software quality measures including usability and the quality aspects required by any mobile learning application.

c) *Questionnaire reliability and validity*

Cronbach's coefficient alpha is a statistical method used to test reliability in questionnaires (Cronbach, 1951). Coefficient alpha estimates the degree of inter-relatedness among a set of question items and variance between these items (Ryu & Smith-Jackson, 2006). Alpha coefficient ranges in value from 0 to 1 but a widely accepted reliability coefficient should be at least 0.70 (Cortina, 1993; Netemeyer, Bearden, & Sharma, 2003). In the case of this study, the responses from the participants showed that the scale was reliable (Coefficient alpha equals to 0.89) and therefore it was used for the final experiment of this research design.

Validity of the research instrument is an important aspect in a research design, which can be defined as "the degree to which a test measures what it claims, or purports, to

be measuring" (J.D.Brown, 1996, p. 231). In this research, the validity of the questionnaire was established by a review of the experts including school educators and researchers of the field before conducing experiments with the actual participants. Selected question items were revised based upon experts' comments and recommendations. However, it could be possible that participants were not able to understand certain terms or had different levels of understanding of the terms used in the questionnaire.

5.1.5.2 Semi-structured group discussions

Qualitative data were gathered in semi-structured group discussions between 23 participants in 8 groups. Three questions in the discussions were asked of the participants for evaluating the application. These questions were used to identify usability and quality aspects of the 'ThinknLearn' application.

For analysing responses from the participants, qualitative content analysis was used in this research. This is a research method that describes the characteristics of language as communication focusing on the content or contextual meaning of text data (Budd, Thorp, & Donohew, 1967; Lindkvist, 1981; Tesch, 1990). Text data might be in verbal, print, or electronic survey questions, focus groups, interviews, observations or print media (Kondracki & Wellman, 2002). The success of content analysis depends on the coding process. The basic coding process in content analysis is to classify large amounts of text into a small number of content categories (Weber, 1990). There are three approaches to developing initial codes in content analysis (Hsieh & Shannon, 2005): *Conventional content analysis*, in which codes are derived during data analysis. *Directed content analysis*, in which codes are identified from the literature or relevant research findings. *Summative content analysis*, in which data is not analysed as a whole; the data is often approached as keywords or in relation to particular content. In this thesis, directed content analysis is used as a method for the subjective

interpretation of the content of semi-structured group discussion responses because categories are derived before and during the data analysis process.

In a directed content analysis approach, the researcher uses prior literature or theory to identify some key categories beforehand (Kyngas & Vanhanen, 1999). As analysis proceeds, additional categories are also included and the coding scheme is updated (Hsieh & Shannon, 2005). Similarly, in this research, the content analysis was begun with some pre-defined initial categories such as 'Easy to use' or 'Enjoyable experience' or 'Relevant suggestions'. However, new categories also emerged during the data analysis such as 'Difficulty in understanding questions' or 'Correct answers straight away'. Categories were identified for each of the questions given to the participants. In addition, the frequencies for each category were counted as depicted in Table 5.4. It should be noted that in assigning data into categories during the data analysis, there may be a chance for bias, which is considered as a limitation of this research. Thus, this should be taken into account when analysing these results.

After identifying key categories from the data and their frequencies, some codes were assigned as presented in Table 5.4. These emergent categories are used to organize and group categories into meaningful clusters or themes (Coffey & Atkinson, 1996; Patton, 2002). In this research, these categories were combined into themes according to the nature of the responses. For instance, 'Easy to use' and 'Easy to understand' are two positive aspects of usability. Similarly, 'Difficulty in understanding questions' and 'Confusion in hypothesis generation' highlight the negative aspects of the application. Thus, these categories were combined into themes as 'Usable application' and 'Difficult application' respectively (see Table 5.5). After combining categories, it was observed that two themes were defined for each of the given questions. Further, the total frequencies of each of these themes were also calculated by adding the frequencies of the combined codes as presented in Table 5.4.

Table 5.4 Group discussion questions, categories and their frequencies in the pilot study data

Q.No.	Questions	Categories	Frequency	Code No.
1	What type of difficulty do you find in using this application?	Easy to use	10	I
		Easy to understand	6	II
		Difficulty in understanding questions	2	III
		Confusion in hypothesis generation	3	IV
2	How do you feel after using this application?	Enjoyable experience	13	V
		Unpleasant experience	4	VI
3	What do you think about suggestions given in the application?	Relevant suggestions	14	VII
		Correct answers straight away	4	VIII

Responses to question 1 in group discussions were based on either of the themes 'Usable application' or 'Difficult application'. The frequencies for 'Usable application' revealed that most of the participants consider this application as usable enough to guide learners and encourage them to think about the topic discussed in the application as shown in Table 5.5. One of the participants said "…*it is easy to use and that is why I enjoy it*". However there were five participants in discussions who found this application a little baffling and supported the other theme of the question 1

(Difficult application). One participant described how "*...it guides me but I am little bit confused to choose the correct hypothesis".* One of the reasons for this difficulty in using this application might be due to their understanding about the topic but this aspect was considered in the final experiment.

Table 5.5 Themes and their total frequencies in the pilot study data

Q.No.	Combined Codes	Categories	Themes	Total Frequencies (Out of 23)
1	I, II	Easy to use	Usable application	16 (69.5%)
		Easy to understand		
	III, IV	Difficulty in understanding questions	Difficult application	5 (21.7%)
		Confusion in hypothesis generation		
2	V	Enjoyable experience	Engaging application	13 (56.5%)
	VI	Unpleasant experience	Boring application	4 (17.4%)
3	VII	Relevant suggestions	Good approach	14 (60.8%)
	VIII	Correct answers straight away	Confusing approach	4 (17.4%)

With respect to how this mobile learning application was enjoyable, interactive and interesting (in response to question 2), around 56% found it an engaging application (theme) as depicted in Table 5.5. One participant stated that *"... there is no doubt that*

163

it is an interesting and interactive application because it makes you think about the topic." In contrast, four participants were unhappy about using this application and considered it a boring application (theme). According to one of them, *"…..this application is boring because I don't prefer to do web browsing on my iPhone as I have to use the zoom function again and again while using it*". In reply to that concern, it is suggested that this adaptive web library 'WURFL' holds information about capabilities and features of many devices but there are some limitations while using it in some contexts (Rabin & McCathieNevile, 2008). On the whole, most participants valued the interactivity, enjoyed the innovative way of learning, and found the application engaging as shown in Table 5.5.

The responses for question 3 were promising and around 61% considering this theme (a good approach to hypothesis generation) felt that the given suggestions were relevant as mentioned in Table 5.5. Although one group said *"…why doesn't this application give correct answers straightaway rather than suggestions?"* One answer to this question is that it is an abductive form of inquiry-based learning application, which helps learners to generate scientific hypotheses. The suggestions given are relevant to the domain-specific knowledge, which not only allows learners to think but also learn about the topic. This shows that this application presents some challenges to the participants 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 a fine balance needs to be maintained between challenge and skill. However, there may be needed to find ways to convince participants of the value of this approach. In short, the qualitative data suggest that the application has substantial usability and mobile quality aspects as required by any mobile learning application. This data further supports the claims that were made from the questionnaire data related to the software quality measures of the application.

5.2 Experiment # 2: Final Experiment

In this final experiment, a similar school example was used as an experimental context, which was used earlier in the pilot study, to further evaluate 'ThinknLearn'. The pilot study was conducted with only one of the science classes. However, this experiment was carried out with a larger number of high school students to compare learners' learning performance with and without using this application while performing abductive inquiry learning activities.

It is suggested in (Sharples et al., 2009) 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 application not only examines how learners perform such inquiry investigations with and without using any guidance, but also measures how this application can be helpful for generating hypotheses and learners' critical thinking skills in understanding the defined topic.

5.2.1 Experimental Design

In this final experiment, two levels including Micro and Meso of the M3 evaluation framework (Vavoula & Sharples, 2009) were applied. The Meso level was the new inclusion after the pilot study, discussed earlier in this chapter. This Meso level investigates the complete learning experience of the learners, to identify learning breakthroughs and breakdowns (Vavoula & Sharples, 2009; Vavoula et al., 2009). In the case of 'ThinknLearn', evaluation at this level involves exploring learners' educational issues; mobile learning experiences, critical thinking skills and learning assessments while performing inquiry learning activities.

The rationale for this experimental design was to evaluate 'ThinknLearn' in terms of its usability and educational issues as defined in Table 5.6 adapted from (Vavoula et al., 2009). For the usability and the learners' learning experiences about the application, the same usability and quality aspects were used as applied in the pilot study. However, for the educational issues, this experiment was designed and evaluated between control and experimental groups.

A control group was used to perform the heat energy experiment in the science laboratory using "pre-test ---> heat energy experiment ---> post-test ---> retention test" method, where the participants carried out the learning activities without using 'ThinknLearn'. On the other hand, the experimental group used this application while performing the same experiment in the science laboratory using "pre-test ---> heat energy experiment + using ThinknLearn ---> post-test ---> retention test" method. It could be argued that the control group participants were not given any kind of alternative assistance such as PowerPoint slides or handouts while performing their experiments. Even if these kinds of assistance were provided to the control group participants, it may be hypothesised that their performance would not be supported to an equivalent level as the experimental group participants because the application 'ThinknLearn' is designed to provide adaptive suggestions to learners during such learning activities, which these kinds of assistance would not able to provide. However, there might nevertheless be a chance that the control group participants could perform better than the experimental group if they were given other alternative forms of learning support. Hence, it can be considered as one of the limitations of this research that the designed application 'ThinknLearn' was not compared with other alternative interventions.

Table 5.6 Evaluating 'ThinknLearn' based on the M3 evaluation framework

M3 Evaluation Framework Level	Evaluation Aspects	Form of Evaluation
Micro Level	Usability Issues (Usability and quality aspects)	Questionnaire Semi-structured group discussions
Meso Level	Educational Issues (Learning outcomes)	(Experimental & Control groups) Pre-post tests Retention tests

Although, both experimental and control groups received the identical experimental context, performed identical learning activities, and occurred during the same period. The learning activities involved pre and post tests during hypothesis formation activities in the context of abductive science inquiry. These tests consist of multiple choice questions (MCQs) and open-ended question regarding hypothesis and its explanation, which assess learners' knowledge about the topic covered in their science classes earlier. An additional test (retention test) was also performed after a span of two months, to measure learning retention of both groups.

This experiment was a between-subject design. The two ways of generating hypotheses and improving learning are considered as the independent variables; using the application 'ThinknLearn' versus the traditional approach, while the dependent variables are learning performance and retention in this experiment. The measurement of the learning performance assesses how well each participant has learnt the given science content (Heat energy transfer) in order to construct scientific

hypotheses. For the retention, the measurement describes how each participant has remembered the given knowledge after some time has elapsed.

5.2.2   Participants

A total of 161 out of 182 students from six science classes voluntarily participated in this final experiment. They were all NCEA level 1 science students, from Albany Senior High school, Auckland, and aged 15-16 years. The response rate for the participation in this final experiment was considerable high from the pilot study that is 88.4 percent. This response rate may be considered as a good participating response based on the literature (De Vaus, 1986; Dillman, 2000; Fowler, 1984; Roth & Be Vier, 1998).

One of the groups was treated as an experimental group, which comprised 86 students from three science classes. The other 75 students were a control group. In the experimental group, 86 students filled in the questionnaire and participated in group discussions regarding the usability of the application. Amongst them, 81 students participated in pre-post activities. However, in the control group, 75 students were involved in pre-post activities without using 'ThinknLearn'. After two months, the retention test was conducted in their classrooms. In this retention test, only 125 students participated. Amongst them, 67 were those students who had been in the experimental group earlier while 58 were control group participants.

For the invitation of the participants, the same procedure had been followed in which participants needed to fill in the individual consent forms for the evaluation if they were 16 years old. And for those students who were less than 16 years of age, they were required to get permission from their parents by filling these consent forms (see Appendix III). These forms briefly explained the nature of the experiment but did not mention the learning topic as described in the pilot study.

For the distribution of the groups (experimental and control), science teachers were insistent on keeping the class structure intact. Therefore, students could not be randomly assigned to any of the groups. However, three classes apiece were selected as experimental and control groups respectively. In each class, there were previously 8-9 sub-groups for performing their classroom activities. So, there was no modification made in their class structure. This experiment was involved six science classes conducted in February, 2012 in which the 1st term of the school was underway. However, the retention test was undertaken almost two months later (the first week of April, 2012).

5.2.3 Apparatus

A similar apparatus to that used in the pilot study, was involved in this final experiment, consisting of three tins with different coloured surfaces including *Black*, *Shiny (Silver)*, and *White*. They were provided for comparing the way the tins radiate heat energy. Both experimental and control groups of participants were asked to measure the temperature inside each coloured tin at a particular time and observe the different properties of these tins. The experimental group was equipped with WiFi enabled mobile devices while the control group was required to perform the experiment in the traditional approach, which is without any mobile devices. Both groups had used the same concepts related to the given topic (Heat energy transfer), which were already covered in their earlier classrooms. For the experimental group, the 'ThinknLearn' application was used to assist the participants to understand those concepts using their mobile devices as depicted in Figure 5.3.
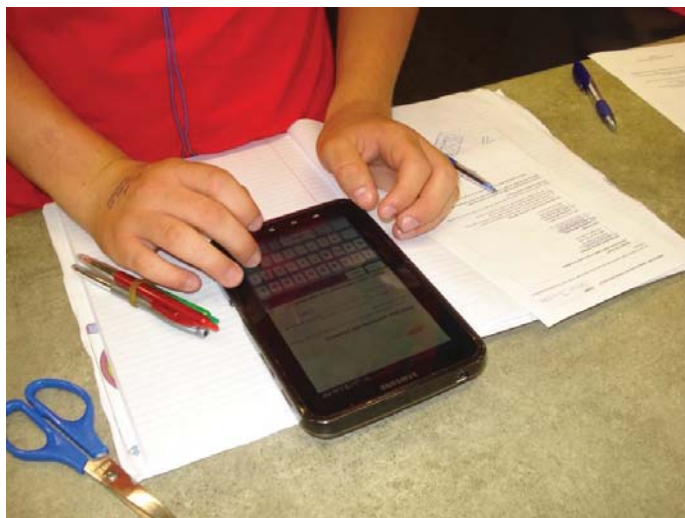
Figure 5.3 One of the experimental group participants using 'ThinknLearn'

For pre and post activities, a MCQ quiz was provided with the instructions according to each group. In addition, a questionnaire was also given to each participant of the experimental group to investigate his/her individual learning experience about the given application. However, for the retention test, participants from both groups were required to answer the same MCQs asked earlier in their pre-post activities.

5.2.4   Procedure

Initially, science teachers introduced the information about the experiment, the purpose of the study, and the data collection process for each group. For the experimental group, participants were asked to answer pre-post quizzes, filled in questionnaires and were involved in semi-structured group discussions while answering the questions posed by the researcher. However, for the control group, they were only required to answer pre-post quizzes.

In this evaluation process, both groups of participants were first asked to answer the pre-test, which was comprised of four MCQs (see Appendix VI). Following this, they were required to perform the heat energy transfer experiment. In this experiment,

they found some data values related to each investigated tin. These data values helped them to understand some key concepts discussed in the given topic. At the end of the experiment, they were asked again to answer the same MCQs with the addition of one open-ended question related to the hypothesis, with its explanation. This question was used to understand how well the participants engaged in the learning and critical thinking process during the inquiry investigation. However, both groups were provided different instructions in their post-tests (see Appendix VII and VIII) as the experimental group was additionally given mobile devices by which they could access the web application 'ThinknLearn' as shown in Figure 5.4. This application could guide them to formulate hypotheses about the given topic.

Figure 5.4 Experimental group participants involved in experimental activities

For evaluating the usability and the utility of the application, experimental group participants were also required to individually rate a 9-question questionnaire on a five-point Likert scale. This questionnaire was the same as used in the pilot study. They were also involved in semi-structured group discussions. In these discussions, participants were posed three questions in their classroom groups, which were related to the usability and the mobile learning quality aspects of the application. However, for the retention test, the same four MCQs were again asked to the participants of both

groups after a span of two months (see Appendix IX). For that purpose, they only required to answer these questions in their classrooms instead of performing science experiments again. The corresponding results are discussed in the following section.

5.2.5 Results and Analyses

The M3 Evaluation Framework supports the technology development process from the very early stages of the design to the final assessment of the technology in a learning context (Vavoula et al., 2009). In this final experiment, two levels of the evaluation were used: Micro and Meso. This section discusses the results and analyses while conducting this final experiment.

5.2.5.1 Micro level evaluation

In this micro level evaluation, the utility and the usability of the application 'ThinknLearn' were investigated. For these purposes, the responses from a quantitative questionnaire and responses from qualitative semi-structured group discussion were gathered from the experimental group participants about their learning experiences of the application. However, the control group participants were not involved at this level of the evaluation.

5.2.5.1.1 Questionnaire responses

The same questionnaire was used in this final experiment, as applied earlier in the pilot study. It was administered to the participants after they had completed the science experiment. The 9 questions in the questionnaire attempted to address different aspects of usability (*learnability*, *understandability*, *operability*) and quality aspects (*metaphor*, *interactivity*, *learning content*). 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 positive and encouraging.

a) Usability aspects

As depicted in Table 5.7, the same three questionnaire statements (S2, S3, and S4) were intended to address the fundamental aspects of usability found in the 'ThinknLearn': *learnability*, *operability*, and *understandability* (ISO, 2003).

Table 5.7 Quantitative responses of usability aspects in the final experiment

Usability aspects	No.	Statements	Mean Response ± S.E (Standard Error)
Learnability	S2	This mobile application was easy to use.	3.66 ± 0.11
Operability	S3	Navigation through this application was easy.	3.87 ± 0.11
Understandability	S4	This application guides me to formulate a hypothesis.	3.45 ± 0.11

Similar to the pilot study, the responses to statement 'S2' and 'S3' revealed that the participants found this application was not difficult to use and navigation was straightforward. The ratings on the statement 'S4' also revealed that our respondents perceived that the guidance towards hypothesis generation and the whole learning process was very easy to understand. A one sample *t*-test against the neutral value

173

3.00 confirmed these interpretations (t_{85} = 6.14, p< .01 for S2; t_{85} = 7.88, p< .01 for S3; t_{85} = 4.20, p< .01 for S4).

b) Mobile learning quality aspects

The responses for the statements about quality aspects this mobile learning application showed positive attitudes from the participants as listed in Table 5.8.

