Design and evaluation of mobile games to support active and reflective learning outdoors

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Thesis submitted to the University of Nottingham

for the degree of Doctor of Philosophy

July 2011

Abstract

This thesis explores the use of situated, location-based mobile games for supporting learning in the field, to determine how these types of activity can support learners with reference to specific curricular aims, beyond just providing highly engaging and motivating activities. A software toolkit was developed to support the design and deployment of situated mobile learning activities. This was used to design and deploy mobile learning activities for two field studies. The first study used the critical incident technique to identify specific benefits and problems arising from outdoor mobile learning. We found that whilst learners were highly engaged by an outdoor learning activity facilitated by mobile devices, they were engaged only in the surface level of the activity and did not reflect on what they were doing. The second study comprised a grounded theory analysis of learner behaviour in the context of a location-based, enquiry-led learning game designed to overcome the problems found in Study 1 and in other projects. We present an analysis of learner interactions with the environment during an enquiry-led learning activity. Compared to an equivalent paper-based activity, the game helped to coordinate the learners' activities and unexpected results from game actions prompted learners to reflect on their actions and what they observed. The physical environment also prompted discussion and reflection, but we saw specific problems arising from learners becoming distracted by their previous experience of the environment and by the proximity of environmental features. We discuss these findings and present implications for the design of future mobile learning games.

Acknowledgements

For Jennie

Thank you, for everything.

And Alex and Holly

For doing your best to keep quiet while I wrote this.

It's been a long journey. Along the way there have been house-moves, children, and various other life events that got in the way. I wouldn't have got even halfway there without ongoing support from my wife Jennie, in both emotional and financial forms. Thank you for your support, encouragement, and patience.

Many people deserve thanks for helping me get this work done. My supervisors, Mike Sharples and Claire O'Malley, have provided essential guidance and advice along the way. Thanks also to Russell Beale and Bob Hendley for their support, and to Terry Wilmer and Ian Pearshouse for valuable technical assistance.

I ran trials at two schools during this PhD, and those could not have happened without the help and cooperation of the teachers, staff, and students at those schools. Particular thanks go to Ian Watts, Pete Gibson and Darren Frearson. And my thanks also to my fellow PhD students at the LSRI who helped out during those trials.

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Chapter 1

Introduction

The thesis investigates how games facilitated by mobile technologies might be used to support active, reflective, enquiry-based learning in the field. This chapter describes the background and motivation for the research, along with a summary of the work conducted, an outline of each of the chapters in this thesis, and a summary of the intended contribution to the field of mobile learning.

1.1 Motivation & background

This research was motivated by the burgeoning use of mobile technologies to support not just 'anywhere learning' but also innovative, interactive learning activities that allow learners to interact with their environment, with one another, and with virtual spaces and representations. A range of projects have successfully used mobile technologies to link virtual and physical spaces for entertainment, with large-scale mobile games such as *Can You See Me Now?* (Benford *et al.*, 2006) demonstrating how these technologies can bridge real and virtual worlds and allow participants to experience both simultaneously. Some educational researchers have seized upon these 'bridging technologies' as a way of enhancing teaching and learning activities, with projects such as *MyArtSpace* (Vavoula *et al.*, 2009) showing how even relatively simple mobile technologies can effectively support innovative learning practice that can take learning outside the classroom and also support it back at the school. One area of particularly promising development is the use of mobile technologies to support active, outdoor learning based on *participatory simulations*: dynamic learning activities where learners play an active role in the simulation of a physical or social system (for example Wilensky and Stroup, 2000), or a group of animals (for example Facer *et al.*, 2004).

The use of mobile technologies to enable outdoor enquiry learning fits well with current calls for the learning of science to be more like to the doing of science (Chinn and Malhotra, 2002; NSTA, 2003) and to better reflect the complexities and skills involved in 21st century citizenship (Bereiter, 2002; Dede *et al.*, 2005). Using mobile technology to facilitate enquiry-based activities, students can be engaged in active enquiry, using realistic tools in authentic environments. Recent work has shown enthusiasm in the education sector for the increased use of ICT to enhance science learning (for example, McFarlane and Sakellariou, 2002; Hennessy *et al.*, 2007; Squire and Jan, 2007; Anastopoulou *et al.*, 2008; Avraamidou, 2008) and various projects have shown how mobile technologies can help take these kinds of investigations out of the classroom and into the field (for example Crawford and Vahey, 2002; Luchini *et al.*, 2002; Tinker *et al.*, 2002; Price *et al.*, 2003; Linn, 2004; Klopfer, 2005; Kurti *et al.*, 2007).

However, whilst recent projects have been successful in demonstrating the potential for mobile technologies to support outdoor, situated, enquiry-based learning activities, they have at the same time shown that moving learning away from the classroom gives rise to a new set of problems. Learners who are outdoors lack the familiar support of the classroom, and become responsible for coordinating their own activities (Frohberg *et al.*, 2009). At the same time, the environment may distract them, or they may lose track of what they should be focusing on entirely.

Games are one particular activity that have been used to engage learners and focus their attention; recent projects (such as Facer *et al.*, 2004; Squire and Jan, 2007; Squire and Klopfer, 2007; Huizenga *et al.*, 2009) have shown that game-like experiences have the power to motivate learners to take part in a learning activity and may provide a suitable scaffold for their activities in the field. However, this research is still in its nascent stage. The combination of these platforms for learning is an area that has only just begun to be explored, and we have yet to determine how to provide comprehensive, effective, and appropriate support for learners in the field with mobile devices.

1.2 Research Aims

This research comprises two complementary aims, centred on the use of games and game-like features to enable and support field-based learning activities.

Our primary research aim is to:

i) Investigate how mobile games might support field-based learning activities.

We are specifically interested in addressing the following research questions:

ii) What are the benefits and problems of being engaged in outdoor, situated learning activities facilitated by mobile devices?

and

iii) How might we design mobile games to exploit these benefits whilst at the same time overcoming any problems that arise?

We are particularly interested in determining whether there are any aspects of games that might be suitable for supporting learning in the field, by offering a framework for activity with which learners are familiar and to which they can easily respond.

Since the research aims of this thesis require the use of a mobile games platform, and at the start of the project such a platform was not readily available using off-the-shelf products[1], this gave rise to a second strand of work that focuses on the design and development of a re-usable platform for designing and deploying mobile learning games in physical environments.

There are several reasons for wanting to implement a generalised, re-usable system:

1. Determining requirements for a re-usable system can help in classifying current participatory simulations and future research directions.

2. It enables us to deploy at least two different learning activities, in at least two different locations, by means of a reusable, customisable system.

3. We wanted a generic, re-usable tool that can be used beyond this PhD, the development of which could provide insights into how to support the future development of situated mobile learning games and the infrastructures required for designing and deploying them.

The current research does not provide a complete solution to the identified need for a generalised development toolkit, but requirements for such a toolkit are identified and a software solution has been developed in an attempt to satisfy those requirements and to enable the running of mobile learning trials that address research aim (i) above.

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[1] No suitable development platform was available when work was being conducted on the development of the mobile learning activities described in this thesis. Recent developments, most notably extensions to the *mscape* toolkit (Hewlett-Packard Development Company, 2009), indicate that off-the-shelf products could now be used to build and deploy the activities described in this thesis, however this was not the case when the studies were carried out.

1.3 Chapter Contents

In *Chapter 2: Literature review*, we introduce the field of mobile learning, and review the use of mobile technologies for facilitating enquiry-led field-based learning activities, as distinct from just enabling 'anywhere' learning. We identify three core approaches to learning that are relevant to situated mobile learning: situated learning, experiential learning, and enquiry learning. The critical characteristics of these approaches are examined, in relation to their use for situated mobile enquiry learning. We then examine the use of games to support mobile enquiry learning, and introduce *augmented reality* and *participatory simulations*, with some key examples. Two exemplary projects, Savannah (Facer *et al.*, 2004) and Environmental Detectives (Squire and Klopfer, 2007), that have directly used games in an outdoor learning environment to support enquiry-based learning are described and critiqued. The problems identified in these projects are reviewed, and compared to the current curriculum aims for enquiry-based science learning in the UK. Our review also indicates a lack of direct comparisons between outdoor learning and equivalent versions indoors. We also identify particular ways in which games might be used to do this, specifically through more explicit use of the core game mechanism of failure, which has been shown to be important for learning (for example Clifford, 1984; Kapur, 2006).

Chapter 3, Research Methods, describes the research methods used in this research – *critical incident technique* (Flanagan, 1954) and *grounded theory* (Glaser and Strauss, 1967) – and offers a rationale for applying them to the studies described in this thesis. Additional details of how these methods were applied to the analysis of Study 1 and Study 2 are included in the appropriate chapters for each study (Chapter 5: Study 1, and Chapter 7: Study 2).

Chapter 4 covers the *Design and Development of the PaSAT software.* In order to carry out trials of the mobile learning activities described in this thesis, a software framework was required for creating and deploying mobile learning activities in the field. We reviewed existing work in this field and found that there were no off-the-shelf systems that fulfilled the needs of our work (at the time of conducting the design and implementation phase of this research). We therefore outline the requirements, design, and implementation of a software toolkit for creating mobile learning games. This toolkit was implemented using the Microsoft .NET platform, and it allows the creation and deployment of mobile learning activities using a combination of a laptop server and handheld mobile clients (PDAs) in the field.

Chapter 5 describes *Study 1*, which explored the benefits and problems arising from the use of mobile technologies to enable an outdoor location-based exploratory learning activity (implemented using the PaSAT toolkit described in Chapter 4). This mobile learning activity was compared to a similar activity conducted indoors, using the same handheld devices, but without use of the physical environment. We used the critical incident technique to identify how the mobile learning activity both supported and hindered learners in the field, using the indoor version as a comparison. This study indicated specific areas where support was required for learners outdoors, and the particular aspects of the outdoor environment that could be exploited for this. We found that whilst learners were highly engaged by the outdoor activity, in particular the location-based aspects, they struggled to coordinate their activities in the field and were only engaged in the surface level of the task. This meant that they treated the task as a treasure hunt and were motivated by the achievement of simple goals rather than being engaged in the underlying learning task. The challenge of completing the activity was noted as a primary motivator for them, with clear 'victory moments' that were not present in the indoor condition, but again they were focused on surface level rather than deep level goals. These results accord with recent work such as

Environmental Detectives (Facer *et al.*, 2004) and Frequency 1550 (Huizenga *et al.*, 2009), and provided valuable insights that allowed the development of requirements for a mobile learning game intended to support enquiry learning, described in Chapter 6, and evaluated in Chapter 7.

Chapter 6 covers the *design of BuildIt, a situated mobile learning game for supporting outdoor enquiry learning*. It describes the requirements, design process, and final implementation of BuildIt, using characteristics of the environment as part of the game activity. We describe requirements derived from the three core learning approaches identified as important for this field of work, namely situated, experiential, and enquiry learning, and outline how BuildIt was designed to fulfil these requirements as well as mapping on to the requirements of the Key Stage 3 curriculum for Scientific Enquiry.

Chapter 7 describes *Study 2: Using a situated mobile learning game to support active enquiry learning in the field.* It investigates the use of a situated mobile learning game – the BuildIt game described in Chapter 6 – intended to support active enquiry learning in an outdoor environment. We describe the evaluation of the game as used in the grounds of a school by Year 7 students, in comparison with a paper-based activity. The students' activities were analysed using both quantitative and qualitative approaches, providing a means of triangulating our results and identifying salient issues. The quantitative analysis used coding of behaviours to identify differences between the use of the game and paper-based activity, and indicated that the game was successful in promoting reflection and in supporting active, self-motivated enquiry learning in the field. We used a grounded theory approach to perform an in-depth analysis of learner activity, focusing on the impact of the game and the environment on the learning processes exhibited by learners. We found that learners demonstrated a range of desirable behaviours related to enquiry learning, such as hypothesis formation, evaluation, and discussion, all of which appeared to be facilitated by the playing of the game and thus the completion of the learning activity. The physical environment played a significant role in the activity, providing learners with prompts and shared artefacts for discussion. However, learners' previous experience of the environment sometimes caused them to move beyond the bounds of task, rejecting possible solutions because of resistance to change and an apparent reluctance to think outside the specific focus of the task. This appeared to be related to the fantasy element of the game itself, with learners appearing to engage in the fiction of the game more than was ideal at times. All of this demonstrated the power of games to provide engaging situated enquiry learning activities, but pointed to the need to design such activities very carefully so as to ensure the environment and game constraints map on to the learning goals of the task rather than conflicting with them.

Chapter 8 provides *Conclusions, Discussion, and Reflections*. It summarises the work presented in this thesis, offers a critique of the BuildIt mobile learning game developed during this research, and considers the implications of the results of the studies (mainly Study 2) in relation to existing learning theory, technological developments, and pedagogical practice in the field of mobile learning.