Table 5.8 Quantitative responses of the mobile quality aspects in the final experiment

Quality aspects	No.	Statements	Mean Response ± S.E (Standard Error)
Interactivity	S6	This application helps me understand the relationships between different variables.	3.50 ± 0.11
	S8	This application helps me to improve my reasoning skills.	3.28 ± 0.12
Learning Content	S1	This mobile learning experience was enjoyable.	3.66 ± 0.11
	S9	It is an effective learning application.	3.55 ± 0.11
Metaphor	S5	The given suggestions in the application were relevant.	3.74 ± 0.10
	S7	The given suggestions help me to understand the topic.	3.54 ± 0.10

According to the results, the participants experienced 'ThinknLearn' as an interactive learning as similarly suggested in the pilot study. The results of the *interactivity* aspects confirm these interpretations ($t_{85} = 4.62$, p< .01 for S6; $t_{85} = 2.38$, p< .01 for S8). The ratings on the statements S1 and S9 revealed that the participants considered that this application was an enjoyable learning experience and by and large an effective learning application ($t_{85} = 5.74$, p< .01 for S1; $t_{85} = 5.11$, p< .01 for S9). These statements cover *Learning content* (quality aspect), which describes learners' feeling about the quality of the application. Similarly, the responses to the other quality aspect, *Metaphor* showed that the participants experienced an overall vision of the learning processes ($t_{85} = 7.10$, p< .01 for S5; $t_{85} = 5.19$, p< .01 for S7). All these results validate the results from the pilot study.

5.2.5.1.2 *Semi-structured group discussions*

The same group discussion questions that were used earlier in the pilot study were posed to the participants about their learning experiences of the application. In this experiment, 25 groups consisting of 86 students from three science classes participated. For analysis purposes, directed content analysis (Hsieh & Shannon, 2005) was used as applied in the pilot study. Further, this analysis was begun with the same categories mentioned in the pilot study (see Table 5.4). However, some new categories were also included during this final experiment as presented in Table 5.9.

After identifying key categories from the data and their frequencies, some codes were assigned as presented in Table 5.9. Similar to the pilot study, these categories were further combined into themes according to the nature of the responses. The same themes mentioned in the pilot study were used in this final experiment (see Table 5.10). However, in this analysis, the number of categories was increased from 8 to 11. Apart from this, the total frequencies of each of these themes were also calculated by adding the frequencies of the combined codes as presented in Table 5.9.

Table 5.9 Group discussion questions, categories and their frequencies in the final experiment data

Q.No.	Questions	Categories	Frequency	Code No.
1	What type of difficulty do you find in using this application?	Easy to use	21	I
		Easy to understand	15	II
		Helpful in understanding a topic	17	III
		Difficulty in understanding questions	10	IV
		Confusion in hypothesis generation	6	V
2	How do you feel after using this application?	Enjoyable experience	64	VI
		Unpleasant experience	10	VII
3	What do you think about suggestions given in the application?	Relevant suggestions	35	VIII
		Provide guidance in generating hypothesis	11	IX
		Correct answers straightaway	5	X
		Less explanation as suggestions	12	XI

According to these discussions, the responses from the participants were straightforward and interesting. As far as the question 1 responses on theme 'Usable application' were concerned, almost 62% considered that 'ThinknLearn' was easy to use and they did not find any difficulty while using it as depicted in Table 5.10. However, there were around 16 participants who found this application difficult in terms of its guidance towards hypothesis generation ('Difficult application' as a theme) (see Table 5.10). One of the groups highlighted that "... *questions were difficult and the given suggestions were not easy to understand*". It could be argued that they did not relate suggestions to understand the given topic. However, the concepts covered in this application had already been discussed in their theory classes earlier. In another instance, one participant of the other group described how "*it was not difficult but confusing on some occasions".* Those participants who considered the application a bit confusing and difficult did not understand the deliberate purpose of this application to exploit participants' higher level skills of critical thinking in such inquiries.

In order to answer the second question of the group discussions, almost all the participants (74.4%) were positive about their learning experiences and they enjoyed using 'ThinknLearn' (see Table 5.10). One of the group participants stated that "*I really enjoyed using it. This application was pretty good and engaging, it helped you to learn about your course (science)*". The other group participants gave an interesting comment about it during the discussions as *"this type of application keeps you on focus and requires better attention but it was an interesting and enjoyable experience*". On the contrary, only ten participants had unpleasant experiences with this application. Amongst them, one group of the participants expressed their experiences as, *"it was boring and confusing and therefore, we did not like it.*" Overall, participants valued the interactivity, enjoyed the innovative way of learning, and found the application engaging as presented in Table 5.10.

177

Table 5.10 Themes and their total frequencies in the final experiment data

Q.No.	Combined Codes	Categories	Themes	Frequencies (Out of 86)
1	I, II, III,	Easy to use	Usable application	53 (61.6%)
		Easy to understand		
		Helpful in understanding a topic		
	IV, V	Difficulty in understanding questions	Difficult application	16 (18.6%)
		Confusion in hypothesis generation		
2	VI	Enjoyable experience	Engaging application	64 (74.4%)
	VII	Unpleasant experience	Boring application	10 (11.6%)
3	VIII,IX	Relevant suggestions	Good approach	46 (53.4%)
		Provide guidance in generating hypothesis		
	X, XI	Correct answers straightaway	Confusing approach	17 (19.7%)
		Less explanation as suggestions		

The responses for the theme 'Good approach' about the hypothesis generation process as providing suggestions were asked in question 3. The responses were not bad actually as around 53% participants felt that the given suggestions were relevant and made them think. However, some interesting comments were obtained related to the thinking process. One of the group participants indicated that "*these suggestions*

178

are relevant to the answers but they make us think". These group participants considered the critical thinking process as a bit of a burden, but on number of occasions, participants understood it as a challenging activity to learn from. One of the participants stated *"…it is a challenging task as we have to think and find out the answers ourselves instead of having straightaway answers but I really enjoyed and learnt the topic from this*". On the other hand, there were 17 participants who remarked like that *"…more detail should be provided" and "… relevant but they (suggestions) did not explain much".* These comments showed that this application presents some challenges to the participants to comprehend the given topic and they considered it a confusing way to generate hypotheses (see Table 5.10). It may be argued that a certain level of challenge was maintained in this application to make it more engaging and interesting. However, some ways may be needed to convince those participants about the value of this approach.

On the whole, the group discussion responses suggest that the application was engaging and the given suggestions made learners think about the knowledge space under investigation, and may exploit their critical thinking skills. The qualitative responses met the expectations in terms of software quality measures of the application. In contrast, there are some threats to validity of the responses to this group discussion such as data not being based on interactions with each individual (Silverman, 2006) or incomplete understanding of the participant's point of view (Lankshear & Knobel, 2004). In the group discussion, responses were not given by each of the individuals participating in the experiments.

5.2.5.2   Meso level evaluation

This level was used to examine the learning performance between experimental and control groups. It involved pre and post activities including answering MCQs and writing hypotheses with explanations while performing science experiments. Further,

the same MCQs test was conducted with these participants for evaluating how the participants retain their knowledge after two months. The results and analyses of this evaluation level are covered in the next section.

5.2.5.2.1   *Learning performance*

In the pre-post tests, participants were asked to answer MCQs related to the learning domain. MCQs are very common tool for assessing learners' performance on their classroom tests (Mavis, Cole, & Hoppe, 2001; Papasalouros et al., 2011; Vuk & Morse, 2012). One of the advantages for using MCQs in classroom tests is the structure of the MCQs tests. These tests can be used to eliminate the potential for examiner bias that may occur in the assessment of open-ended questions or oral examinations, because of the marking scheme, which was very straightforward; a correct answer gains a mark, a wrong answer loses a mark while no answer to questions results in zero mark (Hammond, McIndoe, Sansome, & Spargo, 1998). The other important advantage for using MCQs is the broader coverage of the topics covered in a course (Bacon, 2003). In contrast, some authors have criticized this method due to these reasons such as the limited focus of the question item, which results either hard question for students to answer or did not measure students' real knowledge about the domain (Vuk & Morse, 2012; Walsh & Seldomridge, 2006).   Another criticism to MCQs is related to the guessing answers from students without knowing the substantial knowledge of the given topic (Briggs, 1999).

Despite these threats to MCQs, this method is still used widely for testing students' achievements in classroom tests (DiBattista & Kurzawa, 2011). Thus, this study uses MCQs for evaluating learning performance during the given hypothesis generation activity between experimental and control group participants.

In this section, two paired-samples *t*-Tests were used to compare pre and post test means for both groups; experimental and control. A paired-sample *t*-Test found a

significant difference (p < .01) between scores obtained by the experimental group participants during their pre and post tests. However, another paired-sample *t*-Test, which compared mean scores of control group participants during pre and post tests, did not show statistically significant differences (p = .088). These test results reported that both group participants gained knowledge about the learning domain, before and after conducting science inquiry experiments as shown in Table 5.11.

Table 5.11 Pre and post tests means of experimental and control groups

Group	Test	Participants (N)	Mean (M)	Standard Deviation (SD)	Standard Error (SE)
Experimental	Pre	81	2.05	1.06	0.12
	Post	81	2.67	1.02	0.11
Control	Pre	75	2.09	1.00	0.11
	Post	75	2.30	0.96	0.11

In comparing these two groups, an independent sample *t*-Test was used to find out the learning performance differences. The results showed a significant difference (p = .025) with and without using 'ThinknLearn'. As a matter of fact, the control group participants obtained marginally better scores in their pre-tests as compared to the experimental group participants. Thus, these scores may be used for minimizing one of the potential threats to validity regarding the distribution of stronger classes in favour of experimental groups. However, in the post-tests, both groups improved but the experimental group gained more in learning performance than the control group as

depicted in Figure 5.5. It may be argued that the guidance provided from the application was one of the main reasons for experimental groups' better learning performance because control groups did not get any kind of assistance from the teachers or suggestions on the paper while conducting their science experiments.

	Pre-Test	Post-Test
Experimental	51.23	66.67
Control	52.33	57.67
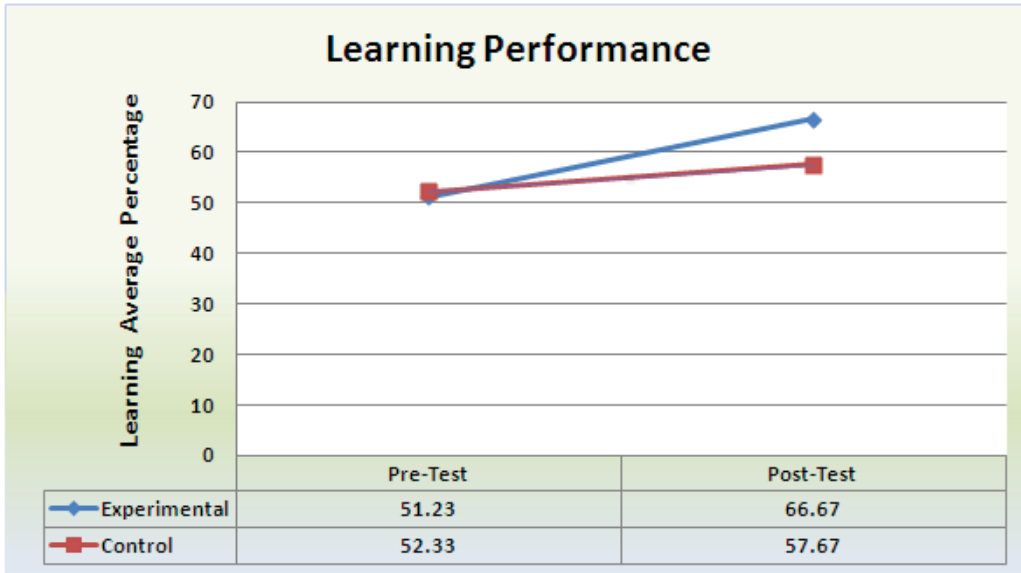
Figure 5.5 Pre-post tests comparison between experimental and control groups

5.2.5.2.2   Hypothesis formation

In the post-tests, both group participants were asked to write a hypothesis about the colour of any of these three tins with the explanation in the open-ended dialog box (see Appendix VII and VIII). As far as the marking of the open-ended question was concerned, it was mutually decided with the science teachers to mark thus: '0' for wrong (or no) hypothesis; '0.5' for a correct hypothesis but a wrong explanation; '1'for a correct hypothesis with its explanation. As an example, one of the answers from the participants who got '1' mark for a correct hypothesis with its explanation was "*Black tin absorbs more heat energy than the other tins and loses more heat energy than the others therefore it keeps the water cool from the inside*". Given that such answers are open to interpretation, and the marking scheme is coarse grained, there is the

potential for bias, which should be taken into account when analysing these results. However, for reducing the variability within the marking of the open-ended question, a marker was assigned to mark all these tests. In addition, the marker was unaware of the group distributions, but there may be a chance that a marker noticed those differences while marking these groups.

According to the applied independent sample t-Test, the results find a significant difference (p = .017) between both groups. The experimental group participants got improvements in their critical thinking and learning while formulating hypotheses about the learning domain. However, the control group participants did not appear to understand the given topic so well and therefore were not able to formulate hypotheses and their explanations at the same level as the experimental group. The participants' scores in percentages confirming these interpretations as illustrated in Figure 5.6.
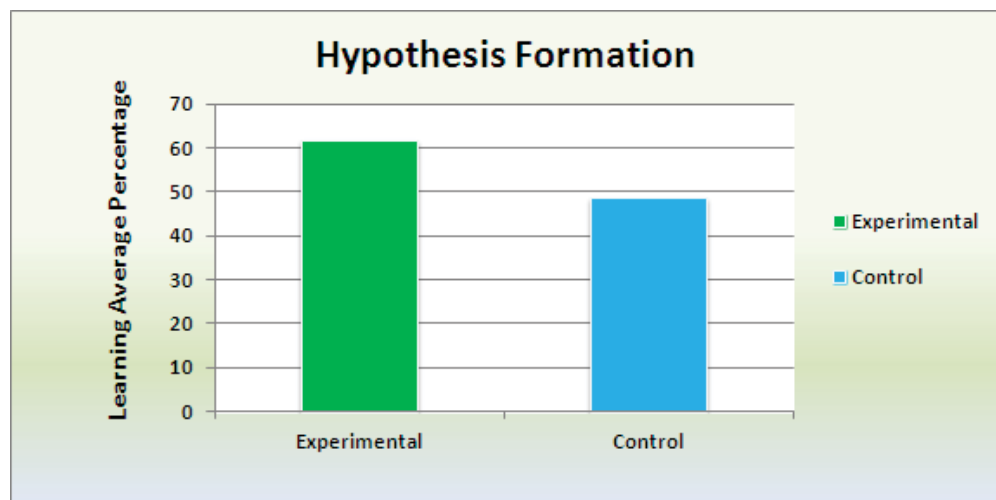
Figure 5.6 Comparison between experimental and control groups in hypothesis formation

5.2.5.2.3   *Learning retention*

The learning retention test was carried out with both groups after two months. In this retention test, only MCQs were asked about the same topic, which was explored in

earlier tests. Both groups' participants performed well in their retention tests but the number of the students' participation was reduced from the previous pre-post tests.

Two paired-samples *t*-Tests were used to evaluate the mean differences between post-test and retention test scores obtained by both groups as listed in Table 5.12. For the experimental group, the paired-sample *t*-Test found a significant difference (p = .012) in retaining participants' knowledge about the given topic after two months. In contrast, the control group participants did not retain significantly in the same time duration. A paired-sample *t*-Test confirmed this interpretation (p = .137).

Table 5.12 Post and retention tests means of experimental and control groups

Group	Test	Participants (N)	Mean (M)	Standard Deviation (SD)	Standard Error (SE)
Experimental	Post	67	2.61	1.04	0.13
	Retention	67	2.97	0.85	0.10
Control	Post	58	2.34	0.89	0.12
	Retention	58	2.60	1.04	0.14

With respect to the comparison between these two groups, an independent sample *t*-Test was used to find out the learning retention differences. The results demonstrated a difference between groups after two months that was statistically significant (p = .032). This showed that the experimental group participants retained advantage for using the application over a period of time as depicted in Figure 5.7. However, the fact of the matter is that both groups' participants maintained their score differences in retention tests from their earlier post-tests. One of the reasons for these results might

be that the participants' final examination would be started in few weeks time. Hence, it may be speculated that both groups' participants were involved in revising their theoretical knowledge of a given topic, which assists them to perform better in these retention tests.
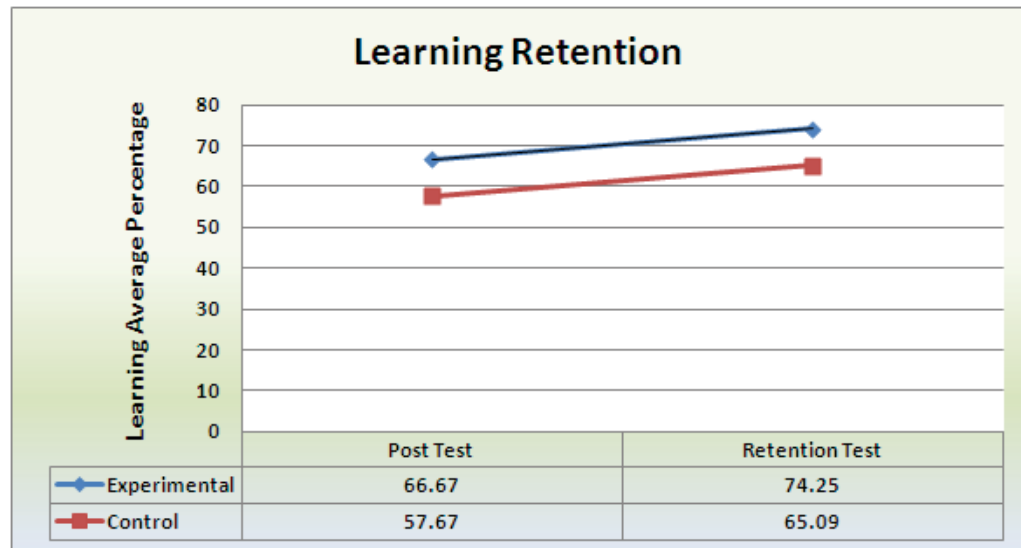
Figure 5.7 Post and retention test scores comparison between experimental and control groups

5.3 Summary

In this chapter, the experimental results from both the experiments have been discussed. In the pilot study, only the Micro level of the evaluation framework (Vavoula & Sharples, 2009; Vavoula et al., 2009) was used while the Meso level along with the Micro level were applied for conducting the final experiment as described in Figure 5.8.
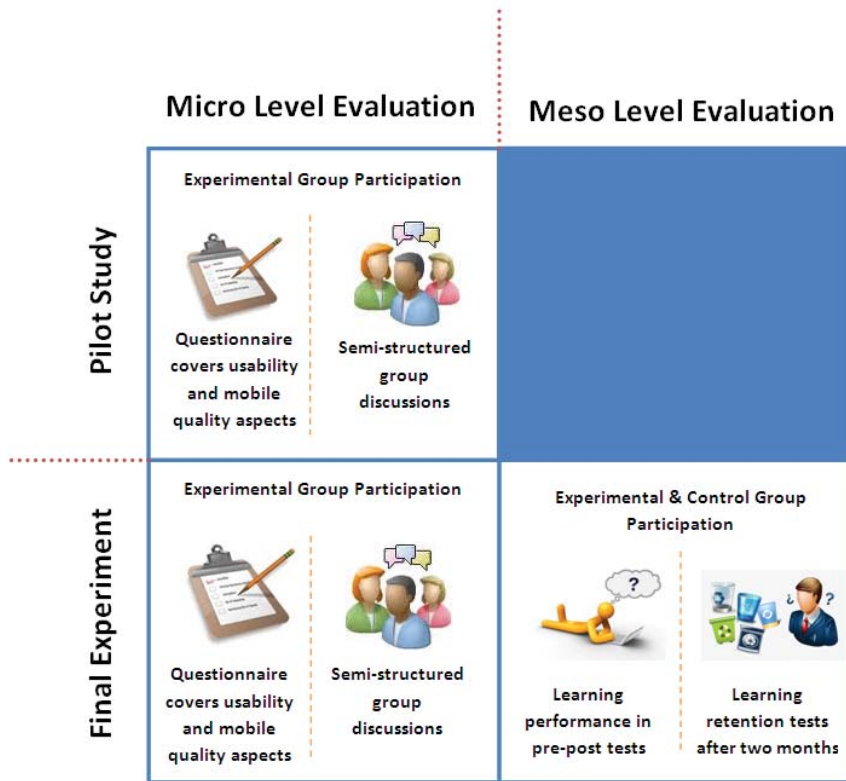
Figure 5.8 Evaluation summary of the experiments

The basis for the pilot study was to evaluate 'ThinknLearn' in terms of its utility and usability aspects only (Micro level evaluation). For the usability purposes, three ISO Metrics (ISO, 2003) including *learnability*, *understandability* and *operability* were used. These aspects focus on the capability of the application to be understood, learned, and operated, when used under specific conditions (Bevan, 2001). In addition, quality aspects including *metaphor*, *interactivity* and *learning content* were used in order to identify the quality of the learning experiences of the learners (Parsons & Ryu, 2006).

The pilot study was conducted with 23 students in 8 groups of a local high school to evaluate the designed application. In this experiment, students were required to compare three tins how they radiate heat energy and then use the application to generate hypothesis about the underlying topic. The responses from the students

186

were collected through a 9-question questionnaire and semi-structured group discussions after using the application. The overall responses were encouraging, which suggest that 'ThinknLearn' provided substantial software quality measures including usability and quality aspects required for any mobile learning application. However, this small sample size of students may not be ideal for evaluating such applications. Therefore, this evaluation level of the application was again investigated with a large sample size in the final experiment.

In the final experiment, both Micro and Meso level were used to evaluate the use of 'ThinknLearn'. A total of 161 students were grouped into experimental and control groups, participated in this experiment. Amongst them, 86 were considered as the experimental group, which was provided with the application to perform the science experiment while 75 students involved as the control group to conduct the same experiment without using the application.

At the Micro level of evaluation (Vavoula et al., 2009); only the experimental group was asked to answer the same 9-question questionnaire and semi-structured group discussions used in the pilot study. The responses about this level were also promising and showed that students developed their positive attitudes towards the use of 'ThinknLearn'. On the other hand, in the Meso level evaluation (Vavoula et al., 2009), the evaluation of the learners includes learning performance and critical thinking skills to generate hypothesis of the given topic as well as their overall learning experiences. For these purposes, the experiment was comprised of pre and post activities including answering MCQs and writing hypotheses with their explanations. In addition, a learning retention test was conducted after two months when pre-post tests were conducted.

According to the results of pre-post tests, the students who used this application performed significantly better compared to those who did not use it while

experimenting. In addition, the results find significant differences in accordance with the use of 'ThinknLearn' for constructing hypotheses about the underlying topic. However, in retention tests, both groups' participants maintained their score differences as they were achieved in their post-tests two months back. Overall, the results indicated that the application 'ThinknLearn' has considerable software quality measures and the use of this application has enhanced learners' learning performance and critical thinking skills in mobile science inquiries.

Discussion

This chapter discusses the research findings from the design and evaluation perspectives of the application 'ThinknLearn' while comparing with the other studies found in the literature. Further, how these findings can be implied to the current theory and practice are addressed in the subsequent section.

6.1 Research Findings

The research findings of this thesis contribute to the literature in two ways: use of ontology-based scaffolding in a learning application, and the evaluation of mobile application for abductive form of science inquiries. Both these aspects are discussed in the following sections.

6.1.1 Ontology-based Scaffolding in Learning Applications

In the area of educational research, ontology-based scaffolding has been used previously in number of studies for generating learning content for either one or both purposes; course content and assessment (Al-Yahya, 2011; Ghidini et al., 2007; Jovanovic et al., 2009; Melia et al., 2005; Vas et al., 2009). However, these studies highlight the creation of ontologies without practical evaluation in applications.

Similarly, in the literature related to science education, support for designing inquiry learning activities by using ontology-based scaffolding has been explored in some studies, such as Chu et al. (2011), De Jong et al. (2011), Kolodner et al. (2003) and Van Joolingen et al. (2007). Although, these studies underline some reasonable opportunities for science learning by developing ontologies of different science topics, but these studies did not focus on the practical evaluation of the use of ontology-based scaffolding in a science inquiry activity. In addition to that, none of these studies target mobile learning environments as well as abductive form of inquiry investigations.

In the case of this research, ontology-based scaffolding has been used for generating learning content in the form of suggestions and multiple choice questions (MCQs) for specific learning activities. Further, these MCQs followed property-based strategies (Papasalouros et al., 2011) for creating question items and distracters. These MCQs and suggestions are generated through the use of the technical architecture (see Figure 4.11), which evaluated the roles of semantic understanding and reasoning capabilities between different concepts defined in the ontologies. The practical evaluation of such ontology-based scaffolding was not previously discussed in the literature. Thus, a proposed application 'ThinknLearn' has been developed and evaluated to support the use of ontology-based scaffolding in a learning application by using design science research methodology (DSRM) (Peffers et al., 2008).

The practical demonstration of 'ThinknLearn' provides insights how ontology-based scaffolding can be implemented in a learning activity, particularly abductive form of science inquiries. This particular finding opens the doors for new directions in the research by which ontology-driven applications can be implemented for generating learning content in a learning activity. Further, other potential uses of ontologies can be also evaluated in applications such as packaging and interoperability, organization

and sequencing, metadata and annotation, and exchange and sharing (Pahl & Holohan, 2009), which were sparsely explored in the literature.

This research can also be considered as a guideline for applying DSRM in order to carry out design science research because this thesis follows each and every step of this methodology (Peffers et al., 2008) to address the research challenges drawn from the literature.

6.1.2 Mobile Abductive Science Inquiry

The results and analyses reported in the earlier chapter indicate that the application 'ThinknLearn' has considerable software quality measures including usability (ISO, 2003) and mobile quality aspects (Parsons & Ryu, 2006). The analyses of the data collected suggest that the application can benefit in number of ways. Among other things, questionnaire responses revealed that students were able to learn domain knowledge being presented in the application and generate scientific hypotheses. In the same way, semi-structured group discussion revealed that the application was engaging and it made students think about the defined domain concepts.

Apart from these software quality measures, 'ThinknLearn' was evaluated students' learning performances during pre-post and retention tests. The empirical data presented in this thesis make a case for the use of 'ThinknLearn' and provide some insights as to why it might be a more effective way of generating scientific hypotheses than the traditional pedagogy. The results and analyses indicate the significant differences in comparison of the learning assessments between experimental and control groups as depicted in Figure 5.5. For learning retention, an interesting result occurred, which indicates that both experimental and control groups' participants improved in scores steadily from their last tests, conducted two months back (see Figure 5.7). However, there are diverse results found in the literature regarding the

benefits of mobile learning in the classroom in terms of learning performance and learning retention. In this regard, some significant work has been done in the past in which researchers found that the use of mobile learning applications fostered positive attitudes towards school education, particularly in learning assessments (Chen & Hsu, 2008; Lai et al., 2007; Zurita & Nussbaum, 2004). The results of these studies showed that participants performed better in their learning activities using technology-assisted learning environments. However, in some other studies the results showed that there was not such difference in participants' learning performance with and without using a mobile learning application (Park, Parsons, & Ryu, 2010).

In the literature related to school sciences, there are many studies (Chen et al., 2008; Huang et al., 2010; Shih et al., 2010) stating that participants equipped with mobile learning applications while performing science learning activities, enhanced their knowledge compared with those who were involved in traditional ways of science learning. Specifically to hypothesis formation activities, there are some studies found in the literature that showed that students have capabilities to make scientific hypotheses and their explanations when appropriate resources are provided to them during science inquiry investigations (Mulder, Lazonder, & De Jong, 2010; Oh, 2011; Peker & Wallace, 2011). However, none of these studies demonstrated the benefits of mobile learning in hypothesis formation activities in the context of abductive science inquiry investigations.

Regarding learning retention, in one study Sandberg et al. (2011) stated that the participants were not able to retain knowledge over a period of time when using a mobile learning application in formal and informal learning environments. In another study, the learning performance of the experimental and the control groups was not significantly improved after five weeks duration (Zhang, Song, & Burston, 2011). On the contrary, there are a few studies which resulted in favour of the use of mobile devices for long term learning retention such as Fozdar and Kumar (2007); Rubio,

White, and Brant (2008); Shih, Chu, Hwang, and Kinshuk (2011). The varying results of these studies do not give a clear indication whether mobile learning can enhance students' performance in their learning activities or if comprehension of domain knowledge can be retained for a longer period of time. These diverse results demand further exploration of the potential benefits of mobile learning.

6.2 Implications of the Research

This research demonstrates to educators how ontology-driven application can be implemented practically for abductive science inquiry investigations. The theoretical and practical implications of this research are explained in the following sections.

6.2.1 Implications for Theory

The thesis mainly contributes to the literature of these areas; use of ontologies in a learning application, abductive form of inquiry investigations in the school sciences and mobile learning experiences in classroom activities in number of ways as listed below:

The evidence from this research suggests that the use of ontology-based scaffolding in learning environments can play an important role for providing adaptive presentation of learning content. It is supported in this study with the help of the practical demonstration of 'ThinknLearn'. The findings further confirmed this evidence by showing that the pre-designed digital resources can provide extensive guidance to facilitate meaningful science learning and promote significant gains in learning performance of the learners.

This work suggests the practical demonstration of Abductive Inquiry Model (AIM) (Oh, 2011) in a technology-assisted learning environment which was not previously discussed in the literature. The findings of this research suggest that the

implementation of such applications not only assists learners in better understanding the domain knowledge but also provide a certain level of challenge to exploit learners' critical thinking skills while performing such inquiry activities.

For the mobile learning literature, this research indicates that the learners valued the interactivity, enjoyed the innovative way of learning and found the application engaging. Apart from these, this also highlights the affordances of mobile technologies in situ learning where learners are involved in their activities even at a fixed location (Science laboratory). This supports the other proponents who conceptualise mobile learning in terms of learners' experiences using mobile technologies without the need of any movement across different locations (Kukulska-Hulme & Traxler, 2005; Parsons et al., 2007; Traxler, 2007). Further, this research also reports that the learners who were involved in using the application 'ThinknLearn' performed better than the ones who did not, in the pre-post tests. However, the learners who were performed better in post tests carried the same advantage in their retention tests (conducted after two months from pre-post tests). These favourable results of the study present some insights about learners' positive attitudes towards the adoption of mobile learning applications in their classroom activities.

6.2.2 Implications for Practice

For the learning application developers, this thesis provides an example of how to implement ontology-driven applications in learning environments. A technical architecture is discussed in this thesis that supports the dynamic generation and presentation of learning content in a specific context. However, this technical architecture may be used for other similar purposes where ontologies are used to generate and present content in technology-assisted learning environments.

This research may inform ontology developers of the potential value of ontologies in education, particularly for adaptive content presentation in multiple ways: course content and MCQs. Hence, it may be implied from this research that the presentation of learning content can provide different learning opportunities where learners can obtain domain knowledge according to their preferences and needs.

This research also highlights the abductive form of reasoning in school sciences where learners are challenged in explaining scientific hypotheses (Haig, 2005; Oh, 2010), which has been sparsely explored in the previous studies. As a matter of fact, this work is one of the first of its kind where abductive mobile science inquiry is being investigated with high school students. Therefore, this research exhibits science educators and about how technology-assisted abductive science inquiry learning activities can be designed and implemented in school contexts.

This research also provides guidelines for design science researchers to address a well-defined research problem and how an artefact can be developed iteratively by using DSRM.

Conclusion and Future Work

This chapter summarizes the work conducted within the thesis. In the conclusions, it elaborates how the main research question is addressed in this study. Subsequently, some limitations of the research work along with an indication of some directions in which this research may be extended are described. At last, the thesis concludes with the final remarks in the epilogue section.

7.1 Conclusion

The work presented in this thesis makes a case for the use of ontologies in mobile science inquiry investigations where learners are engaged in exploring and experimenting in contextual learning activities. This can promote deeper understanding of a particular science domain and can guide learners in interpreting data to create meaningful hypotheses.

The main purpose of the study described in this thesis is to demonstrate to science educators how an abductive mobile application might be implemented in a science inquiry activity. It is suggested that this kind of practical ontology-based application may be useful to support extensive guidance to learners during such inquiry activities. This section further describes how this thesis addresses the defined research question and the other three sub-questions.

7.1.1 Revisiting the Research Questions

Figure 7.1 describes the application design process that was followed by using the design science research methodology (Peffers et al., 2008) as introduced in Chapter 3. Further, the different parts of this design process address sub-questions of this research and the implementation of research design iterations as highlighted in Figure 7.1.
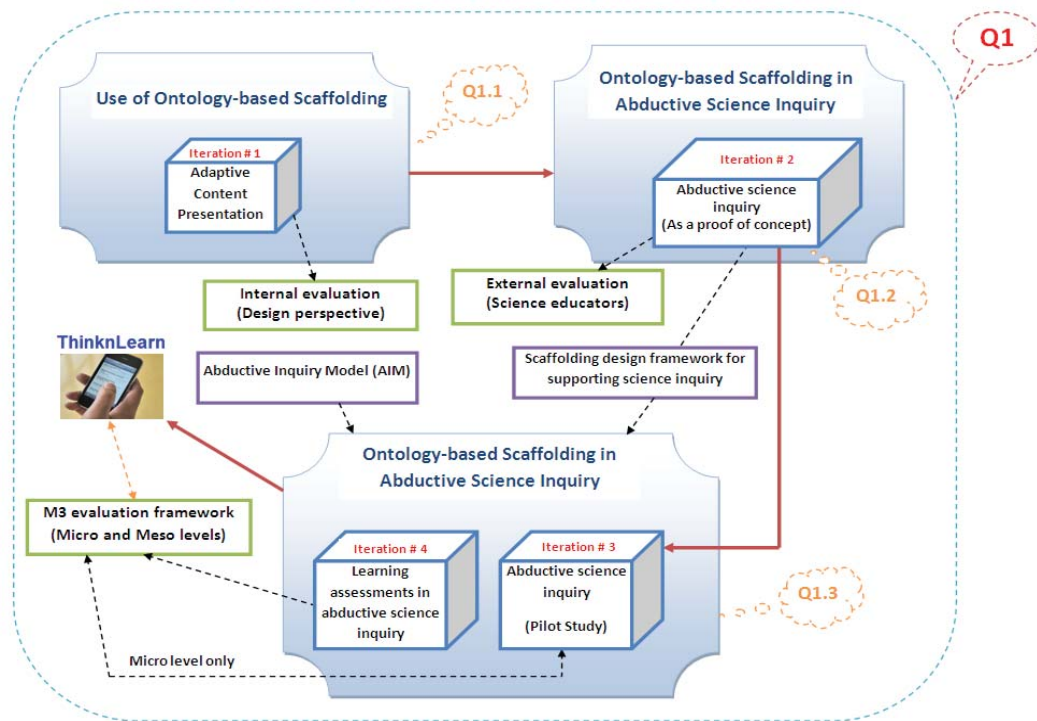
Figure 7.1 Addressing research questions

Q 1: How can an ontology-based scaffolding application provide learning content in mobile abductive science inquiry-based learning environments?

Chapter four of this thesis presented the research design iterations and explained how the proposed application 'ThinknLearn' came into existence. The basic motivation for answering this research question remains intact with the challenges addressed earlier in the introduction chapter of this thesis: *ontology-based scaffolding*, *abductive science*

inquiry and *mobile learning experience*. For that purpose, three sub-questions were derived using Activity Oriented Design Methods (AODM) tools (Mwanza-Simwami, 2009) as mentioned in chapter three of the thesis. These sub-questions are described below.