1.4 Contribution to the field

This research offers the following contributions to the field of mobile learning:

- A field-based evaluation of how games can be used to structure and support outdoor learning activities, addressing problems identified in previous studies and showing directions for future research based on learner needs, not based on technological capabilities

- An extensible software framework using off-the-shelf devices and software platforms, demonstrating the feasibility of the types of mobile learning described and also contributing a reusable platform for building and deploying mobile learning activities

- The development of a grounded theory of mobile game-based field learning, and a comparison with related learning theories and previous mobile learning projects.

Chapter 2

Literature survey: Using situated mobile games to scaffold field-based enquiry learning activities

2.1 Introduction

This chapter reviews the current literature relevant to the use of mobile technologies to support field-based enquiry learning activities for students. We explore the key issues and projects that are central to the studies presented in this thesis.

We begin with a brief introduction to mobile learning, focusing on the use of mobile technologies to scaffold field-based learning, with an emphasis on the use of mobile games to achieve this. We then consider key projects in this area, moving to a focus on enquiry-based[2] activities related commonly to the science curriculum, along with discussion of the over-arching theoretical frameworks in this field. We then present critiques of two key projects in this field – Savannah (Facer *et al.*, 2004) and Environmental Detectives (Squire and Klopfer, 2007; Klopfer and Squire, 2008) – and present some conclusions based on the findings and limitations of these projects and implications for further work derived from our analysis of current work in this field.

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[2] 'Enquiry' is the British English term. In the US the term 'inquiry' learning is the norm, but would have very different connotations in the UK. For clarity we use the term 'enquiry' throughout this thesis, changing 'inquiry' to 'enquiry' wherever necessary when citing or quoting US sources.

2.1.1 Mobile learning

In the past decade, mobile learning has emerged from labs where researchers could tinker with bespoke technologies into everyday activities, including mainstream education settings (Kukulska-Hulme and Traxler, 2007). Developments in this field have been driven inevitably by changing technologies, but also significantly by new and innovative applications of those technologies by researchers, educators, and learners.

This nascent field is characterised by the influence of rapidly changing technologies and a current lack of established theories and models to underpin our understanding of the processes at work during mobile learning activities. Mobile learning has seen rapid growth, an active research community, and ever-increasing attention from conferences and journals alike, but there is still no common understanding of exactly what constitutes 'mobile learning' (Frohberg *et al.*, 2009). A number of high level definitions have been made, for example O'Malley *et al.* (2003) describe mobile learning as any sort of learning that happens when the learner is not at a fixed, predetermined location, or that happens when the learner takes advantage of learning opportunities offered by mobile technologies. However, as noted by Goth & Schwabe (2008), even this definition maintains a technological focus. Goth & Schwabe (2008, citing Goth *et al.*, 2007) suggest instead that "mobile learning is the learning of mobile actors", emphasising the role of the learner and their mobility. The important feature of mobile learning is that the learner is on the move rather than just the devices being used (Scanlon *et al.*, 2005), and several authors (for example Naismith *et al.*, 2004; Sharples *et al.*, 2005) have emphasised this approach in considering what makes effective mobile learning activities.

As noted by Sharples (2005), a first step in establishing a definition of mobile learning is to determine what differentiates it from other forms of learning. The essential characteristic is that learners are on the move, within and between multiple contexts that may differ substantially from one another. Context here refers not only to physical location, but also to time, topic, and levels of engagement – learners are dynamic in all of these dimensions. This means that not only are learners moving, but so is the learning – it is present across these multiple contexts (Naismith *et al.*, 2004) and may be enhanced by this multiplicity of activity. Moreover, mobile learning is more than just 'learning that is facilitated by mobile technologies'. It refers to the set of processes involved in "coming to know through conversations and explorations across multiple contexts amongst people and interactive technologies" (Sharples *et al.*, 2007).

One of the most fertile areas of innovation within mobile learning is the use of mobile technologies to support or scaffold learners engaged in some kind of field-based activity. Kukulska-Hulme *et al.* (2007) note that mobile technologies support a diverse range of learning styles and approaches, but appear to be particularly suited to supporting personalised, situated, authentic, and informal learning. However, it should be noted that despite evidence of innovation in this area, there is still a tendency for mobile learning tools to be used in a more 'traditional' manner, and in established settings. Frohberg *et al.* (2009) note that less than 20% of the projects they surveyed provide any level of learning beyond "factual knowledge or comprehension" (p322), and assert that mobile learning should not be limited in scope in this way, and should instead support learners in "applying, analysis, synthesizing and evaluating their knowledge" (p322).

This fits well with contemporary situative and socio-constructivist approaches to learning, which emphasise the importance of learners engaging in authentic, complex problem-solving activities in order to allow meaningful learning to take place (Brown *et al.*, 1989; Spiro *et al.*, 1992; Scardamalia and Bereiter, 2003), and the past decade has seen a number of projects demonstrating the use of mobile technologies to enable these forms of learning activity. However, this remains the vanguard of research and practice in mobile learning, with the majority of projects still focusing on more traditional, teacher-led, content-oriented activities (see Frohberg *et al.*, 2009 for a review of the current state of the art).

2.2 Using mobiles for field learning

Mobile technologies allow us not just to provide content to the learner in whatever location they may be, but also to use that location itself as part of interactive learning activities. These new technological capabilities offer the promise of new forms of educational experience situated away from the classroom (Roschelle and Pea, 2002). The significant shift here is that these technologies allow learners to interact simultaneously with the physical world, the people in it, and a digital world viewable through a mobile device. It is argued that this *coupling* of the familiar (physical activity and presence) with the unfamiliar (being able to simultaneously view digital resources) promotes reflection and new ways of assisting children's learning (Rogers *et al.*, 2002; Sharples *et al.*, 2002; Price *et al.*, 2003; Stanton and Neale, 2003).

We can find a wide range of mobile learning projects designed to support learners in field-based activities, for example Chen *et al.* (2003; 2004) describe a system that scaffolds students looking for butterflies or birds in the field, and Vavoula *et al.* (2009) describe *MyArtSpace*, a system designed to provide school children with mobile tools for collecting information during a visit to a museum.

Using mobile technologies away from the classroom like this, where the physical environment itself has a meaningful role to play in the learning activity, has been termed the 'physical context' by Frohberg *et al.* (2009) who offer a recent review of state-of-the-art in mobile learning. Using the framework developed by Taylor *et al.* (2006), Frohberg *et al.* survey key projects in mobile learning and categorise them according to a set of meaningful dimensions. Context, referring to the relationship between the mobile technology and the environment in which it is used, is a key part of this framework. Frohberg *et al.* found that roughly a third of the projects they surveyed used this ‘physical context’, with mobile technologies being used to enable learning activities that related directly to the space in which they were used.

2.2.1 The importance of the environment

Learners can learn *in the environment* using mobile devices to deliver learning content and activities at any place or time – this has been referred to as ‘just in time learning’. Learners can also learn *about the environment* whilst present in that environment. This latter approach has received significant attention in the mobile learning field in recent years. Making use of the environment as an integral part of learning activities is a powerful component of learning because learning is a process of creating meaning *in situ*, and the environment of the learner plays a central role in that process (Squire and Klopfer, 2007). The environment constrains activity, affords action, and supports performance (Dewey, 1938; Salomon, 1993). Action is always situated within given environmental constraints and affordances, and expertise may be measured by one’s ability to see the environment in particular ways (Goodwin, 1994; Glenberg, 1997).

To learn about the environment, students need to be able to see it in particular ways, to be attuned to its affordances and constraints and how these relate to variables and solutions (Squire and Klopfer, 2007). An identified problem with most school learning is that the learning is divorced from physical experience of the world that is being taught (Papert, 1980); learners receive a processed, digested version instead of direct experience (Barab *et al.*, 1999).

This approach also fits with recent calls to exploit school grounds as rich learning resources (Clifford, 1984; Malone and Tranter, 2003). There is even concern that children are retreating from the environment, and projects have come into being to address this, some specifically using mobile technologies (for example Williams *et al.*, 2005).

Using the environment to drive enquiries may also reduce the cognitive load on learners by changing the task from manipulation of independent variables (as in a traditional computer simulation) to the *finding* of instances of said variables. This benefit has been highlighted for virtual ambient simulations (de Jong *et al.*, 1998; Moher *et al.*, 2001), and may be equally true for simulations based in the real world.

2.2.2 Beyond data collection

There is an important distinction to make between mobile learning activities that merely enable learning in the field, and those that actively support or scaffold it. Enabling technologies may allow data collection, analysis, and transformation, or may facilitate new forms of interaction within and between groups and individuals. However, these are just extensions of existing technologies – the real power of mobile technologies in the field becomes apparent when we start to look at those systems that enable *situated* (Lave and Wenger, 1991), *constructivist* (Bruner, 1966; Papert, 1980), *enquiry-led* (Bruner, 1961), or *problem-based learning* (Koschmann *et al.*, 1996). Klopfer *et al.* (2005) suggest that the use of handheld or wearable networked devices to enable a range of collaborative learning activities has received possibly the greatest research focus in this field to date.

Colella's seminal work on participatory simulations (Colella, 2000; Colella, 2002) was some of the first to demonstrate the positive influence of mobile devices and connectivity on students' learning, going beyond content delivery to show that these technologies can facilitate rich learning activities that promote critical thinking skills through active engagement and reflection. Colella's Virus Game allowed students to take part in a physical recreation – a *participatory simulation* – of the spread of a virtual virus. Students wore small badges (a variant of Boravoy *et al.*'s (1996) Think Tags) that exchanged data via infra-red. The virus spread from student to student as they walked around a room and met each other. They could see the infection spreading as indicators changed colour on their badges. The underlying rules of the simulation were meant to reflect real-world viruses: some people were immune so could not be infected, but they could carry the infection, and infect others, without them or anyone else knowing it. Also, the virus had an incubation period, which meant that after exposure the infection did not immediately show up on the badge. Learners showed a ready willingness to suspend their disbelief and to accept the simulation on its own terms, behaving as though it was a real event. As the students explored the simulation, they showed structured attempts to understand what was going on, integrating their observations of their own activities and the information from the mobile devices to arrive at an explanation of the spread of the virus. More recent studies (for example Neulight *et al.*, 2006) have shown continuing promise for the use of participatory simulations in the classroom for this domain.

The underlying mechanism here (as noted by Colella, 2000; Facer *et al.*, 2004) is *experiential learning*, based on Dewey's (1916) principles of experience. These assert that lasting understandings can arise from being engaged in meaningful activities. Tanner (1997) also argues that "When children are engaged in an activity of interest to them that possesses difficulties they look for a method of coping with the difficulties and thus acquire new skills" (Tanner, 1997, p44). Colella (2000) reported that direct physical experience and collaboration were central to the success of the simulation. Students had to work together to perform 'experiments', testing out their ideas about the causes of what they were seeing. Colella argued that this direct experience reduces the distance between the learning experience itself and the conceptual understandings formed by the learners. As noted by Facer *et al.* (2004), this accords with Dewey's principles: the more direct the learning experience the better.

This work – as well as later examples such as Klopfer (2005) and Neulight (2006) – demonstrates how mobile technologies can be used to enable effective mobile learning within the science domain, providing learners with participatory learning activities that allow them to construct their own meaning from structured activities.

In recent years, researchers and educators looking for appealing learning activities have turned to games as engaging, interactive experiences, and a number of projects have shown how game-like activities, enabled through mobile and wearable technologies, can create structured activities that support mobile learning.

Before moving on to more specific examples of mobile game-based learning, we will first consider what it is we mean by 'games' to inform our later critique of recent work in this area. Many projects describe games and game-like activities without fully exploring what constitutes a game; it will be useful for us to have a fuller understanding of games to inform our later critique of recent projects.

2.3 Games to scaffold learning

2.3.1 Defining games

Let us begin by identifying what we mean by the key terms 'play' and 'game'. These terms are closely related, but refer to different concepts (in English at least – many other languages do not distinguish between them). The concept of 'fun' is also related to both of these terms, denoting an activity that we find pleasurable to be involved in, for a variety of reasons. For now, let us accept this basic definition of 'fun', but as we shall see below there are a number of factors that can influence why we find a particular activity, specifically games, to be fun to be involved in.

Play can be described as an activity that is not serious, which is undertaken for its own sake, and in which participation is entirely voluntary. Play can be structured by rules and agreed ways of behaving, with tightly defined goals and objectives. Examples of this type of play include recreational games like chess, football, or backgammon (note that some games may also be played for other reasons, such as professional sports, including football). However play can also be entirely unstructured, having no rules at all, and being simply a non-serious activity that is embarked upon for its own sake. Examples of this kind of play generally include things like young children banging objects together, or manipulating them with no goal in mind. However some more adult behaviour, such as doodling, drawing, or even some forms of creative writing, might equally be described as a form of unstructured play. A very general definition that encapsulates all of the above can be found in Fabricatore (2000), who defines play as an "…intellectual activity engaged in for its own sake, with neither clearly recognisable functionalities nor immediate biological effects… and related to exploratory processes that follow the exposure of the player to novel stimuli" (p 2) (although we can question Fabricatore's implication that play is exclusively intellectual).