Q 1.1: How can an ontology-based scaffolding application ensure access to learning content in a learning space?

Sections 4.1 in this thesis demonstrated the use of an ontology-based scaffolding application for accessing learning content, also shown here in Figure 7.1. This question was answered through the implementation of the first research design iteration. This iteration was related to the use of ontology-based scaffolding for presenting learning content in multiple ways: tutorial and multiple choice questions (MCQs). However, at that time, the focus was the use of domain ontology in an application rather than the actual implementation of a learning application for a particular domain.

Q 1.2: How can an ontology-based scaffolding application be used for accessing learning content in an abductive science inquiry-based learning environment?

Section 4.2 of this thesis showed how ontology can be used for accessing learning content in an abductive science IBL environment. For answering this question, an ontology supported IBL activity was designed as a proof-of-concept as illustrated in Figure 7.1. This learning activity was focused on a science inquiry, particularly abductive form of inquiry investigation in which learners needed to generate scientific hypotheses about the underlying domain. However, this application was designed as a showcase to group of science educators discussing how such mobile inquiry learning application can be implemented.

Q 1.3: How can an ontology-based scaffolding application guide mobile learners in an abductive science inquiry-based learning environment?

Section 4.3 and section 4.4 of this thesis answered this question by presenting last two iterations of this application 'ThinknLearn'. One of these iterations was designed to employ the actual example in school science context as decided earlier in a meeting with group of science educators. In this iteration, only Micro level evaluation (Vavoula et al., 2009) was used which explores the usability and mobile quality aspects of the application. However, the same application was further used to evaluate learners' assessments using both levels: Micro and Meso (Vavoula et al., 2009) as depicted in Figure 7.1. These levels were used to examine the usability along with mobile quality aspects of the application and its impact on learners' assessments in their pre-post and retention tests.

7.2 Research Contributions

This research is one of its first kinds where abductive mobile science inquiry is being investigated with high school students. This research demonstrates to science educators how ontology-driven application can be implemented practically for such kinds of inquiry investigations.

This research has made several contributions:

The main contribution of the thesis is to develop and evaluate an abductive mobile web-based application that provides an opportunity to learners to use their critical thinking skills for understanding the given scientific knowledge. This thesis also contributes in the practical demonstration of the abduction theory in school sciences using technology-assisted learning environments.

The other contribution is related to in-depth understanding of ontologies and the implementation of ontology-driven application 'ThinknLearn'. Specifically, in generating and presenting learning content in two ways: course content and multiple choice questions.

The use of design science research methodology (DSRM) for designing this application 'ThinknLearn' is relatively a novel approach to address a well-defined research problem and also provide new insights to researchers about how DSRM can be implemented. Hence, this research work contributed to IS research methodology in order to define how an artefact can be developed iteratively by using DSRM.

The few other additional innovative contributions of this research work including the use of Activity-Oriented Design Methods (Mwanza-Simwami, 2009), Abductive Inquiry Model (Oh, 2011), the part of M3 Evaluation framework (Vavoula et al., 2009), a technological layer of a mobile learning framework (Sharples et al., 2005) and the technical architecture (Draganidis et al., 2008) for designing abductive mobile web application.

Apart from this, the application 'ThinknLearn' is also shared amongst community as an open source project for providing guidelines to educators and developers not only apply to science inquiry domains but also in other professional areas. The project URL can be accessed from: https://sourceforge.net/projects/thinknlearn/

7.3 Limitations of the Research

There are some limitations to this research. One of these limitations is about the representation of a sample from a single science inquiry context, which would need to be repeated in similar contexts to validate the results. Apart from this, it may not be stated to what extent these results may be generalisable to other technology-assisted science IBL activities. Further, this research had no control over the grouping of the students, and since they performed the experiments in groups, there may be a chance that students worked together in answering MCQs and writing hypotheses with their explanations. The other limitation of this research relates to the students from a local high school, a fact that might mean that the promising results of this research may be

locally biased. Therefore, it may be suggested that this work should therefore be replicated with other sample populations to include students from diverse schools.

It is a normal practice in classes that the teachers or instructors design assessment tests for evaluating learners' learning performance in a particular task or activity. Similarly, in this research, science teachers had designed pre-post tests for this specific task. However, for marking these tests, the science teachers were busy in their school work at that time. In consultation with the science teachers about this issue, a marking scheme was agreed, following the answers suggested by the science teachers. For the MCQs, it might not make any difference but there may be the potential for bias while marking open-ended question, related to the hypotheses with their explanations. Given that such answers were open to interpretation, and the marking scheme was coarse-grained, this could be one of the limitations of this research. There is another limitation regarding the use of ontologies of particular domains in this thesis. These ontologies are used as examples for constructing learning content as MCQs in this specific application. However, they may be extended to use in some other contexts but it may not be considered as the only way to structure domain concepts of these ontologies.

Apart from these limitations from the conducted experiments, this research adopts only the technological layer of a mobile learning framework (Sharples et al., 2005) because this layer proposes requirements for the design and evaluation of new technology-assisted mobile learning applications. Moreover, while considering the activity model of this application 'ThinknLearn', only the 'Tool' component of the model was used to generate research questions in this research.

The other limitation of this research comes from the use of the evaluation framework (Vavoula et al., 2009). In which only two levels (Micro and Meso) were used for evaluating the proposed application 'ThinknLearn'. However, at this stage of the

research, Macro level of evaluation is not yet possible because this level examines the longer term impact of any new technology on educational practices (Vavoula & Sharples, 2009).

7.4 Future Research Opportunities

The combination of three different areas including abductive form of science inquiry-based learning, mobile learning and ontologies are introduced in this thesis. However, there are number of future research opportunities that promise interesting results and insights for the research on these areas either separately or jointly. These future opportunities are mentioned in this section according to each research area and future extension required to the application 'ThinknLearn'.

7.4.1 Abductive Form of Reasoning

In the previous literature related to school sciences, the abductive form of reasoning in inquiry investigations has been sparsely explored. Therefore, this research provides an opportunity to demonstrate to science educators the practical implementation of abduction theory in school sciences where learners involve themselves in abductive form of reasoning while performing inquiry activities. However, there is a different dimension of this research area where researchers are keen to use this form of reasoning in the context of ontology-driven applications (Bada, Mungall, & Hunter, 2008; Elsenbroich, Kutz & Sattler, 2006; Klarman, Endriss, & Schlobach, 2011). In which, these applications may use this reasoning technique to infer information embedded within the ontologies. In addition, they may be further extended to explore how well abductive reasoning performs while accessing learning content embedded within ontologies.

Applications of this abductive form of reasoning can be applied to other professional fields of interest where researchers or educators want to explore abduction as a form of reasoning such as medical diagnostics, jury deliberation, scientific theory formulation, accidental investigations (Ross, 2010).

7.4.2 Mobile Learning

The use of mobile technologies in science IBL activities is not new. What is new, are the ways to perform scientific inquiries with the help of abduction theory. There are some opportunities for future research while considering some other variables not accounted for in this study, such as learners' learning styles, motivation, engagement, emotions and other personality traits of learners. In future, this kind of learning activity may be further demonstrated in outdoor settings where learners need to engage in a physical environment and the application may collect the observational data directly with the help of mobile and sensor technologies that is Ubiquitous learning environment (Liu & Hwang, 2010).

Even though the mobile learning activity discussed here in this thesis was conducted in groups, their collaborative efforts for generating scientific hypotheses were not evaluated. This provides a new direction for future research in this area where mobile collaborative learning may play an important role in abductive form of inquiry investigations.

7.4.3 Ontologies

It is recommended that the other uses of ontologies in technology-assisted learning environments which are not discussed in this thesis; packaging and interoperability, organization and sequencing, metadata and annotation, and exchange and sharing (Pahl & Holohan, 2009), may provide the basis for new research directions in future. In the last two iterations of this thesis, a domain ontology of a particular experimental

context was used. There may be an opportunity for future researchers and ontology developers to design an abductive inquiry ontology that can be applied to any kind of abductive science IBL activities. Further, learner and context ontologies may be leveraged with this designed inquiry ontology to develop adaptive and personalized abductive science IBL environments.

Besides these future directions in this area, there is another interesting and potential area of research which argues for the usefulness of abductive reasoning in the context of ontologies (Elsenbroich et al., 2006). There are some open research opportunities in this area, such as the discovery of Description Logics (DLs) that admit tableau-based reasoning (Moller & Haarslev, 2008) techniques for abduction and the study of their computational complexity, and the identification of restrictions on applications, specifically motivated by reasoning over ontologies (Elsenbroich et al., 2006).

7.4.4 Extension to the 'ThinknLearn'

An extended version of the 'ThinknLearn' may be designed for teachers or instructors so that they may generate learning content according to their needs. For instance, learning content (suggestions) may be provided according to learners' knowledge levels (novice or expert) or their learning styles. This extended version may be further evaluated in order to comprehend how such adaptivity features in these kinds of applications may affect learners' learning performance and their learning experiences. Moreover, this research only compares the use of the 'ThinknLearn' with the traditional pedagogy approach (paper-based). However, this work may be extended to compare these two approaches with the context-aware learning approach, which generally applies to content adaptation and device-independence to serve different learners and their situated mobile learning environments (Li et al., 2009).

The Macro level of the evaluation framework (Vavoula et al., 2009) is not considered in this thesis because it is used to examine the longer term impact of the new technology on established learning practices. If this new inquiry practice (abductive) has emerged in supporting science learning in schools, as 'ThinknLearn' is designed for this purpose, then this Macro level needs to be evaluated extensively in the future.

There are some other extensions that can be made to 'ThinknLearn' by enhancing its features with the help of the above discussed future directions in each research area of interest.

7.5 Epilogue

The design process as described in the thesis ends with the development and evaluation of a new, innovative, and potentially useful learning application. As a matter of fact, applications are designed to aid practice, but on the other hand, they may also change and affect practice to some extent. Therefore, the way an application is designed cannot be determined until it is actually used by the target audience in actual settings. On the other hand, with the adoption of new technology, opportunities and circumstances enable users to do activities that may change the way they perceive and perform activities before.

In these regards, this thesis introduces an exciting mobile web application that supports abductive science inquiry learning activities in classroom settings. In this application 'ThinknLearn', dynamic learning content are provided by using ontology-based scaffolding. This scaffolding can be seen as a prospect for future development of learning applications not only in science inquiry investigations but also in other learning domains to progress towards a better understanding of the rapidly changing society.

References

Ahmed, S., & Parsons, D. (2011). ThinknLearn: An ontology-driven mobile web application for science enquiry based learning. *In Proceedings of the 7th International Conference on Information Technology and Application (ICITA 2011)* (pp. 255-260)*.* Sydney, Australia: IEEE Computer Chapter NSW.

Ahmed, S., & Parsons, D. (Best paper award) (2012). Evaluating 'ThinknLearn': A mobile science inquiry-based learning application in practice. *11th World Conference on Mobile and Contextual Learning (MLearn 2012).* Helsinki, Finland.

Ahmed, S., Parsons, D., & Mentis, M. (2012). An ontology supported abductive mobile enquiry based learning application. *In proceedings of the IEEE International Conference on Advanced Learning Technologies (ICALT 2012)*. Rome, Italy.

Ahmed, S., Parsons, D., & Ryu, H. (2010). Supporting adaptive learning interactions with ontologies.*In Proceedings of 11th Annual ACM SIGCHI NZ Conference on Computer-Human Interaction (CHINZ 2010)* (pp. 17-24). Auckland, New Zealand.

Al-Hmouz, A., Shen, J., & Yan, J. (2009). A machine learning based framework for adaptive mobile learning. In M. Spaniol, Q. Li, R. Klamma, & R. W. Lau (Eds.), *Advances in Web Based Learning - ICWL 2009* (Vols. LNCS 5686, pp. 34-43). Springer-Verlag Berlin Heidelberg.

Altin, H., Pedaste, M., & Aabloo, A. (2011). Educational robotics and inquiry learning:A pilot study in a web-based learning environment. *In Proceedings of 11th International Conference on Advanced Learning Technologies* (pp. 224-226). Georgia, USA: IEEE Computer Society.

Al-Yahya, M. (2011). OntoQue: A question generation engine for educational assessment based on domain ontologies.*In Proceedings of IEEE International Conference on Advanced Learning Technologies* (pp. 393-395). IEEE Computer Society.

Amaratunga, D., Baldry, D., Sarshar, M., & Newton, R. (2002). Quantitative and qualitative research in the built environment:application of 'mixed' research approach. *Work Study, 51*(1), 17-31.

Antoniou, G., & Van Harmelen, F. (2009). Web Ontology Language: OWL. In S. Staab, & R. Studer (Eds.), *Handbook on Ontologies* (pp. 91-110). Springer-Verlag Berlin Heidelberg.

Archer, L. B. (1984). Systematic method for designers. In N. Cross (Ed.), *Developments in Design Methodology* (pp. 57-82). London: John Wiley.

Ardito, C., Costablie, M. F., De Marsico, M., Lanzilotti, R., Levialdi, S., Roselli, T., & Rossano, V. (2006). An approach to usability evaluation of e-learning applications. *Universal Access Information Society, 4(3)*, 270-283.

Avraamidou, L. (2008). Propects for the use of mobile technologies in science education. *Association for the Advancement of Computing in Education Journal, 16*(3), 347-365.

Baader, F., Horrocks, I., & Sattler, U. (2005). Description logics as ontology languages for the semantic web. In D. Hutter, & W. Stephan (Eds.), *Mechanizing Mathematical Reasoning* (Vol. LNAI 2605, pp. 228-248). Springer-Verlag Berlin Heidelberg.

Baader, F., Knechtel, M., & Penaloza, R. (2009). A generic approach for large-scale ontological reasoning in the presence of access restrictions to the ontology's axioms. In A. Bernstein, D. R. Karger, T. Heath, L. Feigenbaum, D. Maynard, E. Motta, Thirunarayan, K. (Eds.), *The Semantic Web - ISWC* (Vols. LNCS 5823, pp. 49-64). Springer-Verlag Berlin Heidelberg.

Bacon, D. R. (2003). Assessing learning outcomes: A comparison of multiple-choice and short-answer questions in marketing context. *Journal of Marketing Education*, *25*, 31-36.

Bada, M., Mungall, C., & Hunter, L. (2008). A call for an abductive reasoning feature in OWL-reasoning tools toward ontology quality control. *In Proceedings of the fifth OWL experiences and directions workshops (OWLED 2008).*

Banchi, H., & Bell, R. (2008). The many level of inquiry. *Science and Children*, 46(2), 26-29.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education* (Vol. 1). New York: Springer.

Bates, A. W., & Poole, G. (2003). *Effective teaching with technology in higher education.* San Francisco: Jossey-Bass.

Baudin, V., Faust, M., Kaufmann, H., Litsa, V., Mwanza, D., Pierre, A., & Totter, A. (2004). The Lab@Future Project "Moving towards the future of e-Learning". *Technology Enhanced Learning. IFIP TC3 Technology Enhanced Learning Workshop (TeL'04), World Computer Congress.* Toulouse, France.

Bell, T., Urhahne, D., Schanze, S., & Ploetzner, R. (2010). Collaborative inquiry learning: Models, tools and challenges. *International Journal of Science Education, 32*(3), 349-377.

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education, 93*, 26-55.

Berri, J., Benlamri, R., & Atif, Y. (2006). Ontology-based framework for context-aware mobile learning. *In Proceedings of the 2006 International conference on wireless communications and mobile computing* (pp. 1307-1310). Vancouver, Canada: ACM.

Bevan, N. (2001). International standards for HCI and usability. *International Journal of Human-Computer Studies*, 55(4), 533-552.

Bittencourt, I. I., Isotani, S., Costa, E., & Mizoguchi, R. (2008). Research directions on semantic web and education. *Interdisciplinary Studies in Computer Science, 19*(1), 60-67.

Blachowicz, J. (2009). How science textbooks treat scientific method: A philosopher's perspective. *British Journal for the Philosophy of Science, 60*(2), 303-344.

Bodker, S. (1991). Activity theory as a challenge to system design. In H. E. Nissen, H. K. Klein, & R. Hirschheim (Eds.), *Information System Research: Contemporary Approaches and Emergent Traditions* (pp. 555-564). North Holland: Elsevier Science Publishing BV.

Bodker, S. (1997). Computers in mediated human activity. *Mind Culture and Activity , 4*(3), 149-158.

Bodker, S., & Petersen, M. G. (2000). Design for learning in use. *Scandinavian Journal of Information Systems, 12*, 61-80.

Bodker, S., Knudsen, J., Kyng, M., Ehn, P., & Madsen, K. H. (1988). Computer support for cooperative design. *In Proceedings of the ACM CSCW 88 Conference on Computer-Supported Coolaborative Work.* Portland, Oregon.

Bolchini, C., Curino, C., Orsi, G., Quintarelli, E., Rossato, R., Schreiber, & F. A., Tanca, L. (2009). And what can context do for data? *Communications of the ACM , 52*(11), 136-140.

Borrego, M., Douglas, E. P., & Amelink, C. T. (2009). Quantitative, qualitative, and mixed research methods in engineering education. *Journal of Engineering Education*, 98(1), 53-66.

Borst, W. (1997). *Construction of engineering ontologies.* PhD thesis, Institute for Telematica and Information Technology. University of Twente, Enschede, The Netherlands.

Bota, F., Farinetti, L., & Rarau, A. (2000). An educational-oriented framework for building on-line courses using XML. *In Proceedings of the IEEE International Conference on Multimedia and Expo (ICME)* (pp. 19-22). New York, USA: IEEE.

Bourdeau, J., Mizoguchi, R., Psyche, V., & Nkambou, R. (2004). Selecting theories in an ontology-based ITS authoring environment. In J. C. Lester (Ed.), *Intelligent Tutoring Systems 2004*, (Vol.LNCS 3220,pp. 150-161). Springer-Verlag Berlin Heidelberg.

Breuker, J., Muntjewerff, A., & Bredeweg, B. (1999). Ontological modelling for designing educational systems. *AI-ED 99 Workshop on Ontologies for Intelligent Educational Systems*, (pp. 1-20). Le Mans, France.