'Games' are a form of playful activity that typically involve some kind of structure through facilitating 'organised play' (Prensky, 2001). There seems to be a widespread consensus that games will always constitute play and fun, but it is possible to see that any game can be placed on a continuum with fun at one end and 'non-fun' at the other. The structure of game-based activities can be found in examples such as war-games or training situations, but the element of fun is less prevalent, or can in fact be entirely absent. Games will always represent a situation or location that is not actually present in real life. A key concept of games is the structure and goals they give to activities undertaken by one or more players, who agree to take part in the game voluntarily.

To define a game, we must define the activity we are engaged in when we 'play' the game. Huizinga (1949) offers the following definition of 'play' :

> 'Play is a voluntary activity or occupation executed within certain fixed limits of time and place, according to rules freely accepted but absolutely binding, having its aim in itself and accompanied by a feeling of tension, joy and the consciousness that it is "different" from "ordinary life" ' (Huizinga, 1949 p28)

Huizinga's definition has been widely cited in the field, but is rooted in more archaic frames of reference. Crawford (1982) offers a somewhat more succinct and contemporary definition that contains many of the elements of Huizinga's:

> A game is a closed, formal system that represents a subset of reality. (Crawford, 1982, p16)

What these two definitions tell us is that a game is a collection of interacting entities that interact according to agreed rules, and this collection of entities represent a fixed reality that is necessary and sufficient for the game to be played. Players agree to play a game, and in doing so they agree to be bound by the rules of that game.

The above definitions of games are necessarily imprecise; games can take many forms and the entire universe of games is not easily captured in a short definition. Crawford (1982) identifies five major types of games that are useful in framing our discussion:

1. Board games: in board games, players will typically each have a set of pieces arranged on a playing surface, with the arrangement of the pieces representing current standing in the game. Play is advanced through movement of the pieces, which affects the state of the game according to the agreed rules. The players' primary concern in these games is with the geometric relationships between the pieces.

2. Card games: most commonly played with a 52 card deck (although other card variations exist), card games involve players competing against chance and their own ability to remember and recognise winning combinations of cards in order to advance. The primary concern in card games is the assessment of combinations of cards to determine current standing and therefore decide the risk of subsequent moves.

3. Children's games: these games often emphasise simpler, physical play, and include examples such as Hide and Seek and Tag. Mental and physical challenges are present, but the primary concern in these games is to facilitate the use of social skills in playing with others.

4. Athletic games: these games emphasise physical rather than mental skills. Crawford makes a salient distinction in athletics between games and competitions. Races are competitions and not games, in that technically players compete only against the clock, and not against one another. However, some interaction does take place between the players, in that one player's performance may be affected by the observed performance of other players. Competitions where interaction between players can take place may feasibly be described as games, but, according to Crawford, athletic competitions where the player strives only to complete a task optimally are not games.

5. Computer games: obviously a relatively recent type of game that can actually draw heavily on the other types, but computer games are distinctive enough to be described as an individual type. Two characteristics that distinguish computer games from other types are i) computer games will always include some kind of interactive virtual playing environment, and ii) players of computer games will always face some kind of opposition (either from other players, or from the game itself in the case of single player games) (Fabricatore, 2000).

From reviewing these types of games it is already clear that it is hard to put games into very specific categories, because often a game occupies two or more categories and draws on different types of games to produce something novel. Consider the 'grey' distinction between competitions and games in the area of athletics. It is possible to conceive of a player competing only against themselves in some physical endeavour, which should mean it is not a game, but what if that activity is inherently fun? We need to bear in mind that a number of factors contribute to the quality of an activity being a 'game' and these factors may be more or less important depending on the context.

Crawford goes on to identify four elements that he sees as common to all games. Crawford's identification of the four common elements of all games is a useful tool for describing any game in terms of how it implements those elements, and serves as a primer for the next section on how we might begin to place games into different categories.

Representation: Crawford describes a game as a "closed formal system that subjectively represents a subset of reality" (Crawford, 1982 [online only]). Crawford's key points are that a game contains a defined model upon which the game is based that needs no reference to outside models or rules. The rules of the game are complete in that no situation can be arrived at that is not catered for by those rules (for a properly designed game). The representation within the game is subjective for each player in that each person has their own perception of the game world that leads to their own fantasy. There may be consensus on various elements, but subjective fantasy is a key element in the game representation. Games also only represent a 'subset' of reality so as to maintain their closed and defined model, and to provide a manageable 'fantasy space' for the players.

Interaction: the capacity for games to provide a means for players to interact with the representation they offer is crucial to their appeal. Some things that might be called games, like puzzles, offer limited interactivity and hence limited appeal in the long term, certainly for repeated play. Interactivity appears to be an 'index' of 'gaminess' in that games that provide more interactivity, between players and players and the environment, are more appealing and game-like than activities that offer less interactivity.

Conflict: conflict arises naturally from the interactions that take place within the game. Players have goals, and they may be obstructed from attaining those goals by the game itself, or by other players. They must overcome this opposition to achieve their goals. If opposition is static, the activity is a puzzle. If opposition is dynamic, arising from either another player or intelligent agent within the game, then it is a true game.

Safety: games are safe in that they offer a way to experience a particular reality and to perform actions within that reality with the threat of real and physical consequences arising from those actions. Consequences are present within the game system, but they do not impact on the players' continuing experiences outside of the game-world.

For a more recent take on what defines games, specifically computer games, we can consult Prensky (2001 p118-119) who identifies six structural elements that work together to engage the player:

i) rules

ii) goals and objectives

iii) outcomes and feedback

iv) conflict/opposition

v) interaction

vi) representation or story

Most of these elements are adequately contained within the more general elements described by Crawford above, and this highlights the relatively unchanging nature of the structure of games, even as they have moved into the medium of computer technology. In reviewing Crawford's work we can apply a small caveat to Prensky's definitions, and specify the need for *dynamic* opposition in order to classify an activity as a game rather than a puzzle.

Another core factor in gameplay, implied but not made explicit by the elements identified above, is *failure*, as noted by Squire (2004). An integral part of a good game is that it features an appropriate level of challenge (Lepper and Malone, 1987), and this means that players often fail. But this failure leads to further attempts using modified strategies or simply quicker reflexes: players *learn to play*, and for many years now educators have been wondering whether players might also be able to *play to learn*.

2.3.2 Games and learning

Games are a form of play, and as Crawford (1982) has noted, play is observed as a learning activity in any animal that is capable of learning. Blanchard and Cheska (1985) hold that play is widely perceived as an accepted form of *learning*, not simply the opposite of *work*. Ackerman (1999, cited in Prensky, 2001) describes play as "…our brain's favourite way of learning". The role of play in the social, psychological, and moral development of children has been extensively studied, and play is used successfully as a therapeutic method. However, it is only fairly recently that computer and video games, which offer a wide variety of popular game types, have been considered for use in institutionalised education. A number of educators now agree that such games are a previously "untapped educational resource" (FutureLab, 2009 p1) that may "give a glimpse of how we might create new and more powerful ways to learn in schools" (Shaffer *et al.*, 2005).

Modern educational theories hold that learning should be a self-motivated and rewarding activity (for example Kolesnik, 1970; cited in Amory *et al.*, 1998). The power, and appeal of games – for both players and educators alike – comes from their capacity to generate intrinsic motivation in the players (Malone, 1980). People take part because they want to, because the game is fun, not because they are told to do so (Crawford, 1982). With this capacity to engage, the activity becomes something inherently absorbing, and hence much more memorable and meaningful to the participant. Meaning also comes from providing players with a context that is relevant and appropriate to them – if it has more meaning, it has more power to engage (Dewey, 1916; Tanner, 1997).

This capacity for computer games to generate intrinsic motivation is central to the interest in using games for educational purposes. Bowman (1982) was among the first to wonder whether we could harness this powerful attraction of computer games for educational purposes. Early work such as Lepper & Malone (1987) and Loftus & Loftus (1983) showed promise, but the resulting gamut of 'edutainment' products were widely seen as having failed to effectively harness the power of games to engage players in meaningful educational activities (Papert, 1998). Papert (along with others) believes that efforts from the 1990s to use games to provide educational activities have followed the route of "chocolate covered broccoli" (a phrase introduced by Bruckman, 1999, p1), with boring educational components concealed beneath hopefully appealing game-based activities.

But the interest in designing educational computer games has never completely disappeared, and with the rise of home consoles and online gaming in the 1990s and 2000s, educators again became interested. Some commentators have noted that the reliance on old paradigms and methods is contributing to a failure in modern education to meet the needs of new learners, for whom games and related digital technologies are an integral part of contemporary culture (Prensky, 2001; Beck and

Wade, 2006; Klopfer and Squire, 2008). The growing popularity of games, coupled with increased disengagement from 'digital natives' (Prensky, 2001) has led to renewed interest in how we might be able to exploit modern games and game-like technologies for learning. Students are using digital technologies outside the classroom, thus the school setting should at least begin to engage with these tools (Facer *et al.*, 2003; Facer *et al.*, 2004).

A second wave of interest in the use of games for learning began around 2000, with declarations such as "playing is the new learning" (Hollins, 2002) appearing in the literature and a series of influential reviews into the educational benefits of off-the-shelf games as well as more bespoke efforts (Leemkuil *et al.*, 2002; McFarlane *et al.*, 2002; Kirriemuir and McFarlane, 2004; Mitchell and Savill-Smith, 2004; Egenfeldt-Nielsen, 2005; Sandford and Williamson, 2005; de Freitas, 2006; Ellis *et al.*, 2006). The evidence presented in these reports has not gone unnoticed by policy makers, and the recent Byron review (Department for Children Schools and Families, 2008) remarks on the "unprecedented opportunities to learn, develop and have fun" (p127) that games may offer.

We do not seek to repeat such reviews. Instead we provide a summary of the key aspects of game-based learning that are relevant to our focus on situated mobile learning.

Teachers and parents have noted that games can support the development of skills in a number of key areas (Kirriemuir and McFarlane, 2004):

- Strategic thinking
- Planning
- Communication

- Application of numbers
- Negotiating skills
- Group decision-making
- Data handling

In general terms, the use of games in educational settings can help learners who may be disengaged from the learning process, through perhaps lack of interest or confidence (Klawe, 1994) or self-esteem (Ritchie and Dodge, 1992). Also, learning that is just plain fun to be a part of appears to be more effective (Lepper and Cordova, 1992). Gee (2003) has identified no fewer than 36 learning principles that are embodied within digital games, all of which contribute to encouraging the player/learner to experience different ways of learning and thinking.

At their most basic level, games involve some kind of manipulation of objects. The player is an active participant in the game world and must perform some manipulations in order to advance within the game. According to Leutner (1993) this kind of manipulation can stimulate learning. Similarly, the visualisation, experimentation, and creative activities that take place within games can all enhance the learning experience (Betz, 1995). Turkle (1996) argues that this process of "deciphering the logic of the game" (p180) is part of the pleasure and purpose of learning to play a game, and contemporary theorists such as Koster (2005) contend that pleasure can derive from solving in-game puzzles.

Griffiths (2002) notes that games are particularly effective when used to address a particular problem area or skill. Abstract concepts that can be hard to visualise, such as with maths and science, can be represented through being embedded in gameplay, and creative and critical thought can also be promoted through the use of games (Doolittle, 1995).

There are two main strands running through all of the work on using games for learning. First, there is a belief that we can somehow ‘harness’ games to ‘make learning fun’. However, the problem with this approach is that it can too often lead to versions of Bruckman’s (1999) chocolate coated broccoli and even what Papert (1998) terms ‘Shavian reversals’: examples of learning games that inherit the poorest qualities from their two parents, giving us with learning games that are neither educational nor fun.

The second strand, which in recent years has demonstrated more potential due to advances in available technology, is the notion of enabling *learning through doing*, through simulations and other related games. It should be noted that games and simulations are not the same, and the defining characteristics of each have been debated elsewhere (for example Crawford, 1982; Sauve *et al.*, 2005). A simulation may be a type of game (for example, a game that centres on the simulation of processes and events such as SimCity), but it is also possible that a simulation may include no game-like features at all (for example, a simulation of chemical processes for commercial use). Our focus will be on the former type: simulations that include game-like elements.

We find that many sources use the terms game and simulation loosely and interchangeably, and this is mostly acceptable since there are no formal accepted definitions of either. What is important is what these sorts of activities can deliver in terms of educational advantages. We turn or focus now to the use of game-like simulations for learning, moving on to specific examples that feature mobile technologies.

Simulations are one of the most popular types of games (McFarlane *et al.*, 2002). Games such as *SimCity*, *Civilization*, and *The Sims* have all enjoyed prolonged commercial success, and there are no signs that this trend will change any time soon.

If anything, as technology advances, home computers and consoles will allow ever more realistic and engaging simulations of complex worlds and situations that will continue to enthrall players. One promising area for simulations is science, but a major barrier to take-up of these for educational purposes is that the products are often inaccurate or just too simplististic (McFarlane and Sakellariou, 2002).

Colella's early work, along with related projects at MIT using handheld computers, and Wilensky *et al.*'s NetLogo system (Wilensky and Stroup, 1999) allowing large scale participatory simulations (albeit non-mobile ones), have all demonstrated the power of advancing technology to support contemporary pedagogical aims. Mobile technologies have caught and sustained the attention of educators in the science field, initially because of their capacity to allow for distributed data collection, analysis, viewing, and manipulation.