Briggs, J. (1999). *Teaching for quality learning at university.* Buckingham, UK: Scoiety for Research into Higher Education and Open University Press.

Brown, J. D. (1996). *Testing in language programs.* Upper Saddle River,NJ: Prentice Hall Regents.

Brown, T. H. (2005). Towards a model for m-Learning in Africa. *International Journal of E-Learning, 4*(3), 299-315.

Brusilovsky, P. (2001). Adaptive Hypermedia. *User Modelling and User-Adapted Interaction, 11*(1-2), 87-110.

Brusilovsky, P. (2003). Developing adaptive educational hypermedia systems: From design models to authoring tools. In T. Murray, S. Blessing, & S. Ainsworth (Eds.), *Authoring tools for advanced learning environments: Toward cost-effective adaptive, interactive and intelligent educational software,* (pp. 377-409). Dordrecht, Kluwer.

Brusilovsky, P., & Millan, E. (2007). User models for adaptive hypermedia and adaptive educational systems. In P. Brusilovsky, A. Kobsa, & W. Nejdl (Eds.), *The Adaptive Web.* (Vol. LNCS 4321, pp. 3-53). Springer-Verlag Berlin Heidelberg.

Bryman, A. (2008). *Social research methods.* Oxford: Oxford University Press.

Budd, R. W., Thorp, R. K., & Donohew, L. (1967). *Content analysis of communications.* New York: Macmillan.

Cassel, L., Davies, G., LeBlank, R., Snyder, L., & Topi, H. (2008). Using computer ontology as foundation for curriculum development. *In Proceedings of SWEL@ITS'08*, (pp. 21-30). Montreal, Candada.

Cavus, N., & Ibrahim, D. (2009). M-learning:an experiment in using SMS to support learning new English language words. *British Journal of Educational Technology, 40*(1), 78-91.

Chan, T.-W., Roschelle, J., Hsi, S., Kinshuk, Sharples, M., Brown, T., . . . Hoppe, U. (2006). One-to-One technology-enhanced learning:An opportunity for global research collaboration. *Research and Practice in Technology Enhanced Learning, 1* (1), 3-29.

Chen, C.-M., & Hsu, S.-H. (2008). Personalized intelligent mobile learning system for supporting effective english learning. *Educational Technology & Society, 11*(3), 153-180.

Chen, W., Tan, N. Y., Looi, C.-K., Zhang, B., & Seow, P. S. (2008). Handheld computers as cognitive tools: Technology-enhanced environmental learning. *Research and Practice in Technology Enhanced Learning, 3*(3), 231-252.

Chen, Y. S., Kao, T. C., & Sheu, J. P. (2003). A mobile learning system for scaffolding bird watching learning. *Journal of Computer Assisted Learning*, *19*, 347-359.

Chu, K.-K., Lee, C.-I., & Tsai, R.-S. (2011). Ontology technology to assist learners' navigation in the concept map learning system. *Expert Systems with Applications, 38*(1), 11293-11299.

Chua, B. B., & Dyson, L. E. (2004). Applying the ISO 9126 model to the evaluation of an e-learning system. In R. Atkinson, C. McBeath, D. Jonas-Dwyer, & R. Phillips (Eds.), *Beyond the comfort zone: Proceedings of the 21st ASCILITE Conference* (pp. 184-190).

Chuang, C.-W., Shih, J.-l., & Hwang, G.-J. (2009). Using PDA to enchance social science learning with inquiry-based strategies. In S. C. Kong, H. Ogata, H. C. Arnseth, C. K. Chan, T. Hirashima, F. Klett, et al. (Eds.), *In Proceedings of the 17th International Conference on Computers in Education* (pp. 543-550). Hong Kong: Asia-Pacific Society for Computers in Education.

Churchill, D., & Churchill, N. (2008). Educational affordances of PDAs: A study of a teacher's exploration of this technology. *Computers & Education, 50*, 1439-1450.

210

Coffey, A., & Atkinson, P. (1996). *Making sense of qualitative data: Complementary research strategies.* Thousand Oaks: Sage.

Colazzo, L., Molinari, A., Ronchetti, M., & Trifonova, A. (2003). Towards a multi-vendor mobile learning management system. *In Proceedings of the World Conference on E-Learning.* USA.

Colburn, A. (2000). An Inquiry Primer. *Science Scope, 23*(6), 42-44.

Cole, R., Purao, S., Rossi, M., & Sein, M. K. (2005). Being proactive: Where action research meets design research. In *Twenty-Sixth International Conference on Information Systems* (pp. 325-336). Atlanta: Association for Information Systems.

Colheart, M., Menzies, P., & Sutton, J. (2010). Abductive inference and delusional belief. *Cognitive NeuroPsychiatry, 15*(1/2/3), 261-287.

Coll, R., France, B., & Taylor, I. (2005). The role of models and analogies in science education: Implications from research. *International Journal of Science Education, 27*(2), 183-198.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design Research: Theorectical and methodological issues. *Journal of the Learning Sciences, 13*(1), 15-42.

Corcho, O., Fernandez-Lopez, M., & Gomez-Perez, A. (2003). Methodologies, tools and languages for building ontologies: Where is their meeting point? *Data Knowledge Engineering, 46*(1), 41-64.

Corlett, D., Sharples, M., Bull, S., & Chan, T. (2005). Evaluation of a mobile learning organiser for university students. *Journal of Computer Assited Learning, 21*, 162-170.

Cortina, J. M. (1993). What is coefficient alpha? An examination of theory and applications. *Journal of Applied Psychology and Aging ,78*, 98-104.

Creswell, J. W., Plano Clark, V. L., Gutmann, M. L., & Hanson, W. E. (2003). Advanced mixed methods research designs. In A. Tashakkori, & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 209-240). Thousand Oaks,CA: Sage Publications.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika, 16*, 297-334.

Curtis, M., Luchini, K., Bobrowsky, W., Quintana, C., & Soloway, E. (2002). Handheld use in K-12:A descriptive account. *In Proceedings of IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE)* (pp. 23-30). Los Alamitos,CA: IEEE Computer Society Press.

Da Bormida, G., Bo, G., Lefrere, P., & Taylor, J. (2003). An open abstract framework for modeling interoperatability of mobile learning services. In J. Bezivin, J. Hu, & Z. Tari (Eds.), *In Proceedings of the 1st International Workshop on Web Services: Modelling, Architecture and Infrastructure (WSMAI-2003) in conjunction with ICEIS,2003*, (pp. 9-15). Angers, France.

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

De Jong, T., Van Joolingen, W. R., Giemza, A., Girault, I., Hoppe, U., Kindermann, J., . . . Van Der Zanden, M. (2010). Learning by creating and exchanging objects: The SCY experience. *British Journal of Educational Technology, 41*(6), 909-921.

De Vaus, D. A. (1986). *Surveys in a social research.* London: George, Allen & Urwin.

Dey, A. K. (2001). Understanding and using context. *Personal and Ubiquitous Computing, 5*(1), 4-7.

DiBattista, D., & Kurzawa, L. (2011). Examination of the quality of multiple-choice items on classroom tests. *The Canadian Journal for the Scholarship of Teaching and Learning, 2*(2), 1-25.

Dillman, D. A. (2000). *Mail and internet surveys. The tailored design method.* New York: Wiley.

Dimakopoulous, D. N., & Magoulas, G. D. (2008). An architecture for a personalized mobile environment to facilitate contextual lifelong learning. In H. Ryu, & D. Parsons (Eds.), *Innovative Mobile Learning Techniques and Technologies* (pp. 232-251). Idea Group Inc (IGI).

Dimitrov, D. M., & Rumrill, P. D. (2003). Pretest-posttest designs and measurement of change. *Work , 20*, 159-165.

Dix, A., Finlay, J., Abowd, G., & Beale, R. (1998). *Human-Computer Interaction* (2nd ed.). London: Prentice-Hall.

Dolog, P., Henze, N., Nejdl, W., & Sintek, M. (2003). Towards the adaptive semantic web. In F. Bry, N. Henze, & J. Maluszynski (Eds.), *Principles and Practices of Semantic Web Reasoning* (pp. 51-68). Springer-Verlag Berlin Heidelberg.

Drachsler, H., Hummel, H., & Koper, R. (2008). Navigation support for learners in informal learning enviornments. *In Proceedings of the 2008 ACM Conference on Recommender Systems* (pp. 303-306). New York, USA: ACM.

Draganidis, F., Chamopoulou, P., & Mentzas, G. (2008). A semantic web architecture for integrating competence management and learning paths. *Journal of Knowledge Management, 12*(6), 121-136.

Dufrense, A., Rouatbi, M., & Guerdelli, F. (2008). The use of ontologies to structure and support interactions in LOR. In *Intelligent Tutoring Systems* (Vol. LNCS 5091, pp. 551-562). Springer-Verlag Berlin Heidelberg.

Economides, A. A., & Nikolaou, N. (2008). Evaluation of handheld devices for mobile learning. *Inernational Journal of Engineering Education, 24*(1), 3-13.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenge of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences, 8*(3-4), 391-450.

Eekels, J., & Roozenburg, N. F. (1991). A methodological comparison of the structures of scientific research and engineering design: Their similarities and differences. *Design Studies , 12*(4), 197-203.

Elsenbroich, C., Kutz, O., & Sattler, U. (2006). A case for abductive reasoning over ontologies. *In Proceedings of OWL: Experiences and Directions*, (pp. 1-12). Athens, Georgia, USA.

Engeland, A., Roysamb, E., Smedslund, G., & Soggard, A. J. (2002). Effects of first-aid training in junior high schools. *Injury Control and Safety Promotion, 9*(2), 99-106.

Engestrom, Y. (1987). *Learning by Expanding:An Activity-Theorectical Approach to Development Research.* Helsinki: Orienta-Konsultit Oy, Finland.

Engestrom, Y. (1993). Developmental studies of work as a test bench of activity theory: the case of primary care medical practice. In S. Chaiklin, & J. Lave (Eds.), *Understanding of Practice: Perspectives on Activity and Context* (pp. 64-103). Cambridge, UK: Cambridge University Press.

Engestrom, Y. (1999). Innovative learning in wok teams: Analyzing cycles of knowledge creation in practice. In Y. Engestrom, R. Miettinen, & R. L. Punamaki (Eds.), *Perspectives on Activity Theory* (pp. 377-404). Cambridge: Cambridge University Press.

Eriksson, K., & Lindstorm, U. A. (1997). Abduction - a way to deeper understanding of the world of caring. *Journal of Caring Sciences, 11*, 199-206.

Eslinger, E., White, B., Frederiksen, J., & Brobst, J. (2008). Supporting inquiry processes with an interactive learning environment: Inquiry Island. *Journal of Science Education Technology, 17*, 610-617.

Evans, D., & Taylor, J. (2004). The role of user scenarios as the central piece of the development jigsaw puzzle. In J. Attewell, & C. Savill-Smith (Eds.), *Mobile Learning Anytime Everywhere: Papers from MlEARN 2004* (pp. 63-66). London:LSDA.

Evenson, D. H., & Hmelo-Silver, C. (2000). *Problem-based learning: A research perspective on learning interactions.* Mahwah,NJ:Lawrence Erlbaum.

Facer, K., Joiner, R., Stanton, D., Reid, J., Hull, R., & Kirk, D. (2004). Savannah: Mobile gaming and learning? *Journal of Computer Assisted Learning, 20*, 399-409.

Farrell, R., Liburd, S. D., & Thomas, J. C. (2004). Dynamic assembly of learning objects. *In Proceedings of the 13th International WWW Conference* (pp. 162-169). New York, USA: ACM.

Fellows, R., & Liu, A. (1997). *Research Methods for Construction.* Blackwell Science Limited, Oxford.

Fensel, D. (2001). *Ontologies: A silver bullet for knowledgement management and electronic commerce (2nd ed.).* New York: Springer-Verlag Berlin Heidelberg.

Fischer, S. (2001). Course and excercise sequencing using metadata in adaptive hypermedia learning systems. *ACM Journal on Educational Resources in Computing (JERIC),1* (1), 3-21.

Fischer, C., & Gregor, S. (2011). Forms of reasoning in the design science research process. In H. Jain, A. P. Sinha, & P. Vitharana (Eds.), *Service-Oriented Perspectives in Design Science Research: Proceedings of the 6th International Conference, DESRIST 2011* (Vol. LNCS 6629, pp. 17-31). Springer-Verlag Berlin Heidelberg.

Forbes, C. T., & Davis, E. A. (2008). The development of perservice elementary teachers' curricular role identity for science teaching. *Science Teacher Education, 92*(5), 909-940.

Fowler, F. F. (1984). *Survery research methods.* Beverly Hills, CA: Sage.

Fozdar, B. I., & Kumar, L. S. (2007). Mobile learning and student retention. *International Review of Research in Open and Distance Learning, 8*(2).

Friesen, N. (2005). Interoperability and learning objects: An overview of e-Learning standardization. In A. Koohang (Ed.), *Interdisciplinary Journal of Knowledge and Learning Objects, 1*, 23-31.

Fulcher, A. J., & Hills, P. (1996). Towards a strategic framework for design research. *Journal of Engineering Design, 7*(1), 183-193.

Gavrilova, T., Gorovoy, V., & Petrashen, E. (2009). Ontology-based conceptual domain modelling for educational portal. *In Proccedings of the Ninth IEEE International Conference on Advanced Learning Technologies (ICALT'09)* (pp. 495-496). IEEE Computer Society.

George, S., & Lekira, A. S. (2009). MeCoCo: A context-aware system for mediated communications. *International Journal of Interactive Mobile Technologies (iJIM), 3*(3), 26-33.

Ghidini, C., Pammer, V., Scheir, P., Serafini, L., & Lindstaedt, S. (2007). APOSDLE: learn@work with semantic web technology. *In proceedings of I-MEDIA '07 and I-SEMANTICS '07.* Graz, Austria.

Giemza, A., Kuntke, O., & Hoppe, H. U. (2010). A mobile application for collecting numerical and multimedia data during experiments field trips in inquiry learning. *In Proceedings of the 18th International Conference on Computers in Education* (pp. 422-426). Putrajaya, Malaysia: Asia-Pacific Society for Computers in Education.

Gifford, B. R., & Enyedy, N. D. (1999). Activity centered design: towards a theoretical framework for CSCL. In C. Hoadley, & J. Roschelle (Ed.), *In the Proceedings of the Third Conference on Computer Support for Collaborative Learning (CSCL)* (pp. 196-199). Palo Alto, CA: Stanford University.

Gijlers, H., & De Jong, T. (2005). The relation between prior knowledge and students' collaborative discovery learning processes. *Journal of Research in Science Teaching, 42*(3), 264-282.

Gil, E., & Ben-Zvi, D. (2011). Explanations and contet in the emergence of students' informal inferential reasoning. *Mathematical Thinking and Learning, 13*, 87-108.

Grandy, R., & Duschl, R. A. (2007). Reconsidering the character and role of inquiry in school science: Analysis of a conference. *Science & Education, 16*, 141-166.

Greenhow, C., & Belbas, B. (2007). Using Activity-oriented design methods to study collaborative knowledge-building in e-Learning courses. *International Journal of Computer-supported Collaborative Learning*, *2*(4), 363-391.

Grigoriadou, M., & Papanikolaou, K. (2006). Authoring personalised interactive content. *In Proceedings of first International Workshop on Semantic Media Adaptation and Personalization* (pp. 80-85). IEEE Computer Society.

Gruber, T. R. (1993). A translation approach to portable ontology specifications. *Knowledge Acquisition, 5*(2), 199-220.

Guarino, N. (1998). Formal ontology and information systems. In N. Guarino (Ed.), *Proceedings of FOIS'98* (pp. 3-15). Trento, Italy: IOS Press.

Giunchiglia, F., & Zaihrayeu, I. (2009). Lightweight ontologies. In L. Liu, & M. T. Ozsu, (Eds.), *Encyclopedia of Database Systems* (pp. 1613-1619)*.* New York:SpringerLink.

Haarslev, V., & Moller, R. (2003). Racer: An OWL reasoning agent for the semantic web. *In Proceedings of the International Workshop on Applications, Products and Services of Web-Based Support Systems, in conjunction with the 2003 IEEE/WIC International Conference on Web Intelligence*, (pp. 91-95). Halifax, Canada.

Haig, B. D. (2005). An abductive theory of scientific method. *Psychological Methods, 10* (4), 371-388.

Hammond, E. J., McIndoe, A. K., Sansome, A. J., & Spargo, P. M. (1998). Multiple-choice examinations: adopting an evidence-based approach to exam technique. *Anaesthesia ,53*, 1105-1108.

Happel, H.-J., Maalej, W., & Seedorf, S. (2010). Applications of ontologies in collaborative software development. In I. Mistrik, J. Grundy, A. Van der Hoek, & J. Whiteead (Eds.), *Collaborative Software Engineering* (pp. 109-129). Springer-Verlag Berlin Heidelberg.

Hart, C. (2008). Models in physics,models for physics learning, and why the distinction may matter in the case of electric circuits. *Research in Science Education, 38*(5), 529-544.

Hartson, H. R., Andre, T. S., & Williges, R. C. (2003). Criteria for evaluating Usability evaluation methods. *International Journal of Human-Computer Interaction, 15*(1), 145-181.

Hendler, J. (2001). Agents and the Semantic Web. *IEEE Intelligent Systems, 16*(2), 30-37.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly, 28*(1), 75-105.

Hmelo-Silver, C. E. (2006). Design principles for scaffolding technology-based inquiry. In *Collaborative reasoning,learning and technology* (pp. 147-170). Mahwah, NJ: Erlbaum.

Hmelo-Silver, C. E., & Barrows, H. S. (2006). Goals and strategies of a problem-based learning facilitator. *Interdisciplinary Journal of Problem-based Learning*, 21-39.

Hmelo-Silver, C. E., & Guzdial, M. (1996). Of black and glass boxes: Scaffolding for learning and doing. In D. C. Edelson, & E. A. Domeshek (Ed.), *In Proceedings of ICLS'96*, (pp. 128-134). Charlottesville, VA: AACE.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in Problem-based and Inquiry learning: A response to Kirschner, Sweller,and Clark(2006). *Educational Psychologist, 42*(2), 99-107.