2.4 Mobile technologies and science enquiry learning

> "Ideally science instruction will ensure that students learn complex science in the context of inquiry and have an experience of mastering new topics or technologies relevant to their personal needs or goals" (Linn, 2004, p9)

Enquiry and participation have become central to the question of how to engage students effectively and allow them to learn the processes and concepts involved in science. The dominant perspective in science education for many years has been *constructivism* and the need for learners to develop understandings of basic science concepts (Scanlon *et al.*, 2005). In recent years, we have also seen a shift towards a perspective that emphasises the acquisition and building of knowledge in concert with *participation* (Sfard, 1998). This perspective is particularly important when considering mobile technology and situated learning; the participation metaphor for learning gives us the perspective of learning as *something we do*, rather than something we acquire. The notion of what constitutes good science learning has also broadened to include not just the understanding of difficult concepts, but also the processes involved in science, and science for citizenship (Scanlon *et al.*, 2005).

Another perspective that is highly relevant to our consideration of the use of mobile technologies outside the classroom, making use of the environment for learning, is expressed by Sefton-Green (2004) who argues:

> "Teachers and other educators just simply need to know more about children's experience and be confident to interpret and use the learning that goes on outside the classroom… we need a culture that can draw on a wider model of learning than that allowed for at present. Secondly we need to work within various curriculum locations to develop links with out of school learning experiences on offer" (p32)

As pointed out by Scanlon *et al.* (2005), there is a particular synergy between what mobile technology can offer and the needs of science students. One of the simplest ways in which mobile technology can be used in science is by utilising mobile devices to gather and process data in the field. A number of projects have demonstrated how mobile devices can be used to enable easy data collection and later collation back at the classroom, for example Kravcik *et al.* (2004) describe a system that allows customised data collection using handheld devices. Significantly, mobile devices allow the easy annotation of data with additional sources, such as GPS coordinates (Ryan *et al.*, 1999) or sensor readings (Vahey and Crawford, 2002). The use of handheld devices in science teaching appears to have led to observable benefits, with major surveys suggesting that up to 90% of teachers saw the handhelds as effective instructional tools across the curriculum (Crawford and Vahey, 2002; Vahey and Crawford, 2002).

Koschman (1996) has identified three possible roles for technology in the classroom, namely *tools*, *tutees*, and *tutors*. Roschelle (2003) asserts that most uses of handheld technologies fall into the *tools* categories, and Frohberg *et al.*'s review of the state-of-the-art in mobile learning (Frohberg *et al.*, 2009) found that the vast majority of mobile learning still tends towards tool use, with over 70% of the surveyed projects based on content delivery or interaction for motivation and control. The remainder are spread between guided reflection, reflective data collection, and content construction.

These latter areas are where we are seeing innovation driven both by technological capability and shifts in pedagogical focus. The drive to shift science learning into something more like science doing, and the recognition of the environment in constructing meaningful learning experiences, have led to a number of projects demonstrating the power of mobile technologies to facilitate reflective activities that mirror the kinds of processes of which educators wish to enhance students' awareness. The last few years have seen the availability of cheap, reliable devices that can provide GPS-derived information about location, and additional sensors can be used to allow data gathering with these devices.

2.4.1 Some non-game project examples

Several recent projects of varied technological complexity have demonstrated how mobile technologies can successfully support field-based enquiry learning.

Ambient Wood (Rogers *et al.*, 2002; Rogers and Price, 2004; Rogers *et al.*, 2004) used mobile technologies to create an exploratory, outdoor learning activity where children could explore a wooded area using handheld computers that communicated with ambient, embedded devices. The handheld PDAs responded to the proximity of 'pingers' in the wood by displaying information about the surroundings, such as plants and animals. Other devices allowed learners to experience aspects of the environment that were not normally accessible to them, such as sounds and images. Ambient Wood was successful in promoting observations taken both with the mobile devices and using traditional means. In particular, students responded positively to unexpected results from familiar actions, for example movement triggering information display. Students were supported in their activities and were able to collect data and compare notes, discussing and generalising their findings and making inferences about what the information they had gathered might mean.

Chen *et al.* (2003) describe a system for scaffolding bird watching in the field. A handheld computer successfully supported students in bird spotting and identification whilst in the field, and was able to provide levels of support appropriate to individual learners through the use of scaffolding techniques. *Wildkey* (Bailey, 2006) is a related project that demonstrates the success of a more lightweight approach, using mobile devices to support the identification of wildlife in the field, through onscreen Bayesian keys. Both of these have demonstrated enhanced motivation and structured activity from the learners in response to the handheld technology in the context of the learning activity.

2.4.2 Models of science learning

In discussing the use of mobile technology to support science enquiry learning, we must have a clear idea of the nature of these enquiries.

Contemporary science teaching is based around the logical positivist approach, which outlines the generation and testing of verifiable hypotheses. A flow chart showing the basic cycle of activity within a positivist framework is shown below in Figure 1.

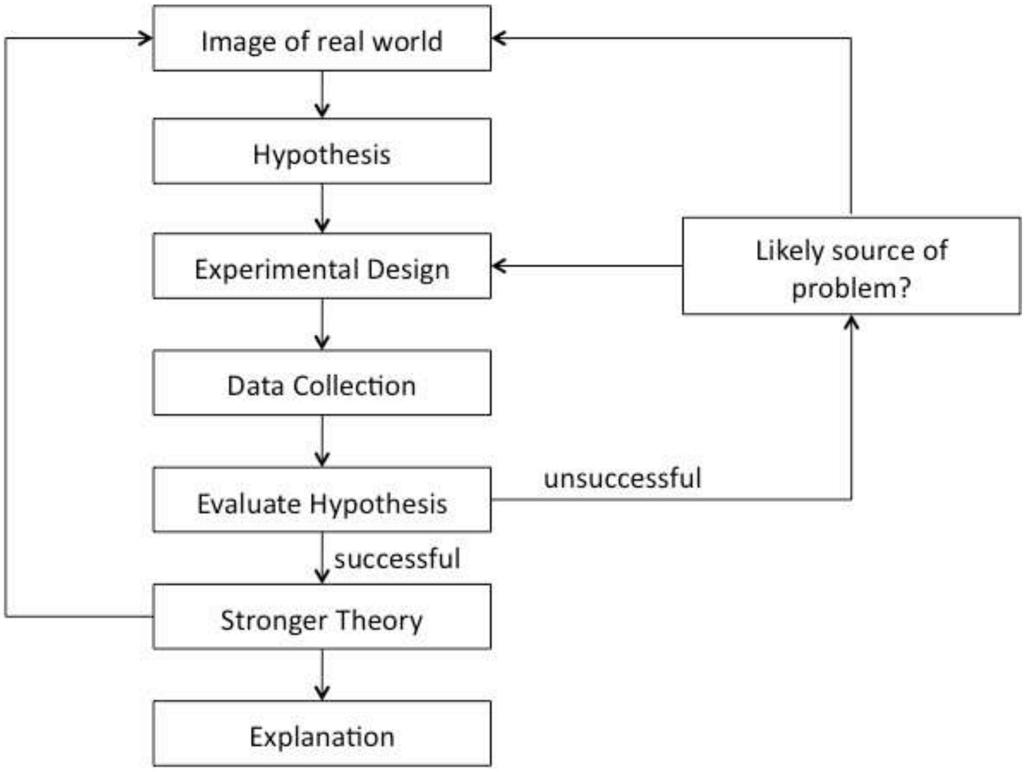

Figure 1: a flow chart of the positivist approach to science, adapted from Harvey (1969)

This process requires learners to engage in a specific set of activities, as described in McFarlane and Sakellariou (2002):

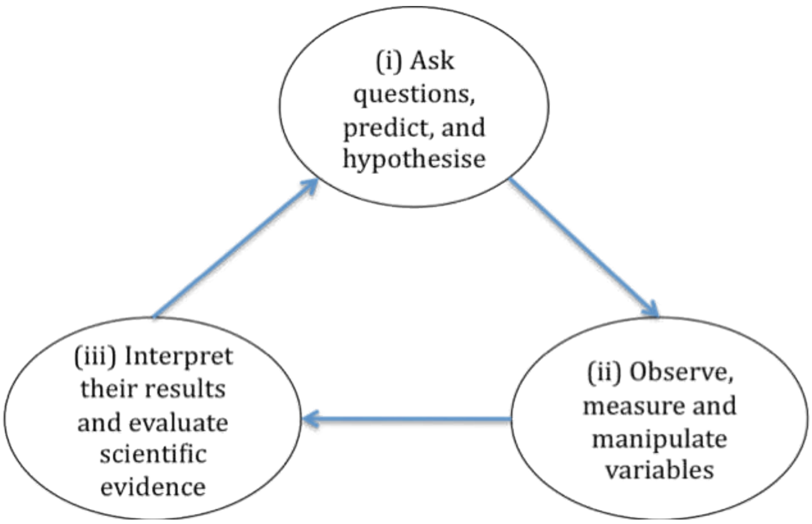

Figure 2: a model of the iterative process of science (adapted from McFarlane 2000)

The model above, adapted from McFarlane (2000), shows the three core activities that learners are expected to engage in during scientific enquiry, and how they should occur in sequence. The underlying premise is that this approach to science is essentially investigative, with students learning about scientific process and theory at the same time (McFarlane and Sakellariou, 2002).

This model maps well on to the UK National Curriculum. The current Programme of Study for Science in the UK describes similar activities. For example, from Key Stage 3 Science:

2 Key Processes

These are the essential skills and processes in science that pupils need to learn to make progress.

2.1 Practical and enquiry skills

Pupils should be able to:

a. Use a range of scientific methods and techniques to develop and test ideas and explanations

b. Assess risk and work safely in the laboratory, field and workplace

c. Plan and carry out practical and investigative activities, both individually and in groups

2.2 Critical understanding of evidence

Pupils should be able to:

a. Obtain, record and analyse data from a wide range of primary and secondary sources, including ICT sources, and use their findings to provide evidence for scientific explanations
b. Evaluate scientific evidence and working methods

2.3 Communication

Pupils should be able to

a. Use appropriate methods, including ICT, to communicate scientific information and contribute to presentations and discussions about scientific issues

Figure 3: extract from Key Stage 3 National Curriculum for Science (National Curriculum, 2009)

As can be seen in the above extract (Figure 3), the three activities of asking questions, collecting data, and interpreting results are all represented.

An important point to note is that despite descriptive models such as that proposed by McFarlane and Sakellariou (2002) and the linear steps still described in science text books (for example Finley and Pocovi, 2000), there is recognition that whilst scientific enquiry may involve cycles of activity, it need not be a linear, sequential process (Reiff *et al.*, 2002; Rogers and Price, 2004). An alternative view is that the enquiry process is somewhat more dynamic, where questions and their possible answers are the force that drives forward the investigation (Moher *et al.*, 2001). Dewey (1964) also believed that the best way of understanding the nature of scientific investigation is for students to carry out their own enquiries. Being successful at scientific enquiry therefore means that students need to be able to make predictions, hypothesise, and analyse data (de Jong and van Joolingen, 1998).

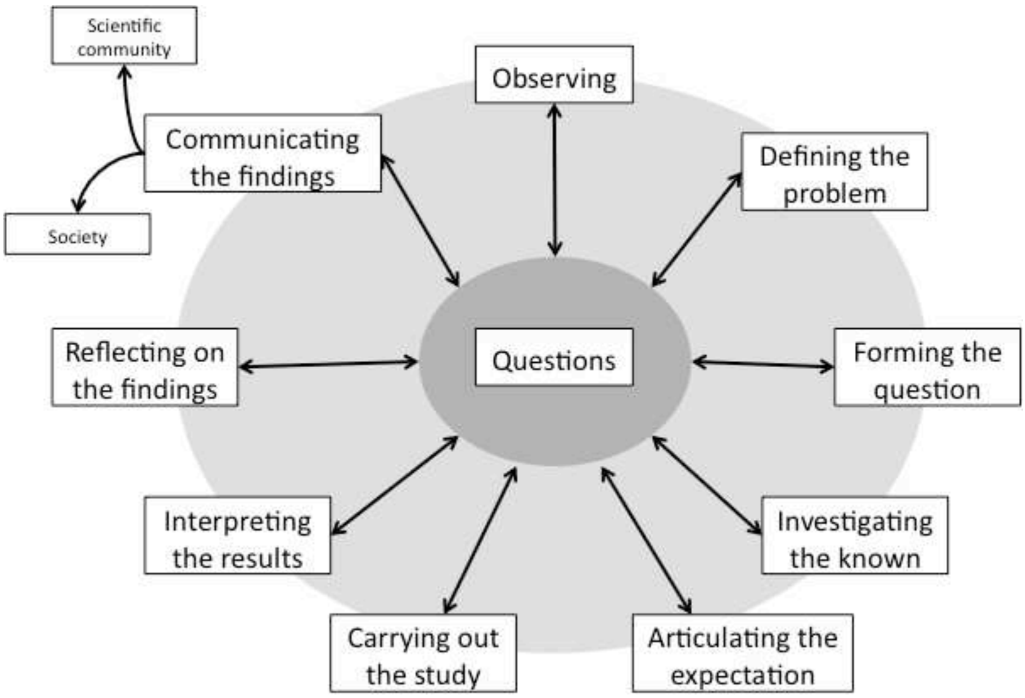

Figure 4: a non-linear model of enquiry learning (from Reiff, 2002)

There has been little work focusing on the design of technologies to promote thoughtfulness and enquiry and provide opportunities for learners to pursue their own questions, especially outside the classroom (Rogers and Price, 2004). The majority of educational technology projects, including those using mobile technologies, rely on tightly focused activities that do not support exploratory activities. This has arisen, at least in mobile learning, because of problems maintaining the focus of learners during the learning activity (Goth *et al.*, 2006), but this approach is at odds with current calls to support more exploratory, reflective, and enquiry-based learning. Some recent work, including the Personal Inquiry Project in the UK (Anastopoulou *et al.*, 2008), has demonstrated the potential for mobile technologies to enable learners to conduct their own investigations, but the mechanisms to support this kind of field work are still being explored.