Hollfelder, S., Rodolfo, S., & Fankhausar, P. (2001). Tailoring training courses using XML-based metadata. *DELOS Workshop on Interoperability in Digital Libraries, in conjunction with ECDL.* Darmstadt.

Holohan, E., Melia, M., McMullen, D., & Pahl, C. (2005). Adaptive e-learning content generation based on semantic web technology. *In Proceedings of International SW-EL Workshop.* Amsterdam, The Netherlands.

Holtzblatt, K., & Beyer, H. (1993). Making customer-centred design work for teams. *Communications of the ACM , 36*, 93-103.

Hong, M. -w., & Cho, D. -j. (2008). Ontology context model for context-aware learning service in ubiquitous learning environments. *Interantional Journal of Computers, 3*(2), 193-200.

Hoppe, H. U., Pinkwart, N., Oelinger, M., Zeini, S., Verdejo, F., Barros, B., & Mayorga, J. I. (2005). Building bridgest within learning communities through ontologies and 'thematic objects'. *In Proceedings of the 2005 Conference on Computer Support for Collaborative Learning* (pp. 211-220). Mahwah, NJ: Lawrence Erlbaum Associates.

Horrocks, I. (2005). Applications of description logics: State of the art and research challenges. In F. Dau, M. Mugnier, & G. Stumme (Eds.), *Conceptual Strucures: Common Semantics for Sharing Knowledge* (Vol. LNCS 3596, pp. 78-90). Springer-Verlag Berlin Heidelberg.

Horrocks, I., Patel-Schneider, P. F., & Van Harmelen, F. (2003). From SHIQ and RDF to OWL: The making of web ontology language. *Journal of Web Semantics*, *1*(1), 7-26.

Hsieh, H.-F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research, 15*(9), 1277-1288.

Huang, Y.-M., Lin, Y.-T., & Cheng, S.-C. (2010). Effectiveness of a mobile plant learning system in a science curriculum in Taiwanese elementary education. *Computers & Education, 54*, 47-58.

Hwang, G.-J., & Chang, H.-F. (2011). A formative assessment-based mobile learning approach to improving the learning attitudes and achievements of students. *Computers & Education, 56*, 1023-1031.

IEEE LTSC. (2002). Retrieved August 25, 2009, from IEEE LTSC (Learning Technology Standards Committee): http://ltsc.ieee.org/wg12/

ISO. (2003). ISO/IEC 9126-2, *Software Engineering* – Product Quality- Part 2 External Metrics, Geneva: Switzerland.

Jick, T. D. (1979). Mixing qualitative and quantitative methods: Triangulation in action. *Administrative Science Quarterly, 24*(4), 602-611.

Johnson, B., & Turner, L. A. (2003). Data collection strategies in mixed methods research. In A. Tashakkori, & C. Teddlie (Eds.), *Handbook of Mixed Methods in Social & Behavioral Research* (pp. 297-320).Thousand Oaks,CA: Sage Publications.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher, 33*(7), 14-26.

Jones, A., Issroff, K., Scanlon, E., Clough, G., & Mcandrew, P. (2006). Using mobile devices for learning in informal settings: Is it motivating? *In Proceedings of the IADIS International Conference Mobile Learning*, (pp. 251-255). Dublin, Ireland.

Jovanovic, J., Gasevic, D., & Devedzic, V. (2009). TANGRAM for personalized learning using the semantic web technologies. *Journal of emerging technologies in web intelligence,1*(1), 6-21.

Kaenampornpan, M., & O'Neill, E. (2004). Modelling context: an activity theory approach: ambient intelligence. *Paper presented at the Second European Symposium, EUSAI 2004* (pp. 367-374). Eindhoven, The Netherlands: Springer.

Kakihara, M., & Sorensen, C. (2002). Mobility: An extended perspective. *In Proceedings of the 35th Hawaii International Conference on System Sciences (HICSS-35)* (pp. 1756-1766). BigIsland, Hawaii: IEEE.

Kaptelinin, V., & Nardi, B. (1997). Activity theory: Basic concepts and applications. *In Proceedings of the Computer Human Interactions Extended Abstracts (CHI EA '97) on Human Factors in Computing Systems* (pp. 158-159). ACM: New York, USA.

Kaptelinin, V., Nardi, B. A., & Macaulay, C. (1999). The activity checklist: a tool for representing the space of context. *Interaction*, *6*(4),27-39.

Kelly, D., & Tangney, B. (2005). 'First Aid For You': Getting to know your learning style using machine learning. *In Proceedings of the Fifth IEEE International Conference on Advanced Learning Technologies (ICALT'05).*

Khaddage, F., Lanham, E., & Zhou, W. (2009). A Mobile Learning model for Universities -Re-blending the current learning environment. *Intrenational Journal of Interactive Mobile Technologies (iJIM), 3*(1), 18-23.

Khan, S. (2007). Model-based inquiries in chemistry. *Science Education*, 877-905.

Klarman, S., Endriss, U., & Schlobach, S. (2011). Abox abduction in the description logic ALC. *Journal of Automated Reasoning, 46*, 43-80.

Kleinhans, M. G., Buskes, C. J., & De Regt, H. W. (2005). Terra incognita: Explanation and reduction in earth science. *International Studies in the Philosophy of Science, 19*(3), 289-317.

Knight, C., Gasevic, D., & Richards, G. (2006). An ontology-based framework for bridging learning design and learning content. *Educational Technology & Society, 9*(1), 23-37.

Koch, N., & Rossi, G. (2002). Patterns for adaptive web applications. *In Proceedings of 7th European Conference on Pattern Langauges of Programs.*

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., . . . Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design(tm) into practice. *Journal of the Learning Sciences, 12*(4), 495-547.

Kondracki, N. L., & Wellman, N. S. (2002). Content analysis: Review of methods and their applications in nutrition education. *Journal of Professional Nursing, 19*, 372-381.

Kong, S. C. (2012). Using mobile devices for learning in school education. *In Proceedings of the Seventh IEEE International Conference on Wireless, Mobile and Ubiquitous Technology in Education (WMUTE'12)* (pp. 172-176). Takamatsu,Kagawa, Japan: IEEE Computer Society.

Kordaki, M., & Dardoumis, T. (2009). Critical thinking as a framework for structuringsychronous and asynchronous communication within learning design-based e-learning systems. In Dardoumis, T., Caballe, S., Marques,J.M. & Xhafa, F. (Eds.), *Intelligent Collaborative e-Learning Systems and Applications,* 246**,** 83-98. Springer-Verlag Berlin Heidelberg.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75-86.

Krupa, M. P., Selman, R. L., & Jacquette, D. S. (1985). The developments of science explanations in children and adolescents: A structural approach. In S. F. Chipman, J. W. Segal, & R. Glaser (Eds.), *Thinking and Learning Skills* (Vol. 2, pp. 427-455). Hillsdale:Erlbaum.

Kuechler, B., & Vaishnavi, V. (2008). On theory development in design science research:anatomy of a research project. *European Journal of Information Systems, 17*, 489-504.

Kuhn, D., Black, J., Keselman, A., & Kaplan, D. (2000). The development of cognitive skills to support inquiry learning. *Cognition and Instruction, 18*(4), 495-523.

Kukulska-Hulme, A. (2010). Mobile learning as a catalyst for change. *Open Learning: The Journal of Open, Distance and e-Learning, 25*(3), 181-185.

Kukulska-Hulme, A., & Traxler, J. (2005). *Mobile learning: A handbook for educators and trainers.*London:Routledge.

Kukulska-Hulme, A., Sharples, M., Milrad, M., Arnedillo-Sanchez, I., & Vavoula, G. (2009). Innovation in mobile learning: A european perspective. *International Journal of Mobile and Blended Learning, 1*(1), 13-35.

Kukulska-Hulme, A., Sharples, M., Milrad, M., Arnedillo-Sánchez, I., & Vavoula, G. (2011). The geneis and development of mobile learning in Europe. In D. Parsons, *Combining E-Learning and M-Learning: New Applications of Blended Educational Resources* (pp. 151-176). IGI Global.

Kurti, A., Spikol, D., & Milrad, M. (2008). Bridging outdoors and indoors educational activities in schools with the support of mobile and positioning technologies. *International Journal of Mobile Learning and Organisation, 2*(2), 166-186.

Kuutti, K. (1996). Activity theory as a potential framework for human-computer interaction research. In B. A. Nardi (Ed.), *Context and Consciousness: Activity Theory and Human-Computer Interaction* (pp. 17-44). Cambridge, MA: MIT Press.

Kyngas, H., & Vanhanen, L. (1999). Content analysis as a research method [Finnish]. *Hoitotiede, 11*, 3-12.

Labrou, Y., & Finin, T. (1999). Yahoo! as Ontology - Using Yahoo categoriesto describe as documents. *In Proceedings of the Conference on Information and Knowledge Management (CIKM)* (pp. 180-187). Kansas City, USA: ACM.

Lai, C. -H., Yang, J. -C., Chen, F. -C., Ho, C. -W., & Chant, T. -W. (2007). Affordances of mobile technologies for experiential learning: the interplay for technology and pedagogical practices. *Journal of Computer Assisted Learning*, 326-337.

Lankshear, C., & Knobel, M. (2004). *A handbook for teacher research.* Berkshire: Open University Press.

Laudan, L. (1981). *Science and hypothesis.* Dordrecht, the Netherlands:Reidel.

Lave, J., & Wenger, E. (1991). *Situated learning Legitimate pheripheral participation.* New York: Cambridge University Press.

Lawson, A. E. (2005). What is the role of induction and deduction in reasoning and scientific inquiry? *Journal of Research in Science Teaching, 42*(6), 716-740.

Lee, D., & Chu, W. W. (2000). Comparative analysis of six XML schema languages. *ACM SIGMOD Record, 29*(3), 76-87.

Leont'ev, A. N. (1981). The Problem of Activity in Psychology. In J. V. Wertsch (Ed.), *The Concept of Activity in Soviet Psychology: An Introduction.* New York:M.E.Sharpe, Inc.

Leydens, J. A., Moskal, B. M., & Pavelich, M. J. (2004). Qualitative methods used in the assessment of engineering education. *Journal of Engineering Education*, *93*(1), 65-72.

Li, D. D., & Lim, C. P. (2008). Scaffolding online historical inquiry tasks: A case study of two secondary school classrooms. *Computers & Education, 50*, 1394-1410.

Li, X., Feng, L., Zhou, L., & Shi, Y. (2009). Learning in an Ambient Intelligent Wordl:Enabling Technologies and Practices. *IEEE Transactions on Knowledge and Data Engineering , 21*(6), 910-924.

Lim, B.-R. (2004). Challenges and issues in designing inquiry on the web. *British Journal of Educational Technology , 35*(5), 627-643.

Lin, M.-F., Fulford, C. P., Ho, C. P., Iyoda, R., & Ackerman, L. K. (2012). Possibilities and challenges in mobile learning for K-12 teachers:A pilot retrospetive survey study. *In Proceedings of the Seventh IEEE International Conference on Wireless,Mobile and Ubiquitous Technology in Education (WMUTE'12)* (pp. 132-136). Takamatsu,Kagawa, Japan: IEEE Computer Society.

Lindkvist, K. (1981). Approaches to text analysis. In K. E. Rosengren (Ed.), *Advances in Content Analysis* (pp. 23-41). Beverly Hills, CA: Sage.

Linn, M. C. (2000). Designing the knowledge integration environment. *International Journal of Science Education , 22*(8), 781-796.

Liu, G.-Z., & Hwang, G.-J. (2010). A key step to understanding paradigm shifts in e-learning: towards context-aware ubiquitous learning. *British Journal of Educational Technology, 41*(2) E1-E9.

Longworth, N. (2003). *Lifelong learning in action: Transforming education in the 21st century.* London: Kogan Page.

Lonsdale, P., Baber, C., Sharples, M., & Arvanitis, T. N. (2004). A context-awareness architecture for facilitating mobile learning. In J. Attewell, & C. Savill-Smith (Eds.), *Learning with Mobile Devices: Research and Development* (pp. 79-85). London: Learning and Skills Development Agency.

Looi, C. (1998). Interactive learning enviornments for promoting inquiry learning. *Journal of Education Technology Systems , 27*(1), 3-22.

Looi, C.-K., Wong, L.-H., So, H.-J., & Seow, P. (2009). Anatomoy of a mobilized lesson: Learning my way. *Computers & Education, 53*, 1120-1132.

Looi, C. -K., Zhang, B., Chen, W., Seow, P., Chia, G., Norris, C., & Soloway, E. (2011). 1:1 mobile inquiry learning experience for primary science students: A study of learning effectiveness. *Journal of Computer Assisted Learning*, *27*(3), 269-287.

Lubrano, R., Romero, S., Scoppi, P., Cocchi, G., Baroncini, S., Elli, M., . . . Mostacelli, R. (2005). How to become an under 11 rescuer: A practical method to teach first aid to primary schoolchildren. *Resuscitation* , 303-307.

Mahootian, F., & Eastman, T. E. (2009). Complementary frameworks of scientific inquiry: Hypothetico-deductive, hypothetico-inductive, and observational-inductive. *World Features:The Journal of Global Education, 65*, 61-75.

Maldonado, H., & Pea, R. D. (2010). LET'S GO! To the creek: co-design of water quality inquiry using mobile science collaboraties. *In Proceedings of the sixth international IEEE conference on Wireless, Mobile and Ubiquitous technologies in Education(WMUTE 2010)*, (pp. 81-87).

Manlove, S., Lazonder, A. W., & De Jong, T. (2006). Regulative support for collaborative scientific inquiry learning. *Journal of Computer Assisted Learning*, *22*(2), 87-98.

Manlove, S., Lazonder, A. W., & De Jong, T. (2007). Software scaffolds to promote regulation during scientific inquiry learning. *Metacognition Learning, 2*, 141-155.

Manouselis, N., Drachsler, H., Vuorikari, R., Hummel, H., & Koper, R. (2011). Recommender systems in technology-enhanced learning. In F. Ricci, L. Rokach, B. Shapira, & P. B. Kantor (Eds.), *Recommender Systems Handbook* (pp. 387-415). SpringerLink.

March, S., & Storey, V. C. (2008). Design science in the information systems discipline: An introduction to the special issue on design science research. *MIS Quarterly, 32*(4), 725-729.

Markett, C., Arnedillo-Sanchez, I., Weber, S., & Tangney, B. (2006). Using short message service to encourage interactivityin the classroom. *Computers & Education, 46*, 280-293.

Markus, M. L., Majchrzak, A., & Gasser, L. (2002). A design theory for systems that support emergent knowledge processes. *MIS Quarterly, 26*(3), 179-212.

Martin, E., Carro, R. M., & Rodriguez, P. (2006). A mechanism to support context-based adaptation in M-learning. In W. Nejdl, & K. Tochtermann (Eds.), *Innovative Approaches for Learning and Knowledge Sharing* (pp. 302-315). Springer-Verlag Berlin Heidelberg.

Mavis, B. E., Cole, B. L., & Hoppe, R. B. (2001). A survey of student assessment in U.S medical schools: The balance of breadth versus fidelity. *Teaching and Learning in Medicine,13*, 74-79.

Mays, N., & Pope, C. (2000). Accessing quality in qualitative research. British Medical Journal (*BMJ), 320*, 50-52.

McGuinness, D. L., & Van Harmelen, F. (Eds.) (2004). *OWL Web Ontology Language Overview*. Retrieved August 25, 2009, from World Wide Web Consortium (W3C) Recommendation: http://www.w3.org/TR/owl-features/.

McNeill, K. L., & Krajcik, J. (2007). Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations. In M. Lovett, & P. Shah (Eds.), *In the proceedings of the 33rd Carnegie symposium on cognition* (pp. 233-265). Mahwah: NJ:Lawrence Erlbaum Associates, Inc.

McNeill, K. L., Lizotte, D. J., Krajicik, J., & Marx, R. W. (2006). Supporting students' cosntruction of scientific explanations by fading scaffolds in instructional materials. *The Journal of Learning Sciences, 15*(2), 153-191.

Melia, M., Holohan, E., McMullen, D., & Pahl, C. (2005). Ontology-based adaptive content navigation. *In Proceedings of International Conference on Methods and Technologies for Learning (ICMTL)* (pp. 435-440). WIT Press.

Metcalf, J. S., Karjcik, J., & Soloway, E. (2000). MODEL-IT: A design retrospective. In M. J. Jacobson, & R. B. Kozma (Eds.), *Innovations in science and mathematics education* (pp. 77-115). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Metz, K. E. (2004). Children's understanding of scientific inquiry: Their conceptualization of uncertainty in investigations of their own design. *Cognition and Instruction, 22*(2), 219-290.

Moller, R., & Haarslev, V. (2008). Tableau-based reasoning. In *Handbook of Ontologies* (2nd ed.). Springer-Verlag Berlin Heidelberg.

Motiwalla, L. F. (2007). Mobile learning: A framework and evaluation. *Computers & Education, 49*, 581-596.

Mulder, Y. G., Lazonder, A. W., & De Jong, T. (2010). Finding out how they find it out: An empirical analysis of inquiry learners' need for support. *International Journal of Science Education, 32*, 2033-2053.

Mulder, Y. G., Lazonder, A. W., & De Jong, T. (2011). Comparing two types of model progression in an inquiry learning enviornment with modelling facilities. *Learning and Instruction*, *21*(5),614-624.

Mwanza-Simwami, D. (2001). Chaning tools, chaning attitudes: effects of introducing a CSCL system to promote learning at work. In *Proceedings of the Euro-CSCL 2001: 1st European Conference on Computer-Supported Collaborative Learning* (pp. 470-477). Masstricht, The Netherlands.

Mwanza-Simwami, D. (2009). Using Activity-Oriented Design Methods (AODM) to investigate Mobile Learning. In G. Vavoula, N. Pachler, & A. Kukulska-Hulme (Eds.), *Researching Mobile Learning, Frameworks, methods and research designs* (pp. 97-122). Peter Lang (Oxford).