2.4.3 Theoretical foundations

There is a general agreement in the field of the learning sciences that deep learning is best achieved through situated learning in purposeful and engaging activity (for example, see Brown *et al.*, 1989; Bransford *et al.*, 2000). Exactly how this situated learning is achieved, and how we create purposeful and engaging activity, is open to some interpretation, and there are a number of perspectives that share core values but differ in the details and emphases they describe.

From reviewing recent work on the use of mobile technologies to support and scaffold field-based learning activities, we describe below three core theoretical perspectives that are relevant to the work surveyed in this literature review, and to the work presented in the remainder of this thesis. That is not to say that other theoretical approaches are not relevant, but the perspectives described below are the most relevant to our particular focus, and are the ones that have been discussed by other authors in the field in relation to this area of work.

The over-arching framework for the use of mobile technologies to support learning in the field in this way is social constructivism (Vygotsky, 1978; Vygotsky, 1982). This approach emphasises intrinsic learning through social interactions such as modelling or imitation and accepts that events and concepts can hold multiple meanings for participants. Social constructivism is Vygotsky's enhancement of the earlier constructivist paradigm, which remains a dominant framework within contemporary education, especially science (Scanlon *et al.*, 2005). Constructivism is a theory of learning first developed by Piaget (for example, Piaget, 1929). Piaget described mechanisms by which learners internalise knowledge through the processes of accommodation and assimilation, building up new knowledge from their experiences. Assimilation is the process by which new knowledge is incorporated into existing knowledge structures without the need to modify those structures; accommodation is the process of reframing internal representations in order to fit with new experiences that do not fit into existing knowledge.

Three specific learning approaches that sit within the social constructivist framework and which are particularly relevant to the use of mobile games for learning include:

- Enquiry learning
- Experiential learning
- Situated learning

These approaches are well cited in the mobile learning literature as the theoretical basis for a range of projects and theoretical reviews, for example (Mitchell, 2004; Sharples *et al.*, 2005; Sharples *et al.*, 2007). Some researchers assert that constructivism is the over-arching learning theory, with approaches such as situated and experiential learning comprising ways in which constructivist learning may be enabled, for example Wishart (2007). We review these approaches below and consider their relevance for mobile learning with reference to salient example projects.

2.4.3.1 Enquiry learning

Enquiry learning is an instructional strategy that is used as the basis for designing active learning where students are engaged in some kind of investigation that involves the generation of questions and then applied work to find answers to those questions. Enquiry learning stems from work by Bruner (1961) and Dewey (1938), and is hence closely related to experiential learning. De Jong (2006) describes enquiry learning as "learners asking questions about the natural or material world, collecting data to answer those questions, making discoveries and testing those discoveries rigorously", and Keselman (2003) asserts that enquiry learning is "an educational activity in which students are placed in the position of scientists gathering knowledge about the world" (p898). This theorisation is often cited in relation to the use of mobile technologies to support field-work facilitated by mobile devices (for example Rogers and Price, 2004; Anastopoulou *et al.*, 2008). This approach, and specifically the challenges involved in using it, is discussed in more detail below in Section 2.4.4.

2.4.3.2 Experiential Learning

It is a long held notion within the learning sciences that children construct their own understandings of the world through experience (Dewey, 1916; Papert, 1980 ; Tanner, 1997). The core premise of this perspective on learning is epitomised in Dewey's notion of 'education through experience' (Dewey, 1938; Rosenbaum *et al.*, 2007). This was the basis for the early development of participatory simulations such as Colella's Virus Game (Colella, 2000; Colella, 2002), and more recent work has also cited the influence of Dewey (for example, Facer *et al.*, 2004).

Dewey (1938) describes a theory of learning that emphasises 'learning by doing'. Central to this theory is the inherent value of action by participants in a learning activity. From this learning by doing perspective, learning is viewed as a process of knowledge creation through transformative experience, with optimal learning occurring when learners are able to link new concepts they are learning about with past experience (Kolb, 1984). Experiential learning also emphasises the use of tangible learning concepts that learners encounter and are directly engaged with (Kolb, 1984), rather than abstracted knowledge.

As noted by Piementel (1999), the early work of Piaget and other prominent learning researchers demonstrated that effective learning requires an *environment* where learners can have appropriate *experiences*. Experiential learning further emphasises the role that these environments and experiences can have on the learning process. In experiential learning the learner directly encounters the phenomena being studied rather than just thinking about them or studying the experiences of others. This means that learners are able to ground their understandings and new discoveries within their own previous, concrete experiences and can therefore actively construct ideas and relationships (Barab *et al.*, 2002).

Experiential learning has been embraced by mobile learning researchers from one of two perspectives. Firstly, experiential learning fits well with the kinds of activities and environments that mobile and wearable learning technologies, especially context- or location-aware technologies, can offer. A second, complementary perspective is that technological intervention may actually help solve some of the problems seen as inherent to the experiential learning approach. These two perspectives are expanded on below.

2.4.3.2.1 Using mobile technologies to enable experiential learning

Early work seeking to employ experiential, constructivist approaches made use of the computers available at the time, in the form of 'microworlds' that could be created through the programming of graphical representations and systems (Papert, 1980). These microworlds were originally conceived to provide children with a kind of computational 'sandbox'; a virtual world in which they could manipulate virtual objects and observe their interactions. Microworlds have been hailed as flexible tools for enabling powerful insights through the construction of precise experiences (diSessa, 1986), and they have been used to teach children about the concepts and relationships involved in a wide range of topics, from geometry and mathematics to interactive eco-system simulations. The power of these microworlds comes from their capacity to provide children with a context in which to explore discrete space as real and not as abstraction away from their normal everyday experience of physical reality (Pufall, 1988).

Recent work has seized upon the opportunities offered by mobile technologies to enable these sandbox contexts not through virtual worlds on the screen but in real physical spaces that can be explored by learners using mobile and wearable devices. Colella's seminal work on participatory simulations using wearable, networked tags drew on Dewey's original principles of experiential learning to develop a learning activity that allowed learners to experience directly a simulation of a physical system, creating a direct link between learners' personal experiences in physical space with the underlying rules that governed the underlying simulation (Colella, 1998; Colella *et al.*, 1998; Colella, 2000).

This work has since inspired a number of projects seeking to exploit the capacity of mobile devices to provide a way of linking physical experience with the behaviour of an informatic system. Environmental Detectives (Squire and Klopfer, 2007), Savannah (Facer *et al.*, 2004), Mad City Mystery (Squire and Jan, 2007), and Frequency 1550 (Huizenga *et al.*, 2009) have all drawn on Colella's original work, and in many cases have themselves cited Dewey and related work in the development of their mobile learning activities.

2.4.3.2.2 Using mobile technologies to address the problems of experiential learning

Aside from the apparently innate capacity for mobile technologies to enable experiential learning, there is also a complementary perspective that holds that technological intervention may actually help solve some of the problems seen as inherent to the experiential learning approach. At its heart, experiential learning requires that a learner be engaged in a process of self-motivated activity within a learning environment. Engaging learners is relatively easy, but the requirement for self-motivated and self-directed activity has given rise to some criticism of the concept of experiential learning, with some researchers (for example McCullan and Cahoon, 1979; Miettinen, 2000) pointing to the difficulties in achieving such self-motivation in learners and suggesting that a core problem of experiential learning environments is often the distinct lack of a mechanism to focus the learner's awareness. Another suggested problem is that learners may spend too little time reflecting on their experience (Vince, 1998).

A recent example of a project that employs mobile technology to enhance an experiential learning activity can be found in Lai *et al.* (2007), who describe a mobile system intended to support field-based activities such as taking photographs and recording notes, through the use of prompts via a mobile computer to support a script-based activity. Evaluation indicated that the use of the mobile device led to enhanced performance and supported the experiential nature of the task. Other projects such as MyArtSpace (Vavoula *et al.*, 2009) have demonstrated the effectiveness of mobile technologies in providing structured experiential learning activities away from the classroom.

2.4.3.3 Situated learning

The situated learning approach (Brown *et al.*, 1989; Lave and Wenger, 1991) has been the umbrella term under which the importance of meaningful learning in authentic environments has been emphasised over the past 20 years or so. It is easy to see why this approach has seemed so relevant to mobile learning: portable technologies and networks can take learning out of the classroom and into the situated environments in ways that only ten years ago would have seemed infeasible or even impossible.

Theorists such as Bereiter (2002) and Dede *et al.* (2005) have called for classroom activities to better reflect the complexities of contemporary, 21st century work and living. Students require new sets of skills for the modern day 'information economy', and traditional classrooms are poor at teaching these new skills (Rosenbaum *et al.*, 2007). Lave and Wenger's original conceptualisation of situated learning was of communities of practice centred on real problems (Lave and Wenger, 1991), but this perspective has been picked up and transformed into providing students with exploratory spaces where they can participate in safer versions of reality that allow investigations of the core learning concepts (Barab and Duffy, 2000).

Situated learning can be viewed very much as complementary to the experiential learning perspective described above, emphasising as it does the role of exploratory spaces and practical activities to enhance the learning process. As such, situated learning is similarly cited as the basis for mobile learning research, albeit for projects that focus more on the implementation of authentic activities rather than innovative learning practice (as tends to be the case for those citing experiential learning as their theoretical basis).

Recent examples of the use of mobile technologies to enable learning activities based on the situated paradigm include Pfeiffer *et al.* (2009) who describe an activity supported by portable technology to enhance biology learning in the field. Their paper notes the perceived gap between formal, school-based learning and real-life problem solving, as described by Resnick (1987). The school setting emphasises individual, subject-bound activities, decontextualised from the topic being taught, whereas in real life collaboration with others and direct, contextual interaction with the environment is often required to solve problems. This has led some to note that knowledge acquired in a school setting may be 'inert' and may not be transferred to real-world problems (Bransford *et al.*, 1987). Mobile devices are seen as a highly effective way of enabling real-world learning activities that can lead to highly efficient learning, by providing the means for learners to carry knowledge from the classroom into the real-world (Falk and Dierking, 2000) and thus bridging the gap between the classroom and the real-life learning situation (Naismith *et al.*, 2004; Vavoula *et al.*, 2009) and more generally reducing the disconnect between informal learning and classroom education (Sharples, 2007).

Other significant projects, such as the *HandLer* prototype developed at the University of Birmingham (Sharples *et al.*, 2002) and the *MyArtSpace* project (Vavoula *et al.*, 2009) have also drawn on situated learning theories to inform system design, and this perspective on learning remains important (as noted in Roschelle, 2003; Naismith *et al.*, 2004; Frohberg *et al.*, 2009) as researchers and educators explore new ways of taking learning out of the classroom and into the field using mobile technologies.

2.4.3.4 Reflection

As well as over-arching learning approaches, it is important to explore particular aspects of learning that are relevant to developing situated, experiential learning activities. As has been noted by several researchers, *reflection* is a key component to learning from experience. For example, Ackerman (1996) asserts that reflection – stepping back from an experience and inspecting it – is essential in order to learn from that experience. Thus, enabling reflection should be a key part of designing a learning activity that is experiential in nature. Reflection can be considered to be an essential component in developing skills that help the learner in regulating their own learning processes (Bransford *et al.*, 2000) – skills which are known as meta-cognitive skills.

Dewey (1910) defined reflection as "Active, persistent, and careful consideration of any belief or supposed form of knowledge in light of the grounds that support, and further conclusions to which it tends" (p6). Dewey used this term to describe a model of deductive reasoning, i.e. reflecting on new and existing knowledge to apply it to the current situation. A more contemporary view comes from Schön (1983) who uses the term in a different way, describing thought processes ongoing in the present. Schön (1983) uses the term "reflection on action" to refer to what we more commonly think of as reflection today: introspective thought such as reflecting on our behaviour. Reflection, which is commonly discussed within the context of teaching, can be viewed as a form of debriefing, a discussion of recent events and activities so that they may be learned from and enable further learning.

The challenge of supporting reflection is related to supporting engagement – the two processes need to occur in order to give rise to a flow state (Czikszentmihalyi, 1990) that allows learners to remain motivated but also to be able to 'step back' from their activities and reflect on them (Ackermann, 1996). By managing this process, we can help students learn through a process of *knowledge building* (cf. Scardamalia and Bereiter, 2003), rather than just *knowledge acquisition*.

Prensky refers to an implicit assumption that games do not naturally provide opportunities for reflective learning, and this has to be designed in (Prensky, 2001). There are examples of designers going to great lengths to include structured reflective activities to get the most out of off-the-shelf games (for example Squire, 2004).

However, learning – if not specifically reflection – is increasingly considered to be an inherent component of gameplay and hence commercial game design (for example Gee, 2003). This does not mean that commercial games designers have recently decided to start including learning as part of their designs, rather that learning has always been an inherent quality of digital game play, and the very process of discovering how to play a game requires and engenders learning (Crawford, 1982). For a game to be fun, it must have just the right amount of challenge (Malone, 1980; McFarlane *et al.*, 2002) and hence game designers must pay attention to the 'learning curves' within their games, ensuring that they are neither too hard nor too easy to learn to play (Habgood and Overmars, 2006). To make effective use of games to promote reflection, we also need to consider the nature of the reflection that occurs. Players may reflect simply on their actions in order to *learn to play* the game, or they may be prompted to reflect on associated aspects so that they *learn through the game*.

So the issue of whether games inherently foster reflection (and of what type) by virtue of requiring learning in order to play them remains an open one. However, there remains a burgeoning interest in the use of games for learning, and open acknowledgement of the motivation, engagement, and structure that they can bring to children's activities.

2.4.4 Challenges in enquiry learning

In considering how we might use mobile technologies to support enquiry-based learning, let us examine the specific challenges that arise from enabling enquiry learning in the first place, and where students typically encounter difficulties. Enquiry learning offers compelling opportunities for science teaching, but there are many challenges to overcome, and many researchers have found that children struggle to conduct scientific investigations (for example Schauble *et al.*, 1995; Krajcik *et al.*, 1998).

Several recent studies indicate that learners have difficulties in applying the processes of hypothesis formation, experimentation, and dealing with evidence and interpreting models, and learners often lack skills in regulating their own learning, for example planning, monitoring, and effectively evaluating what they have learnt (for example de Jong, 2006; Manlove *et al.*, 2006).

Research suggests that there are several core areas that students struggle with in performing enquiry-based learning. For example, students may struggle with the following:

i) Persistent misconceptions that undermine progress: children often fail to recognise multiple causalities, or tend to focus on just one, do not recognise cumulative effects, or even think that causes may vary between multiple investigations (Keselman, 2003). Students' misconceptions can be persistent and interfere with progress, and Linn argues that to address this enquiry learning should make thinking more visible and support thinking skills by providing prompts and examples of evidence (Linn, 2003).

ii) Inability to connect theory with experimentation: as demonstrated by Duveen *et al.* (2002), children at the start of Key Stage 3 of the UK National Curriculum have little idea about the nature of experiments and that scientists predict the results and then test these predictions. Instead, students view results as random and unpredictable.

Science teaching based on practical work is prone to problems due to lack of visibility of underlying causation, which can lead to pupils being unable to grasp the abstract theories underpinning what they are seeing (McFarlane and Sakellariou, 2002).

The problem is that students find it difficult to engage in *scientific argumentation*, which means they are unable to follow the desired cycle of *critical thinking* required for science enquiry in the classroom (Kuhn, 1999). A particular problem is that children lack the meta-cognitive skills to develop an awareness of where their knowledge came from, and so are unable to differentiate between established facts and hypothetical ideas yet to be proven. Evidence tends to be interpreted as support for what they already believe to be true, with a lack of awareness of how evidence can demonstrate how things may actually be untrue or unknown.

2.4.5 Mapping gaming principles on to enquiry learning

Digital games may be one productive way of developing scientific argumentation and enquiry skills in school children (Squire and Jan, 2007). A study exploring the argumentation around the popular online game *World of Warcraft* found that such discourse mapped more closely on to the desired benchmarks in science literacy than is reported in many classrooms (Steinkuehler and Chmiel, 2006). Game-based learning activities have been proposed as an innovative instructional strategy that may engage learners in situated, complex thinking tasks that are driven by authentic, meaningful questions, incorporate multiple tools, rely on learning by doing, and guide learners through a path and into a particular way of thinking (Barab *et al.*, 2005; Shaffer *et al.*, 2005; Shaffer, 2008).

Games may include core features that are relevant to enquiry learning: cycles of making choices, experience consequences arising from those choices, interpreting the state of the game, building explanations, having multiple experiences, and building a cognitive model as a result (Squire, 2005; Squire, 2006). Specific examples such as the historical strategy game *Civilization* demonstrate exactly these elements being enacted within gameplay (Squire, 2004).

Squire & Jan (2007) identify several aspects of gaming that may apply to science education. They describe game activities as organised around challenges (Malone, 1981), which in contemporary designs may include complex systems of multiple challenges and rewards designed to support engagement, collaboration and learning. The capacity for games to elicit goals from the player and to create visible win conditions that players then strive to achieve are core features that may be leveraged for educational benefit (Squire, 2005; Squire, 2005; Squire and Jan, 2007).

2.4.6 Games for enquiry learning: Augmented Reality and Participatory Simulations

Game-based activities have also been successfully used to support enquiry-led learning activities, and in recent years there have been a number of significant projects that have employed mobile technologies and outdoor spaces to achieve this. Two notable approaches have been employed in this field, namely *participatory simulations* and *augmented realities*. Participatory simulations, first described by Colella (1998), place learners within a simulation of a physical, social, or other dynamic system, giving them a specific, active role to play (as either a character or element) and making visible the behaviour of the simulation in response to their actions and the actions of others. Typically, this has been achieved using mobile or wearable technologies that can simultaneously display the state of the simulation to the learners whilst allowing learners to perform actions within the simulation itself. Often, a physical space is used as the setting for a participatory simulation, with movement or other physical action on the part of the learners forming an integral part of the activity. In this way, these activities exploit *augmented reality*, either using the physical space as a 'blank canvas' on to which the virtual simulation can be overlaid (for example Facer *et al.*, 2004), or actually incorporating elements of the physical space into the simulation itself (for example Huizenga *et al.*, 2009).

Early work involving mobile technologies and participatory simulations required bespoke hardware and software, but recent advances in handheld technologies, specifically PDAs and GPS, have led to more recent work using off-the-shelf components with only bespoke software required. For example, Mad City Mystery (Squire and Jan, 2007) used PDAs to present students with a place-based participatory simulation that requires students to investigate scientific phenomena through a mystery-based game. The goals of the simulation are to help students develop investigative and enquiry skills through observing phenomena, relating these to underlying scientific processes, asking questions about the impact of human processes on the environment, engaging in scientific argumentation, and developing conceptual understandings. Learners are presented with an open-ended problem (a death) and are able to gather location-based evidence by exploring a physical area with a GPS-enabled PDA. Frequency 1550 (Huizenga *et al.*, 2009) also uses standard components to provide learners with a place-based game to explore local history, using a mystery-based game platform similar to Mad City Mystery.

Two exemplary projects (as noted by Frohberg *et al.*, 2009) that demonstrate the use of situated mobile learning games to engage and motivate students in enquiry-led learning activities are reviewed in detail below. We present brief summaries of each, followed by a review of their findings and critique of their design and evaluation. Where appropriate to illustrate specific points, we compare these projects to other recent related work.

2.4.6.1 Savannah

Savannah (Facer *et al.*, 2004) used networked PDAs with GPS to allow school children to play the role of lions in a savannah, using their school playing field as a playing space. The PDAs enabled the children to 'sense' the savannah by providing location-based information as the children move around on the field. The savannah contained a number of threats which had to be avoided, and other interactive elements such as cubs from another pride that were to be killed, prey to be hunted (which required coordinated group activity), and sources of water and shade. Children were able play at being lions, discovering the kinds of threats and constraints that act on these animals in the wild.

Savannah was successful in creating a learning activity that engaged the students and allowed them to learn through taking on a role in a simulation. The activity was evaluated using an ethnographic approach, with the researchers selecting episodes for analysis that featured evidence of engagement and identification with roles within the game.

In terms of gameplay, the system was a success (with inevitable technical problems common to any deployment of GPS-enabled networked smart devices in the field), but there were several significant observations about the mismatch between the children's expectations and what the game could deliver. For example, interviews with the children indicated how they were accustomed to rich, interactive media, and this could not be delivered using the handhelds. The game itself had rewarding elements, such as attacking and killing prey, but this led to an over-emphasis on these elements because the gameplay was not sufficiently structured to guide them on to something else.

Although Savannah used a school field as the play space, none of the physical characteristics of the field were incorporated into the game, instead overlaying a virtual space on to the real one. This was identified as a 'clash of realities', and the authors suggest that future games should incorporate the real world and use aspects of it as part of the game play.

Learners readily applied their knowledge of gameplay to the activity, but this did lead to some problems of mismatches between what they thought would happen and the mechanics of the game. For example, when the children received messages that they were too hot, they attempted to cool down by 'attacking' the water – this was the only action they could initiate within the game (other than actual movement). However, when this action failed (attacks could only be performed on prey, and not generalised to other objects) the children had to turn to the observers for help. This kind of thinking is common within video games: discovering the method for interacting with in-game objects often involves trial and error, and actions within games are often 'overloaded' in this way. However, in this case the operation of the in-game action was ambiguous and led to a breakdown in the activity.

Savannah used an additional 'Den' setting in concert with activity in the outdoor space. This den was a space for facilitated reflection, where children could examine concepts they had encountered outside and follow-up on things they had marked for later discussion. However, the authors acknowledge that this separation of activity from reflection, trying to combine formal school activity with the game play activity, was one of the least successful aspects of the trial. They note that the children were not given the opportunity to act as self-motivated learners within the Den setting, thus negating the engaging and motivating effects of the game they had been playing outside (the activities in the Den were teacher led with little direction from the students). De Freitas & Oliver (2006) cite Savannah when discussing the evaluation of exploratory games, and note that this disjuncture between the game and classroom contexts contributed to problems mapping Savannah on to curricular goals.

Whilst Savannah was good at engaging the children and providing experiential learning, there is not much evidence of reflection taking part in the field, most likely due at least in part of the separation of activity and reflection as described above. As the authors note, general gameplay styles favour 'just in time' learning, with prompts coming from teachers and other facilitators only upon request.

Savannah was a successful demonstration of the use of mobile technologies to create a location-based learning activity that engaged and motivated learners, and the actual role play elements were effective and appeared to stimulate the children. However, the design of the activity did not in itself support enquiry-led activities in the field, and as such the children did not get to make the most of the participatory simulation they were playing in. This was not a specific aim of Savannah, but we highlight this issue because it highlights how mismatches between expectations and reality can influence the learners' experience, and it suggests that an approach favouring more integration between activity and reflection may be beneficial in terms of supporting enquiry learning.

2.4.6.2 Environmental Detectives

Environmental Detectives (Klopfer *et al.*, 2002; Squire and Klopfer, 2007; Klopfer and Squire, 2008) also demonstrates the power of networked PDAs with GPS to create location-based learning activities based in the real world. Environmental Detectives gave learners the challenge of locating the source of a virtual chemical spill, by taking a series of readings of the concentration of the spilled substance. Using GPS coordinates, the game running on the PDA was able to provide simulated readings based on a model of such a spill occurring within the physical space where the game was played. Environmental Detectives incorporated the physical playing space into the learning activity by having the nature of the spill reflect the physical characteristics of the land. For example, porous soil led to a higher accumulation of the chemical. The aim of the activity was to promote awareness of situated environmental science investigations through role-playing within an augmented reality participatory simulation enabled by the PDAs.

As with Savannah (above) learners were highly engaged, clearly willing to act in the role of an Environmental Detective, and successfully used the in-game mechanisms to locate the source of the spill. However, there were specific issues with learners' activities in the field, relating to strategy and framing the problem. This was especially true for younger students (high school students). In particular, they observed that in many cases the students treated the task as a 'treasure hunt', being driven by the collection of data obtained through the game's 'take sample' mechanism. As the authors note, "…wherever there was a problem, the answer was to drill more samples" (Squire and Klopfer, 2007, p400).

Klopfer and Squire (2008) described the Environmental Detectives game as featuring several options for obtaining samples from the environment, with a trade-off between speed, accuracy, and admissibility in court. The authors state that this led to more discussion between the students about which method to use, but it does not seem that there was any real way in which this choice impacted on the players, other than to change the amount of time required to obtain samples. Students showed evidence of focusing on local factors, rather than maintaining an over-arching view of the task. For example, in trying to locate the source of the chemical spill, they repeatedly took readings and moved towards the highest one. As noted by the authors, the game offered plenty of opportunities for problem-solving, but further scaffolding is needed to help structure learners' activities. The authors suggest that this may be included within the game, or provided by peers or teachers, but note that the latter is difficult within a geographically distributed game.