Mwanza-Simwami, D., & Engestrom, Y. (2003). Peadagogical adeptness in the design of E-learning environments:Experiences from the Lab@Future Project. In A. Rossett (Ed.), *Proceedings of E-Learn 2003* (pp. 1344-1347). Pheonix,AZ: Association of the Advancement of Computing in Education (AACE).

Naismith, L., Lonsdale, P., Vavoula, G., & Sharples, M. (2004). *Literature review in mobile technologies.* Bristol: NESTA FutureLab.

Narine, J. S. (2010). *Psychology* (5th ed.). Belmont, CA: Wadsworth:Cengage Learning.

National Research Council (1996). *National science education standards.* Washington DC.

National Research Council (2000). *Inquiry and the national science education standards.* Washington:National Academy Press.

Netemeyer, R. G., Bearden, W. O., & Sharma, S. (2003). *Scaling procedures: Issues and applications.* Thousand Oaks, CA: Sage Publications, Inc.

Niu, W. T., & Kay, J. (2010). PERSONAF: Framework for personalised ontological reasoning in pervasive computing. *User Modelling and User-Adapted Interaction: The Journal of Personalization Research, 20*, 1-40.

Noy, N. (2005). Order from Chaos. *Queue*, *3*(8), 42-49.

Nunamaker, J. F., Chen, M., & Purdin, T. (1990). Systems development in information systems research. *Journal of Management Information Systems , 7* (3), 89-106.

Ogata, H., & Yano, Y. (2004). Context-aware support for computer-supported ubiquitous learning. *In Proceedings of IEEE International Workshop on Wireless and Mobile Technologies in Education* (pp. 27-34). IEEE Computer Society.

Oh, P. S. (2008). Adopting the Abductive Inquiry Model (AIM) into undergraduate earth science laboratories. In V. Eriksson (Ed.), *Science Education in the 21st Century* (pp. 263-277). New York:Nova.

Oh, P. S. (2010). How can teachers help students forumulate scientific hypotheses? Some strategies found in abdcutive inquiry activities of earch science. *International Journal of Science Education, 32*(4), 541-560.

Oh, P. S. (2011). Characteristics of abductive inquiry in earth science: An undergraduate case study. *Science Education, 95*(3), 409-430.

Oppenheim, A. N. (1992). *Questionnaire design, interviewing and attitude measurement.* New York City: St.Martin's press.

Pahl, C., & Holohan, E. (2009). Applications of semantic web technology to support learning content development. In Koohanga, A. (Ed.), *Interdisciplinary Journal of E-Learning and Learning Object*, 5**,**1-25.

Papasalouros, A., Kotis, K., & Kanaris, K. (2011). Automatic generation of tests from domain and multimedia ontologies. *Interactive Learning Environments, 19*(1), 5-23.

Papasalouros, A., Kotis, K., & Nikitakos, N. (2010). Towards an intelligent tutoring system for environmental decision makers. *Environmental Engineering and Management Journal , 9*(2), 197-204.

Park, J., Parsons, D., & Ryu, H. (2010). To flow and not to freeze: Applying flow experience to mobile learning. *IEEE Transactions on Learning Technologies, 3*(1), 56-67.

Parr, C. S., Jones, T., & Songer, N. B. (2004). Evaluation of a handheld data collection interface for science learning. *Journal of Science Education and Technology*, 233-242.

Parsons, D. (2008). *Dynamic Web Application Development Using XML and Java .* Cengage Learning EMEA.

Parsons, D., & Ryu, H. (2006). A framework for assessing the quality of mobile learning. *In Proceedings of the 6th IEEE International Conference on Advanced Learning Technologies.* Kerkrade, The Netherlands: IEEE Computer Society.

Parsons, D., Ryu, H., & Cranshaw, M. (2007). A design requirements framework for mobile learning environments. *Journal of Computers*, *2*(4), 1-8.

Pastor, R., Sanchez, J., & Dormido, S. (2003). A XML-based framework for the development of web-based laboratories focused on control systems education. *International Journal of Engineering Education, 19*(3), 445-454.

Patokorpi, E. (2009). What could abductive reasoning contribute to human computer interaction? A technology domestication view. *PsychNology Journal, 7*(1), 113-131.

Patton, M. Q. (2002). *Qualitative research and evaluation methods.* Thousand Oaks: Sage.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2008). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems, 24*(3), 45-77.

Peker, D., & Wallace, C. S. (2011). Characterizing high school students' written explanations in biology laboratories. *Research in Science Education, 41*(2), 169-191.

Pessoa, R. M., Calvi, C. Z., Filho, J. G., de Farias, C. R., & Neisse, R. (2007). Semantic context reasoning using ontology based models. In M. van Sinderen, & A. Pras (Eds.), *EUNICE* (pp. 44-51). Springer-Verlag Berlin Heidelberg.

Pinkwart, N., Hoppe, H. U., Milrad, M., & Perez, J. (2003). Educational scenarios for cooperative use of Personal Digital Assistants. *Journal of Computer Assisted Learning, 19* (3), 383-391.

Pintrich, P. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of Self-Regulation* (pp. 451-502). Academic Press, London.

Popescu, E., Trigano, P., & Badica, C. (2007). Evaluation of a learning management systems for adaptivity purposes. *International Multi-Conference on Computing in the Global Information Technology - ICCGI.*

Preece, J., Rogers, Y., & Sharp, H. (2002). *Interaction Design.* NewYork: NY:John Wiley & Sons.

Prince, M., & Felder, R. (2007). The many faces of inductive teaching and learning. *Journal of College Science Teaching, 36*(5), 14-20.

Quintana, C., Eng, J., Carra, A., Wu, H., & Soloway, E. (1999). Symphony: A case study in extending learner-centered design through process space analysis. *In Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems* (pp. 473-480). Pittsburgh, Pennsylvania, USA: ACM.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., . . . Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences, 13(3)*, 337-386.

Quintana, C., Soloway, E., & Krajcik, J. (2003). Issues and appraoches for developing learner-centered technology. In M. Zelkowitz (Ed.), *Advances in Computers* (Vol. 57, pp. 271-321).

Rabin, J., & McCathieNevile, C. (Eds.). (2008). *Mobile Web Best Practices 1.0*. Retrieved April 12, 2012, from Mobile Web Initiative: http://www.w3.org/TR/mobile-bp/

Raholm, M.-B. (2010). Abductive reasoning and the formation of scientific knowledge within nursing knowledge. *Nursing Philosophy*, *11*(4), 260-270.

Randell, C., Phelps, T., & Rogers, Y. (2003). Ambient Wood: Demonstration of a digitally enhanced field trips for schoolchildren. *Adjunt Proceedings of the Fifth International Conference on Ubiquitous Computing.* IEEE.

Reigeluth, C. M. (1999). *Instructional-design theories and models: A new paradigm of instructional theory* (Vol. 2). Mahwah, NJ: Lawrence Erlbaum Associates.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *Journal of the Learning Sciences,13*, 273-304.

Rogers, Y., Price, S., Fitzpatrick, G., Fleck, R., Harris, E., Smith, H., . . . Weal, M. (2004). Ambient Wood: Designing new forms of digital augmentation for learning outdoors. *In Proceedings of the 2004 Conference on Interaction Design and Children*: Building a Community (pp. 3-10). New York: ACM.

Rogers, Y., Price, S., Randell, C., Fraser, D. S., Weal, M., & Fitzpatrick, G. (2005). Ubi-learning integrates indoor and outdoor experiences. *Communications of the ACM, 48*(1), 55-59.

Roschelle, J. (2003). Keynote paper: Unlocking the learning value of wireless mobile devices. *Journal of Computer Assisted Learning, 19*, 260-272.

Ross, J. M. (2010). Informatics creativity: A role for abductive reasoning? *Communications of the ACM, 53*(2), 144-148.

Rossman, G. B., & Wilson, B. L. (1991). Numbers and words revisited:being 'shamelessly electric'. *Evaluation Review, 9*(5), 627-643.

Roth, P. L., & Be Vier, C. A. (1998). Response rates in HRM/OB survey research: Norms and correlates. *Journal of Management Studies, 24*, 97-117.

Rozeboom, W. W. (1999). Good science is abductive, not hypothetico-deductive. In L. L. Harlow, S. A. Mulaik, & J. H. Steiger (Eds.), W*hat if there were no significance tests?* (pp. 335-391). Hillsdale,NJ:Erlbaum.

Rubio EI, B. M., White, M. A., & Brant, W. E. (2008). Effect of an audience response system on resident learning and retention of lecture material. *American Journal Roentgen, 190*, W319-W322.

Ryu, H., & Parsons, D. (2009). Designing learning activities with mobile technologies. In H. Ryu, & D. Parsons (Eds.), *Innovative Mobile Learning: Techniques and Technologies* (pp. 1-20). New York:Information Science Reference.

Ryu, Y. S., & Smith-Jackson, T. L. (2006). Reliability and validity of the mobile phone usability questionnaire (MPUQ). *Journal of Usability Studies, 2*(1), 39-53.

Sandberg, J., Maris, M., & De Geus, K. (2011). Mobile english learning: An evidence-based study with fifth graders. *Computers & Education, 57*, 1334-1347.

Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. *The Journal of Learning Sciences, 12*, 5-51.

Satoh, K., Inoue, K., Iwanuma, K., & Sakama, C. (2000). Speculative computation by abduction under incomplete communication environments. *Paper presented at the Fourth International Conference on Multi-Agent Systems.*

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *The Journal of the Learning Sciences , 1*, 37-68

Scornavacca, E., Huff, S., & Marshall, S. (2009). Mobile phones in the classroom: If you can't beat them,join them. *Communications of the ACM, 52*(4), 142-146.

Seppala, P., & Alamaki, H. (2003). Mobile learning in teaching training. *Journal of Computer Assisted Learning, 19*(3), 330-335.

Scriven, M. (1967). The Methodology of Evaluation. In R. Tyler, R. Gagne, & M. Scriven (Eds.), *Perspective of Curriculum Evaluation* (pp. 39-83). Chicago, USA.

Sharma, P., & Hannafin, M. J. (2007). Scaffolding in Technology-Enhanced Learning Environments. *Interactive Learning Environments, 15*(1), 27-46.

Sharples, M., Arnedillo-Sanchez, I., Milrad, M., & Vavoula, G. (2009). Mobile Learning Small Devices, Big Issues. In N. Balacheff, S. Ludvigsen, T. De Jong, A. Lazonder, & S. Barnes (Eds.), *Technology-Enhanced Learning Principles and Products* (pp. 233-249). Springer Netherlands.

Sharples, M., Collins, T., Feibt, M., Gaved, M., Mulholland, P., Paxton, M., & Wright, M. (2011). A "Laboratory of Knowledge-Making" for Personal Inquiry Learning. In G. Biswas, S. Bull, J. Kay, & A. Mitrovic (Eds.), *Artificial Intelligence in Education* (Vol. LNAI 6738, pp. 312-319). Springer-Verlag Berlin-Heidelberg.

Sharples, M., Lonsdale, P., Meek, J., Rudman, P., & Vavoula, G. (2007). An evaluation of Myartspace: A mobile learning service for museum trips. *In Proceedings of the 6th Annual Conference on Mobile Learning, MLearn 2007.* Melbourne, Australia.

Sharples, M., Taylor, J., & Vavoula, G. (2005). Towards a theory of mobile learning. *In Proceedings of MLearn 2005 Conference.* Cape Town, South Africa.

Shen, J. (2010). Nurturing students' critical knowledge using technology-enhanced scaffolding strategies in science education. *Journal of Science Education Technology, 19*, 1-12.

Shen, J., & Confrey, J. (2007). From conceptual change to transformative modelling: A case study of an elementary teacher in learning astronomy. *Science Education, 91*(6), 948-966.

Shen, L., Wang, M., & Shen, R. (2009). Affective e-Learning: Using "Emotional" data to improve learning in Pervasive Learning Environment. *Educational Technology & Society, 12*(2), 176-189.

Shih, J. -L., Chu, H. -C., Hwang, G. -J., & Kinshuk. (2011). An investigation of attitudes of students and teachers about participating in a context-aware ubiquitous learning activity. *British Journal of Educational Technology, 42*(3), 373-394.

Shih, J. -L., Chuang, C. -W., & Hwang, G. -J. (2010). An inquiry-based mobile learning approach to enhancing social science learning effectiveness. *Educational Technology & Society, 13*(4), 50-62.

Silverman, D. (2006). *Interpreting qualitative data* (3rd ed.). Lodon: Sage.

Sirin, E., Parsia, B., Grau, B. C., Kalyanpur, A., & Katz, Y. (2007). Pellet: A practical OWL-DL reasoner. *Journal of Web Semantics: Science, Services, and Agents on the World Wide Web*, *5*(2), 51-53.

Slotta, J. D. (2004). The web-based inquiry science environment (WISE): Scaffolding knowledge integration in the science classroom. In M. Linn, E. A. Davis, & P. Bell (Eds.), *Internet Environments for Science Education* (pp. 203-233).

Smith, B. (2003). Ontology. In L. Floridi (Ed.), *The Blackwell Guide to the Philosophy of Computing and Information* (pp. 155-166). Malden, MA:Blackwell.

Smith, B. K., & Reiser, B. J. (1998). National geographic unplugged: Classroom-centered design of interactive nature films. In C. Karat, A. Lund, J. Coutaz, & J. Karat (Eds.), *In Proceedings in CHI 98 on Human Factors in Computing Systems* (pp. 424-431). Reading,MA:Addison-Wesley.

Snae, C., & Brueckner, M. (2007). Ontology-driven e-learning system based on roles and activities for Thai learning environment. (A. Koohang, Ed.) *Interdisciplinary Journal of Knowledge and Learning Objects , 3*(1), 1-17.

Soloway, E., Norris, C., Blumenfield, P., Fishman, B., Krajcik, J., & Marx, R. (2001). Handheld devices are ready-at-hand. *Communications of the ACM, 44*, 15-20.

Songer, N. B., Huber, A., & Lee, S. Y. (2003). Evoluation of the technology-rich, inquiry-based BioKIDS curriculum. *Paper presented at the Annual Meeting National Association of Research in Science Teaching (NARST).* Philadelphia,PA.

Southerland, S. A., Abrams, E., Cummins, C. L., & Anzelmo, J. (2001). Understanding students' explanation of biological phenomena: Conceptual frameworks or p-prims. *Science Education, 85*, 328-348.

Specht, M. (2009). *Learning in a Technology Enhanced World: Context in Ubiquitous Learning Support.* Heerleen, The Netherlands: Open University of the Netherlands.

Spikol, D., Milrad, M., Maldonado, H., & Pea, R. (2009). Integrating co-design practices into the development of mobile science collaboratives. *In Proceedings of the Ninth IEEE International Conference on Advanced Learning Technologies* (pp. 393-397). Riga, Latvia: IEEE Computer Society.

Stone, L. (2011). The WoLF Project: Work-based learners in further education. In N. Pachler, C. Pimmer, & J. Seipold (Eds.), *Work-based Mobile Learning Concepts and Cases* (pp. 71-90).

Studer, R., Benjamins, R., & Fensel, D. (1998). Knowledge engineering: Principles and methods. *Data & Knowledge Engineering, 25* (1-2), 161-198.

Svetlana, K., & Yonglk-Yoon. (2009). Adaptation e-learning contents in mobile environment. *In Proceedings of the 2nd International Conference on Interaction Sciences:Information Technology, Culture and Human. 403*, pp. 474-479. Seoul, Korea.

Sweller, J. (2004). Instructional design consequences of an analogy between evolution by natural selection and human cognitive architecture. *Instructional Science, 32*, 9-31.

Takeda, H., Veerkamp, P., Tomiyama, T., & Yoshikawam, H. (1990). Modelling design processes. *AI Magazine , 11*(4), 37-48.

Tarasewich, P. (2003). Designing mobile commerce applications. *Communications of the ACM, 46*, 57-60.

Taylor, J., Sharples, M., O'Malley, C., Vavoula, G., & Waycott, J. (2006). Towards a task model for mobile learning: A dialectical approach. *International Journal of Learning Technology, 2*(2-3), 138-158.

Tesch, R. (1990). *Qualitative research: Analysis types and software tools.* Bristol, PA: Falmer.

Thornton, P., & Houser, C. (2005). Using mobile phones in English education in Japan. *Journal of Computer Assisted Learning, 21*, 217-229.

Traxler, J. (2005). Mobile learning - it's here but what is it? *Interactions, 9*(1). Warwick: University of Warwick.

Traxler, J. (2007). Defining, discussing and evaluating mobile learning:The moving finger writes and having writ. *International Review of Research in Open and Distance Learning, 8*(2), 1-12.

232

Traxler, J. (2009). Learning in a mobile age. *International Journal of Mobile and Blended Learning, 1*(1), 1-12.

Trifonova, A., & Ronchetti, M. (2004). A general architecture to support mobility in learning. *In Proceedings of the IEEE International Conference on Advanced Learning Technologies (ICALT'04).*

Tsarkov, D., & Horrocks, I. (2006). FaCT++ Description Logic Reasoner:System Description. In U. Furbach, & N. Shankar (Eds.), *Automated Reasoning* (Vol. LNAI 4130, pp. 292-297). Springer-Verlag Berlin Heidelberg.

Tsianos, N., Germanakos, P., Lekkas, Z., Mourlas, C., Samaras, G., & Belk, M. (2009). Working memory differences in e-learning environments: Optimization of learners' performance through personalization. In G.-J. Houben, G. McCalla, F. Pianesi, & M. Zancanaro (Eds.), *User Modelling Adaptation and Personalization* (Vol. LNCS 5535, pp. 385-390). Springer-Verlag Berlin Heidelberg.

Twining, P., & Evans, D. (2005). Should there be a future for Tablet PCs in schools? *Journal of Interactive Media in Education, 20*, 1-18.

Uden, L. (2007). Activity theory for designing mobile learning. *International Journal of Mobile Learning and Organisation , 1* (1), 81-102.

Uschold, M., & Gruninger, M. (2004). Ontologies and semantics for seamless connectivity. *SIGMOD Record, 33*(4), 58-64.