Students' initial framing of the problem was also identified as an area that would benefit from scaffolding. Unlike Savannah, Environmental Detectives drew directly on features of the environment to act as constraints within the game. This proved to be an effective mechanism to help guide students' actions, and the authors note that this may be 'the strongest pedagogical value' (Squire and Klopfer, 2007, p403) of the project. They note that the students were easily able to synthesise existing information about the environment with information presented to them via the augmented reality of the simulation, and Squire & Klopfer (2007) identify this as a key pedagogical benefit of augmented reality participatory simulations. However, despite the success of the environment in guiding action, there was apparently little evidence of students using the environment to discuss the processes at work within the simulation (the spread of the toxin), because they tended to frame the task as one centred on the collection of information rather than gathering data, explaining it, and then finding a workable solution.

2.4.6.3 Critique

In this section we offer a critique of the above projects related to our previous discussions on the nature of game-based activities, the nature of enquiry learning, and the evaluations of the learning activities. We draw mainly on the two projects described in detail above, with reference to related work to support our analysis.

2.4.6.3.1 Implementing games-based activities

The authors of both Environmental Detectives and Savannah describe their learning activities as games, and indeed they do feature a number of characteristics of games that we describe in Section 2.3 above. However, there are some core features of games, as identified in multiple sources, that are not included in the learning activities of either Environmental Detectives or Savannah.

Let us consider the core aspects of games that we have previously identified: goals and objectives, outcomes and feedback, conflict/dynamic opposition, interaction, and representation or story. In looking at these aspects from a high level perspective, it seems that all of these elements are present in Environmental Detectives and Savannah. However, these aspects imply other features that are not in fact present, or are not present in meaningful ways.

For Savannah, a key problem (as identified by the authors) was a lack of sufficient challenge to engage the players in the task. The children were accustomed to much higher degrees of challenge than were presented in the Savannah activity, so in fact opposition was not present to the ideal degree in this activity. In Environmental Detectives, there appears to be a high degree of challenge, but a core element of gameplay is missing, one which is in fact predicated by the presence of opposition: the possibility of failure. As noted by Squire (2004), failure is a core component of gameplay – one of the first things that happens when someone plays a game for the first time is that they fail. This failure, and subsequent feedback and reflection on what caused the failure, leads to intrinsic motivation to try again, leading to learning (Malone, 1980).

Games require these failure states so that players have to try again – this is the nature of challenge within gameplay, there is always a way to fail. Without this possibility, there can be no second or subsequent attempts, and hence no learning. When a player fails to achieve a goal within a game, relevant feedback is essential so that they can see how close they came to achieving it, and this modify their strategy appropriately.

The role of failure is also acknowledged within the constructivist theory of learning: Piaget's (1929) original descriptions of the process of accommodation demonstrate that failure can be a core component of learning. If we perform an action and the result is not as we expect, then we must accommodate that result by modifying our understanding of our actions and their effects on the world.

The role of failure in learning has been acknowledged in specific domains such as mathematics (Kapur, 2009), and in physics tutoring systems (VanLehn *et al.*, 2003). VanLehn *et al.* found that for learning to be successful, students had to reach an impasse, a point where they could not see how to proceed. Impasses were seen to cause the successful learning of a physical law, whereas students who did not reach impasses rarely learned the concept. Other work by Kapur has also showed that despite apparently 'chaotic' results in the form of complex group discussions, productive failure was in fact a highly effective form of learning for students (Kapur, 2006; Kapur, 2008).

Allowing unstructured events such as failure, that might otherwise be considered unproductive, has previously been seen as desirable (Dillenbourg, 2002; Kirschner *et al.*, 2006), but widespread acknowledgement and application of such a principle in teaching and learning goes against current general principles, and as such would require a paradigm shift (Clifford, 1984). This shift has not occurred in general education, but the role of failure in effective learning is widely acknowledged. Schank *et al.* (1993) also assert that failure is a crucial part of the learning process – learners must form expectations and encounter failure in order to learn, and must see exceptional cases in order to engender failure. Squire (2005) concurs, and describes a an extensive study of *Civilization III* in learning history and geography, describing how, in games, you start with failure – the task is to overcome it, not through explanation but through action. Squire describes the occurrence of failure as a "critical precondition for learning". Similarly, Shaffer *et al.* (2005) discuss epistemic frames and events characterised as "expectation failure" (Schank, 1997) – these are critical incidents that engender learning because learners see that their frames, their ideas underlying their understanding, do not fit with what they are seeing and so they must transform these frames to proceed. This process is widely acknowledged to take place within video games, but has barely been touched upon in the field of simulation-based learning. As has been noted, short term performance failure may lead to longer term gains for the learning process (Clifford, 1984; Schmidt and Bjork, 1992). As suggested by Kapur (2009), we should resist the urge to 'over-structure' learning activities and instead investigate how instructional design might give rise to productive failure events instead, allowing learners the space to make mistakes and learn from them.

Whilst Savannah did provide opportunities to fail (through hunger or failing to catch prey), there was limited *feedback* to indicate to the players how well they had performed. The transition between a win state (being alive) and a failure state (being dead) appeared to be fairly rapid from the descriptions given, with little information being provided to the learners about how well they had performed. To be fair to the designers of Savannah, the activity was intended to be supported by teachers and other facilitators and provide reflection within the separate Den space. We are highlighting this lack of feedback as an illustration of how the potential of games to support learning in the field has not yet been fully exploited.

Feedback was even more conspicuously absent in Environmental Detectives. Students in the field had to choose actions and interpret data, with no indication from the system about how close they were to a solution. The in-game action of taking samples meant that they could test hypotheses about the source and spread of the virtual toxin, but because there was no way to fail within the task they could learn from their mistakes and then go on to have a second attempt. In fact the authors state that one of the primary aims of Environmental Detectives was to provide a context where students could test out ideas 'without fear of failure' (Squire and Klopfer, 2007, p400). In this regard, Environmental Detectives is more of a simulation than a game, and this is indicated as the original intention, but again we highlight this issue to show how games might be further exploited to support students in the field.

2.4.6.3.2 Supporting enquiry learning

Let us examine the scope of support for enquiry learning provided by Savannah and Environmental Detectives to gain an indication of the level of support offered by these projects for enquiry-based learning.

To frame our discussion, we can use the core activities required for enquiry as identified by McFarlane & Sakellariou (2002):

Ask questions, predict, and hypothesise: as identified above, hypothesis generation was difficult for the learners in both Environmental Detectives and Savannah. The activities promoted a generally questioning approach, with the game-like nature of the task requiring learners to 'find out' what was going on. However, there was little evidence of learners spontaneously generating ideas about what was happening.

Similar results have been found in related projects that support outdoor experiential learning, such as Ambient Wood (Rogers and Price, 2004).

Observe, measure and manipulate variables: both Savannah and Environmental Detectives provided multiple opportunities and methods for learners to collect or at least observe information that arose from their activities within the game. However, there were observations that this 'collection' served as an unhelpful focus for the learners, particularly in the case of Environmental Detectives. The students treated the activity as a 'scavenger hunt', with the focus becoming one of collecting as much as data as possible, rather than careful collection and manipulation of variables to observe the effects. So the core action of 'collection' was easily supported, but learners were not discerning in what they collected. Significantly, even the university students in Environmental Detectives were 'driven almost exclusively by the collection of water quality data' (p400). The younger, college students were also caught up in this 'collection' mentality, defining the goal as 'collect as many interviews as quickly as possible'. All of this suggests that whilst providing opportunities for students to collect meaningful data is relatively easy, encouraging them to do adopt strategies for collection and to understand that planning how collection is performed can form part of the problem-solving exercise is more difficult.

Interpret results and evaluate evidence:

Evidence from Environmental Detectives suggests that despite the quantity of data collected, students were unable to interpret it, and became fixated on simple explanations that did not take into account actual observations. Students failed to discern the nature of the problem, and became fixated on a single, simple task: locate the source of the chemical spill. In fact the task they had been given was to identify ways to ameliorate the situation.

2.5 Future directions

As identified above, current studies have demonstrated the potential for mobile game-based learning to support outdoor enquiry learning, but specific issues need to be addressed in order to make the most of the opportunities offered by these new learning environments. We identify specific future areas of priority below.

2.5.1 The problem of control: balance

Most mobile learning projects use full or mainly teacher control (Frohberg *et al.*, 2009), but this is at odds with good learning practice. However, where too much control of the activity is given over to learners, we see evidence of problems arising from this approach. Learners find it difficult to coordinate their own activities, so whilst they may be initially engaged and motivated in a 'free play' activity, they lose track of their goals and struggle to keep on task. Some things are hard when control is with the learners, for example getting them to hypothesise requires intervention from adults (Rogers *et al.*, 2002). The optimum balance is to provide learners with freedom to make their own choices but to scaffold and support their activities in appropriate and flexible ways.

We therefore want learners to have some control, but not too much. Recent work has demonstrated the potential of scripts to support students engaged in active enquiry learning (Anastopoulou *et al.*, 2008). We argue that games also have the potential to provide just the right level of control, allowing learners to form plans, take actions, but step back and seek advice and so on when appropriate.

2.5.2 Making the most of the environment

Mobile learning situated in the environment has attracted a lot of attention and several projects have shown how we can use physical spaces to create engaging learning activities. This approach fits well with current calls to expand the use of spaces such as school grounds to encourage outdoor learning (Teaching Space, 2009).

Environmental Detectives, Mad City Mystery, and Frequency 1550 have all successfully used real physical spaces to provide the backdrop for mobile learning activities, but these are typically spaces that students are not familiar with. As pointed out by Blumenfeld *et al.* (1991), a problem-solving task should connect with students' current interests, experience and motivations – we would argue that school grounds themselves are an overlooked space for creating mobile learning activities that could draw on learners local interests and experience. Squire & Klopfer (2007) describe how learners across all groups drew on their knowledge of the landscape to mediate their discussions, the authors suggest that this integration with the physical space may have been the 'strongest pedagogical value' of the project. Recent work on the Personal Inquiry project in the UK has also explored the use of school grounds as meaningful locations for students to engage in Geography enquiry work (Kerawella *et al.*, 2009).

2.5.3 Using core game mechanisms for learning

Games, or rather game-like activities, have proved to be a popular and somewhat effective method for engaging learners in a range of activities, including mobile learning tasks. However, many recent projects citing the use of games actually omit core game mechanics from the design of the learning task itself. We would argue that the most fundamental of these is the role of failure to promote retries and reflection. Too many projects shy away from actually allowing learners to fail, but when playing games this is exactly what learners expect and this can be a powerful mechanism for learning.

2.5.4 Comparative studies

None of the mobile research projects reviewed for this literature review performed any kind of comparison with equivalent non-mobile activities. There is a great deal of enthusiasm for the use of these new technologies for learning which has led to great examples of innovation, but in some cases we need to re-examine what are the specific advantages and, more importantly, problems associated with taking learning into the field (Frohberg *et al.*, 2009; Huizenga *et al.*, 2009).

2.6 Conclusion

We have reviewed the field of mobile learning to explore the use of situated mobile learning activities to support enquiry-based learning. A number of projects have demonstrated the suitability and effectiveness of mobile technologies for supporting learning in this area. In particular, there is specific interest in the use of games to provide structured, motivating, and supportive activities, and again projects have demonstrated success with these activities.

Within science teaching there appears to be a widespread acknowledgement of the need to transform teaching and learning into something that relies more on 'doing' and 'experiencing' rather than abstract knowledge delivered in the classroom. The use of mobile technologies to encourage thoughtful and reflective practice in authentic environments is a promising avenue, and the use of games to achieve this appears to be a particularly successful strategy. However, there are specific problems involved in implementing experiential learning activities, which are further compounded by the problems engendered by taking learners away from the familiar classroom environment into the field where they can find it difficult to coordinate their own activities. The weaknesses in students' meta-cognitive skills means that scientific enquiry and argumentation is something they find difficult, yet this is something at the core of contemporary science education. Might there be a way of supporting students in these activities by providing concrete, familiar tasks in the form of games where argumentation and reasoning are part of that familiar context? The challenge is to use popular platforms such as games to deliver meaningful scientific enquiry activities. Despite promising results, example projects such as Savannah and Environmental Detectives have demonstrated that learners require more specific support for reflection and structuring their own learning. We also see that games, whilst hailed as powerful motivational platforms for learning, have yet to be exploited to their full potential, with particular regard to supporting exploratory, enquiry-led activities. Perhaps the most significant mechanism involved in learning to play a game, the role of explicit failure states, retries, and strategy modification, is yet to be explored in a mobile game-based study.

Chapter 3

Research Methods

This chapter outlines the research methods used in this thesis for the evaluation of the mobile learning activities used in Studies 1 and 2. We describe the general approach taken during this work and describe two methods used in analysing learner activity: the *critical incident technique* and *grounded theory*. This chapter discusses only *research* methods; for the approaches used in designing and developing the PaSAT software used for this research see Chapter 4.