Uzunboylu, H., Cavus, N., & Ercag, E. (2009). Using mobile learning to increase environmental awareness. *Computers & Education, 52* (2), 381-389.

Vahey, P., Tatar, D., & Roschelle, J. (2007). Using handheld technology to move between the private and public in the classroom. In M. van't Hooft, & K. Swan (Eds.), *Ubiquitous Computing in Education: Invisible Technology, Visible Impact* (pp. 187-210). Lawrence Erlbaum Assoc.

Vaishnavi, V., & Kuechler, W. (2007). *Design Science Research Methods and Patterns: Innovating Information and Communication Technology.* New York: Auerbach.

Van Joolingen, W. R., & Zacharia, Z. C. (2009). Developments in Inquiry Learning. In N. Balacheff, S. Ludvigsen, T. De Jong, A. Lazonder, & S. Barnes (Eds.), *Technology-Enhanced Learning Principles and Products*, 21-37. SpringerLink.

Van Joolingen, W. R., Bollen, L., Hoppe, U., & De Jong, T. (2007). Ciel, architecture for collaborative inquiry and experiential learning. In J. M. Spector, D. G. Sampson, T. Okamoto, Kinshuk, S. A. Cerri, & M. Ueno et al. (Eds.), *In Proceedings of the ICALT* (pp. 308-312). Los Alamitos, CA: IEEE Computer Society.

Van Joolingen, W. R., De Jong, T., & Dimitrakopoulout, A. (2007). Issues in computer supported inquiry learning in science. *Journal of Computer Assisted Learning*, *23*(2), 111-119.

Van Joolingen, W. R., De Jong, T., Lazonder, A. W., Savelsbergh, E. R., & Manlove, S. (2005). Co-Lab: Research and development of an online learning environment for collaborative scientific discovery learning. *Computers in Human Behavior, 21*, 671-688.

Vas, R. (2007). Educational Ontology and Knowledge Testing. *The Electronic Journal of Knowledge Management, 5*(1), 123-130.

Vas, R., Kovacs, B., & Kismihok, G. (2009). Ontology-based mobile learning and knowledge testing. *International Journal of Mobile Learning and Organisation,* 3(2),128-147.

Vavoula, G., & Karagiannidis, C. (2005). Designing mobile learning experiences. In P. Bozanis, & E. N. Houstis (Eds.), *Advances in Informatics* (Vols. LNCS, 3746, pp. 534-544). Springer-Verlag Berlin-Hiedelberg.

Vavoula, G., & Sharples, M. (2009). Meeting the challenges in evaluating mobile learning:A 3 level evaluation framework. *International Journal of Mobile and Blended Learning, 1*(2), 54-75.

Vavoula, G., Sharples, M., Rudman, P., Meek, J., & Lonsdale, P. (2009). Myartspace: Design and evaluation of support for learning with multimedia phones between classrooms and museums. *Computers & Education, 53*, 286-299.

Verbert, K., Klerkx, J., Meire, M., Najjar, J., & Duval, E. (2004). Towards a global component architecture for learning objects: An ontology based approach. *In Proceedings of OTM 2004 Workshop on Ontologies, Semantics and E-Learning.* Agia Napa, Cyprus.

Vogel, B., Spikol, D., Kurti, A., & Milrad, M. (2010). Integrating mobile, web and sensory technologies to support inquiry-based science learning. *In Proceedings of the sixth IEEE WMUTE International Conference on Wireless, Mobile and Ubiquitous technologies in Education.*

Vuk, J., & Morse, D. T. (2012). College students' behavior on self-tailored, multiple-choice examinations. *Innovative Teaching, 1*(4)*,* 1-7.

Vuorikari, R., & Berendt, B. (2009). *Study on contexts in tracking usage and attention metadata in multilingual Technology-Enhanced Learning* (Vol. 154). Gesellschaft für Informatik.

Vygotsky, L. S. (1978). *Mind and Society.* Cambridge, MA: Harvard University Press.

Walls, J., Widmeyer, G., & El Sawy, O. (2004). Assessing information system design theory in perspective: How useful was our 1992 initial rendition? *Journal of Information Technology Theory & Application, 6*(2), 43-58.

Walsh, C. M., & Seldomridge, L. A. (2006). Critical thinking: Back to square two. *Nursing Education,45*, 212-219.

Walton, D. (2004). *Abductive Reasoning.* Tuscaloosa,AL: The University of Alabama Press.

Wang, H.-C., & Hsu, C.-W. (2006). Teaching-Material Design Center: An ontology-based system for customizing reusable e-materials. *Computers & Education, 46*, 458-470.

Wang, M., Shen, R., Novak, D., & Pan, X. (2009). The impact of mobile learning on student's learning behaviours and performance: Report from large blended classroom. *British Journal of Educational Technology, 40*(4), 673-695.

Wang, X. H., Gu, T., Zhang, D. Q., & Pung, H. K. (2004). Ontology based context modelling and reasoning using OWL. *In Proceedings of the Second IEEE Annual Conference on Pervasive Computing and Communications Workshop 2004* (pp. 18-22).

Wang, Y.-K. (2004). Context awareness and adaptation in mobile learning. *In Proceedings of the 2nd IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE'04).* IEEE Computer Society.

Weal, M. J., Michaelides, D. T., Thompson, M. K., & De Roure, D. C. (2003). Hypermedia in the ambient wood. *New Review of Hypermedia and Multimedia, 9*, 137-156.

Weber, R. P. (1990). *Basic content analysis.* Beverly Hills, CA: Sage.

Weinbrenner, S., Engler, J., Bollen, L., & Hoppe, U. (2009). Ontology-based support for designing inquiry learning scenarios. *In Proceedings of the Seventh Internationl Workshop Ontologies and Semantic*

Web for E-Learning in conjuctin with the International Conference. Artificial Intelligence in Education(AIED'09).

Weinbrenner, S., Engler, J., & Hoppe, U. H. (2011). Ontology-supported scaffolding of concept maps. In G. Biswas, S. Bull, J. Kay, & A. Mitrovic (Eds.), *Artificial Intelligence in Education* (Vol. LNAI 6738, pp. 582-584). Springer-Verlag Berlin Heidelberg.

Windschitl, M. (2002). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Teacher Education*, 112-143.

Winn, W. (2003). Research methods and types of evidence for research in educational psychology. *Educational Psychology Review, 15*, 367-373.

Wong, B., Nguyen, T. T., Chang, E., & Jayaratna, N. (2003). Usability metrics for e-learning. In *Workshop on human computer interface for semantic web and web applications* (Vol. LNCS 2889, pp. 235-252). Catania, Sicily, Italy: Springer-Verlag Berlin Heidelberg.

Wyeth, P., Fitzpatrick, G., Good, J., Smith, H., Luckin, R., Underwood, J., . . . Benford, S. (2008). Learning through treasure hunting: The role of mobile devices. *In Proceedings of the International Conference on Mobile Learning*, (pp. 27-34). Algarve,Portugal.

Yarnall, L., Shechtman, N., & Pennel, W. R. (2006). Using handheld computers to support improved classroom assessment in science: Result from a field trial. *Journal of Science Education and Technology, 15*(2), 142-158.

Ye, J., Coyle, L., Dobson, S., & Nixon, P. (2007). Ontology-based models in pervasive computing systems. *Thye Knowledge Engineering Review, 22*(4), 315-347.

Yee, K. Y., Tiong, A. W., Tsai, F. S., & Kanagasabai, R. (2009). OntoMobiLe: A generic ontology-centric service-oriented architecture for mobile learning. *In Proceedings of the Tenth International Conference on Mobile Data Management Systems, Services and Middleware*, (pp. 631-636).

Zhang, B., Looi, C.-K., Seow, P., Chia, G., Wong, L.-H., Chen, W., . . . Norris, C. (2010). Deconstructing and reconstructing: Transforming primary science learning via a mobilized curriculum. *Computers & Education, 55*, 1504-1523.

Zhang, H., Song, W., & Burston, J. (2011). Reexamining the effectiveness of vocabulary learning via mobile phone. *TOJET:The Turkish Online Journal of Educational Technology, 10*(3), 203-214.

Zheng, Y., Li, L., & Zheng, F. (2010). An analysis framework of activity context in e-Learning environments. In X. Zhang (Ed.), *Edutainment 2010* (pp. 258-268). Springer-Verlag Berlin Heidelberg.

Zhou, Y., Percival, G., Wang, X., Wang, Y., & Zhao, S. (2011). MOGCLASS: Evaluation of a collaborative system of mobile devices for classroom music education for young children. *In Proceedings of the ACM SIGCHI International Conference on Human-Computer Interaction*, (pp. 523-532). Vancouver, BC, Canada.

Zimmerman, C. (2000). The development of scientific reasoning skills, *20*(1), 99-149.

Zurita, G., & Nussbaum, M. (2004). Computer supported collaborative learning using wirelessly interconnected handheld computers. *Computers & Education, 42*, 289-314.

Zurita, G., & Nussbaum, M. (2007). A conceptual framework based on Activity Theory for mobile CSCL. *British Journal of Educational Technology, 38* (2), 211-235.

Appendix I: Low Risk Notification

13 September 2011

Sohaib Ahmed
38 Borneo Drive
Fairview Heights
AUCKLAND 0632

Dear Sohaib

Re: **Mobile Science Enquiry-Based Learning**

Thank you for your Low Risk Notification which was received on 7 September 2011.

Your project has been recorded on the Low Risk Database which is reported in the Annual Report of the Massey University Human Ethics Committees.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis that it is safe to proceed without approval by one of the University's Human Ethics Committees.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

A reminder to include the following statement on all public documents:

"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor John O'Neill, Director (Research Ethics), telephone 06 350 5249, e-mail humanethics@massey.ac.nz".

Please note that if a sponsoring organisation, funding authority or a journal in which you wish to publish requires evidence of committee approval (with an approval number), you will have to provide a full application to one of the University's Human Ethics Committees. You should also note that such an approval can only be provided prior to the commencement of the research.

Yours sincerely

John G O'Neill (Professor)
**Chair, Human Ethics Chairs' Committee and
Director (Research Ethics)**

cc   Dr David Parsons   Prof Tony Norris, HoI
      Institute of Information and Mathematical   Institute of Information and Mathematical
         Sciences   Sciences
      Albany   **Albany**

Appendix II: Approval from the Principal of Albany Senior High School

18 August 2011

Massey University Human Ethics Committee
Research Ethics Office
Private Bag 11.222
Palmerston North 4442

To whom it may concern,

As the Principal of Albany Senior High School I am satisfied that the project at Albany Senior High School can proceed and that it can be based on a low risk notification to the Massey University Human Ethics Committee.

I am aware that in order to reach the low risk notification criteria, the University will be requesting written consent from both the students participating in the activity (because their identities will be known to the researchers) and from the parents (because some of the students will be under 16).

Thank you.

Yours faithfully

Barbara Cavanagh
Principal

Appendix III: Participants Consent Form

Mobile Learning For Science Inquiry

PARTICIPANT AND PARENTAL CONSENT FORM - INDIVIDUAL

We invite you to participate in an experiment related to mobile learning technologies, designed to supporting your science learning. In this experiment, students will undertake a learning activity as part of their regular science classes, using mobile devices equipped with WiFi. We would like you to use your own mobile device if possible (any device that can connect to the mobile internet can be used). Some other devices will also be available for use in the classroom. The activity will involve using a software application that is intended to be beneficial to your learning experience, and will take place in your usual class time. There is no requirement for you participate in the mobile learning aspect of the classroom activity and no course marks are dependent on participation.

If you choose to participate you will be asked to fill in a questionnaire at the end of the experiment and may also be interviewed by one of the researchers. All data gathered will be anonymous, and the questionnaire and the interview will not contain questions or topics related to personal data.

By participating, you would be helping us to improve the application. We hope you will also enjoy the experience and learn something as well, though the purpose of the experiment is to evaluate the software; you will not be personally assessed in any way.

I agree to participate in this study under the conditions set out above.

Student Signature: .... Date: ....

Full Name - printed ....

IF YOU ARE UNDER 16, PARENTAL CONSENT IS ALSO REQUIRED

I agree to this student participating in this study under the conditions set out above.

Parent/Guardian Signature: .... Date: ....

Project Contacts

Sohaib Ahmed (PhD candidate), QA 2.17, Quad Block A, IIMS, Massey University, Albany campus x 9248 Email: s.ahmed@massey.ac.nz

Dr. David Parsons QA 2.15, Quad Block A, IIMS, Massey University, Albany campus x 9138 Email: d.p.parsons@massey.ac.nz

Ethics Statement
This project has been evaluated by peer review, and judged to be low risk. Consequently it has not been reviewed by one of the University's Human Ethics Committees. The researchers named above are responsible for the ethical conduct of this research.
If you have any concerns about the conduct of this research that you wish to raise with someone other than the researchers, please contact Professor John O'Neill, Director (Research Ethics), telephone 06 350 5294, e-mail humanethics@massey.ac.nz.

Information Sheet   Page 1 of 1

Appendix IV: Learning Experience Questionnaire

MOBILE LEARNING SCIENCE INQUIRY-QUESTIONNAIRE

This questionnaire is about your learning experience regarding the given mobile learning application **ThinknLearn**. For answering the given questions, a five option scale is given. Please follow the instructions below.

INSTRUCTIONS

Please read the questions carefully and tick one of the options beside each question. Please make sure that you have answered all the questions.

Questions	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1. This mobile learning experience was enjoyable.					
2. This mobile application was easy to use.					
3. Navigation through this application was easy.					
4. This application guides me to formulate a hypothesis.					
5. The given suggestions in the application were relevant.					
6. This application helps me understand the relationships between different variables, such as heat loss and surface colour tins.					
7. The given suggestions help me to understand the topic.					
8. This application helps me to improve my reasoning skills.					
9. It is an effective learning application.					

If you find any difficulty in understanding any questions then please feel free to contact me.

Contact: **Sohaib Ahmed** (PhD candidate), Massey University, Albany campus;
Email: s.ahmed@massey.ac.nz

Appendix V: Group Discussion Questions

Discussion Questions
Q.1: What type of difficulty do you find in using this application?
Q.2: How do you feel after using this application?
Q.3: What do you think about suggestions given in the application?

Appendix VI: Pre-test for Control and Experimental Groups

PAINTED TINS – WHICH STAYS HOT; WHICH GETS COLD?

NAME:

BEFORE YOU START

Circle the best answer based on your current knowledge.

Dark (like black) coloured surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and stay warm.
4. reflect light and stay cool.

Shiny surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and stay warm.
4. reflect light and stay cool.

Light (white) coloured surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and stay warm.
4. reflect light and stay cool.

The hot water in the tin will cool down because (Select more than one answers)
1. the air is colder than the tin so heat energy is transferred out of the tin.
2. the warm water particles have more energy so will move out the tin to cool down.
3. the cold air particles absorb the heat energy from the tin.
4. the heat energy is transferred by convection from the tin to the air.

HAND THIS TO YOUR TEACHER PLEASE

NEXT: DO THE EXPERIMENT AND POST ACTIVITIES

Appendix VII: Post-test for Control Group

PAINTED TINS – WHICH STAYS HOT; WHICH GETS COLD?

NAME:

EXPERIMENT:

Look at the three tins. Each was filled with hot water at the 100° C, the starting temperature of each tin. In this experiment, you have to compare the way these tins radiate heat energy. In the end, you have to generate a hypothesis from the collected data during this experiment.

Once you have finished, circle the best answer based on your current knowledge.

Dark (like black) coloured surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and stay warm.
4. reflect light and stay cool.

Shiny surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and stay warm.
4. reflect light and stay cool.

Light (white) coloured surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and stay warm.
4. reflect light and stay cool.

The hot water in the tin will cool down because (Select more than one answers)
1. the air is colder than the tin so heat energy is transferred out of the tin.
2. the warm water particles have more energy so will move out the tin to cool down.
3. the cold air particles absorb the heat energy from the tin.
4. the heat energy is transferred by convection from the tin to the air.

Write a hypothesis about the colour of a tin and how well it keeps the water temperature.

HAND THIS TO YOUR TEACHER PLEASE

Appendix VIII: Post-test for Experimental Group

PAINTED TINS – WHICH STAYS HOT; WHICH GETS COLD?

NAME:

EXPERIMENT:

Look at the three tins. Each was filled with hot water at the 100° C, the starting temperature of each tin. In this experiment, you have to compare the way these tins radiate heat energy. In the end, you have to generate a hypothesis from the collected data during this experiment.

USING ThinknLearn:

Use your mobile device that can access to this website http://www.mclassroom.com/thinknlearn . Follow this web application, based on the data you collect from the experiment.

Dark (like black) coloured surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and stay warm.
4. reflect light and stay cool.

Shiny surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and stay warm.
4. reflect light and stay cool.

Light (white) coloured surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and stay warm.
4. reflect light and stay cool.

The hot water in the tin will cool down because (Select more than one answers)
1. the air is colder than the tin so heat energy is transferred out of the tin.
2. the warm water particles have more energy so will move out the tin to cool down.
3. the cold air particles absorb the heat energy from the tin.
4. the heat energy is transferred by convection from the tin to the air.

Write a hypothesis about the colour of a tin and how well it keeps the water temperature.

HAND THIS TO YOUR TEACHER PLEASE

Appendix IX: Retention-test for Control and Experimental Group

PAINTED TINS -
WHICH STAYS HOT; WHICH GETS COLD?

NAME:

HOW MUCH HAVE YOU REMEMBERED?
Circle the numbered options which you think best complete each statement
(there may be more than one possibility.

Dark (like black) coloured surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and get warm.
4. reflect light and stay cool.

Shiny surfaces:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and get warm.
4. reflect light and stay cool.

Light (like white) coloured objects:
1. absorb light and get warm.
2. absorb light and stay cool.
3. reflect light and get warm.
4. reflect light and stay cool.

The hot water in the tin will cool down because
1. the air is colder than the tin so heat energy is transferred out of the tin
2. the warm water particles have more energy so will move out the tin to cool down
3. the cold air particles absorb the heat energy from the tin
4. the heat energy is transferred by convection from the tin to the air

HAND THIS TO YOUR TEACHER
PLEASE