3.1 Evaluating mobile learning

Mobile learning is a new and immature field but is developing rapidly (Traxler, 2007). The frameworks and methods for evaluating mobile learning studies are still evolving, and researchers in this field borrow heavily from other related fields such as technology-enhanced learning and mobile human-computer interaction. However, in a survey of current evaluation practice Traxler & Kukulska-Hulme (2005) find that most evaluation studies in mobile learning are not adapted to the mobile nature of the activity, and that attitudinal measures (such as Likert scales of learning satisfaction and so on) are the norm, with methods such as interviews, focus groups and observations used less often.

Sharples (2009) is critical of the use of attitude surveys and interviews in evaluating mobile learning, expressing the view that whilst interviews and observations can provide *descriptions* of the learning process, they do not give us any more information about the *nature* of any learning that has occurred, or an indication as to how permanent it may be. Methods such as these are better used as supplementary methods, with other approaches being better suited to exploring the actual processes that take place during learning activities.

Research on mobile game-based learning, like the majority of mobile learning projects in general, tends to focus on the motivational effects of the activities (Huizenga *et al.*, 2009). A specific problem highlighted by Sharples (2009) is that attitudinal surveys used to assess reactions to new technologies tend to give positive results, typically in the range 3.5 – 4.5 on a standard 5 point Likert scale, which tells us nothing about the quality or nature of the learning activities themselves. Parr & Fung (2000) also remark on the disconnect between attitudinal measures and learning outcomes, basing their comments on work found in other reviews such as Wood *et al.* (2000).

The current literature discussing evaluation in mobile learning specifically advocates the modification of research methods to fit with the situated nature of mobile learning, and emphasises a focus on processes rather than outcomes. In selecting evaluation methods for this work we attempted to address these current calls.

3.2 Evaluation aims

A number of evaluation activities were performed for the work described in this thesis, with evaluation being part of a theory-led design, implementation and evaluation of a mobile learning game and associated authoring toolkit.

The work conducted for this thesis was organised around several phases:

1. A review of existing research.
2. Technical implementation and testing.
3. A pilot study to determine specific problem areas and potential solutions.
4. The design of a theory-based mobile learning game, BuildIt, to address current problems.

5. Deployment of the BuildIt game.

6. Evaluation of BuildIt to assess the extent to which problems and issues had been addressed.

7. Development of a grounded theory from structured evaluation.

Evaluation thus formed an integral part of this work, being an important component of phases (2), (3) and (6). Early evaluation and testing, including pilot studies with the toolkit and Study 1, contributed to formative evaluation that fed into later development work and the deployment of the BuildIt mobile learning game. A summative evaluation of BuildIt was then conducted, and data from this study was used to develop a grounded theory model (grounded theory is described in 3.5.1) of learner interactions with the environment and the mobile game.

We therefore had two primary aims for the evaluation methods used in this research. Firstly, we wished to identify critical aspects of outdoor mobile learning activities that could support and hinder learners engaged in an enquiry-based learning activity. For this evaluation, we were interested in finding those factors that appeared central to particular difficulties or breakthroughs. A research method that has been successfully employed for this kind of evaluation in previous work is the Critical Incident Technique. We present an overview of this method below. The specific application of this method to Study 1 is then described in Chapter 5.

Critical incidents were important because we wished to explore how mobile technologies could support new forms of learning outdoors, not just more efficient performance of existing activities. This meant that we needed a method that allowed us to determine whether these new learning activities were taking place or whether they were actually hindered by factors such as the environment, the technology, and learners' interactions with their peers. We were thus looking for evidence from the field of how and when activities such as reflection and engagement occurred (or did not occur) in the field, and the critical incident technique provided the means to identify that evidence.

Our second evaluation aim was to explore the ways in which a situated mobile learning game could support the *process* of learners carrying out an enquiry-led learning activity outdoors. Because of our focus on process, rather than outcomes, we needed a method that allowed detailed analysis of the activities that learners were engaged in, and ways in which we could explore the relationships between the learner, the game, the technology, and the environment. At the same time, we did not wish to become entrenched in the work of others; mobile learning itself is a nascent field, and mobile learning games even more so. Given the lack of current theorisations in the mobile learning field, we wished to develop explanations based solely on what was observed in the studies conducted for this thesis.

A research method that allows in-depth analysis of human activity without requiring a basis in earlier work is *grounded theory*. We describe this research method below, and its specific application to Study 2 is described in Chapter 7.

3.3 General approaches used in this research

3.3.1 Quasi-experimental design

The research presented in this thesis focuses on the design, implementation, and evaluation of mobile learning activities intended to promote and support field-based learning. In the case of Study 2, further emphases were placed on *game mechanisms* and *enquiry-based learning*.

For each of the studies presented, we wished to compare the use of the mobile learning activity with an equivalent, non-mobile activity. The intention of this was to provide us with a means to examine what aspects of learning were influenced by the mobile learning activity, and which were influenced by the context in which the learning took place and the high-level conceptual design of the activity itself. In Study 1, we wanted to explore what aspects of the outdoor environment and mobile learning activity running the PDA would help or hinder the students. Therefore we used an indoor activity, using the same mobile devices, as the comparison condition. For Study 2, we explored the use of a mobile location-based game activity to support enquiry learning. In this case, we used a paper-based version of the activity so that we could see how the use of the game on the PDA supported students over and above being outdoors with a problem-solving task.

This design is experimental in nature because we are seeking to compare two specifically designed conditions. However, it is not truly experimental because we are not seeking to vary independent variables and observe the effect on dependent variables. Instead, we were interested in exploring the differing nature of the two conditions. This constitutes a quasi-experimental design.

We believe that adopting this quasi-experimental, comparative approach provided us with a significant advantage over other work that has sought to evaluate mobile learning, either in the field or in the classroom or lab setting. This advantage comes from having a way of determining the origins of the effects and phenomena that we observe. In related work, it is common to see the use of a mobile learning system being evaluated in terms of the engagement or satisfactions displayed by learners, or the impact on learners' recall, and user satisfaction scores. But in the majority of cases, there is no way to tell if these benefits might not have been observed if a similar interactive task had been performed in the same context without using the mobile learning system itself. The problem with this lack of comparison to equivalent, non-mobile activities has been highlighted by several researchers, for example Dede & Dunleavy (2007), Huizenga *et al.* (2009) and Frohberg *et al.* (2009).

3.4 *Study 1: Comparing outdoor and indoor learning*

3.4.1 Critical Incident Technique

The critical incident technique (CIT), first described by Flanagan (1954) is a method used to identify and resolve issues pertinent to the operation of a dynamic system or process. It is a flexible method, and so can be modified for use in a range of domains, but it commonly features the core aspects of incident identification, issue identification, decision on remedial action, remedial action being taken, and finally evaluation of the remedial action taken. CIT is therefore useful for any work involving systems design because, unlike many other evaluation methods, it places a focus on identifying solutions for problems and evaluating those solutions as part of the method itself, rather than just describing the problems that were observed.

CIT has been used in the field of human-computer interaction (for example Westerlund, 2007) and technology-enhanced learning for over a decade, and is particularly suited to early identification of issues in the design of user-centred systems . Some examples include Sharples (1993), which describes the use of CIT to identify learning breakdowns and breakthroughs in a computer-mediated communication system, and more recently Anastopoulou *et al.* (2008) where CIT is used to identify salient issues in the requirements gathering phase for a project designing handheld tools for science enquiry learning.

A typical application of CIT is as follows. The researcher identifies a particular episode or series of episodes of human activity to be analysed. A specific number of people who are involved in these activities are the participants for the study. After the completion of these activities, critical incidents are identified during interviews with participants, or through some other means such as reviewing video or audio footage. Incidents may be identified by searching for episodes that meet with predefined criteria relevant to the study being conducted, or by looking for specific key events that have been flagged as a point of interest. After the initial identification of critical incidents, the incidents are reviewed in collaboration with the participants (or other experts) to determine their cause and implications. From this set of elaborated critical incidents, recommendations and guidelines can be inferred that can contribute to developing and correcting faults in the system, as well as supporting the subsequent identification of incidents.

A major disadvantage of CIT as originally conceived is its reliance on the memory of participants to elicit details of salient incidents. In recent years, this has been obviated by the use of real-time data gathering (such as video footage and system logging) to provide accurate data that can be mined, often in collaboration with participants, to identify incidents.

The critical incident technique was originally developed to focus on the identification of *breakdowns* to indicate how to correct faults within systems, but in applying this method to the evaluation of educational technology is it also relevant to look at *breakthroughs* which can indicate novel activity and conceptual change.

In the field of learning technology, this direct involvement of participant is not always possible because of either to time constraints or the age of the participants themselves making it difficult for them contribute to the identification of issues. In such cases, researchers may take on the role of identifying critical incidents, with learners involved in later exploration and explanation by watching a collation of critical incidents and discussing their nature, cause, and implications (for example Sharples *et al.*, 2007; Vavoula *et al.*, 2009). Alternatively, the incidents may be examined 'as is' without any further involvement of the learners (Anastopoulou *et al.*, 2008).

CIT was chosen as a method for Study 1 because:

- It could be adapted to fit with the intended field studies.

- It is a method suitable for the identification of problematic issues early in the design of interactive systems.

- It builds-in the need to review issues at a later date after steps have been taken to reduce or eliminate the observed issues.

3.5 Study 2: Evaluating a location-based game for field-based enquiry learning

3.5.1 Grounded Theory

There is a strong case for evaluating mobile learning in naturalistic settings rather then in artificial settings such as a lab. Kjeldskov *et al.* (2003) surveyed research methods used in the field of mobile HCI, and found that there is a strong bias towards evaluation in lab settings. They note that field studies and other investigations using grounded data (i.e. data that is centred on specific events and contexts rather than being more generalised) have disadvantages in terms of bias and potential lack of generalisability, but argue there is a case for increasing the number of studies that evaluate mobile apps and devices in situ.

Since mobile learning is a new and developing field (Lee and Chan, 2007) and there is still no common agreement on what exactly constitutes mobile learning (Frohberg *et al.*, 2009), this field is thus suitable for the application of methods such as *grounded theory* that allow the generation of applied theories that fit emerging data (Cook *et al.*, 2008). This is especially true of mobile games for learning. There are few studies addressing the experiences of learners using mobile learning games.

In recent years, grounded theory has been used in a number of high profile mobile learning studies. Two of these, Huizenga *et al.* (2009) and Squire & Klopfer (2007) used grounded theory specifically to evaluate participatory games, whilst others including Botzer & Yerushalmy (2007) and Mitchell (2004) demonstrate that grounded theory is applicable to mobile learning as a whole.

3.5.1.1 Summary of Grounded Theory

Grounded theory is a qualitative research approach that emphasises (and requires) the generation of new theory from data, rather than testing data against established theory. The term 'grounded theory' refers to both the concept of generating theory from data, and also to a set of tools and methods developed for performing this process. Grounded theory has its origins in health research, originally developed by Glaser and Strauss (1967) when studying awareness of dying in terminally ill patients. Since then, grounded theory has been used in a variety of domains, gaining popularity in the social sciences, including psychology and education. The power of grounded theory comes from the opportunity to generate new explanations that are not based on pre-existing interpretations, but are instead grounded in the researcher's own experience of gathering and analysing data, and the context from which that data is drawn, as well as the *constant comparison* of data with the theory that is being developed.

Data used in grounded theory typically consists of transcribed interviews, but as it become more popular in the social sciences the approach has also been applied to field notes, official documents and other archival material as well as transcriptions. As new methods for collecting data have developed, and grounded theory has been applied to a wider range of human activities, an ever wider range of media have been used as the source material for grounded theory studies. Silverman (1993, cited in Strauss and Corbin, 1998) notes that data for grounded theory can be pretty much anything, including interviews, transcripts, videos, and pictures.

Grounded theory differs from more general ethnographic analysis in that there are identified tools and methods to apply to the data, and a notion of the process by which this should be done. However, it is important to note that grounded theory analysis is not a step-by-step, sequential approach to analysis. Instead, grounded theory emphasises a non-linear approach, with the research moving between different phases and using different methods concurrently to arrive at conceptualisations and re-descriptions of the data. Similarly, the tools and methods that have been developed to support the application of grounded theory are intended as a guide, and not a prescriptive set of methods (Strauss and Corbin, 1998).

At its heart, grounded theory maintains that micro-analysis leads to conceptualisations and theory – the idea is that the data should be allowed to speak, and that the lowest possible level of meaning should be examined, and only then should these concepts be allowed to form higher level abstractions and eventually a theory that explains the data in question. Grounded theory does not start with identifying themes; it starts with identifying low-level meaning from data.

The central process underlying this analysis is often referred to as *line-by-line analysis*, referring to how transcripts may be coded by placing notes against each line. However, this does not mean that every line has to have a code, and it does not mean that every line has to be analysed: the researcher is expected to be familiar with the data, and be able to pick out potentially interesting segments to analyse. Line-by-line does not then mean literally line-by-line (Strauss and Corbin, 1998), and thus when we apply this method to other forms of data we find that we must choose an appropriate strategy for segmenting the data into "lines".

In contrast to more general, ethnographic approaches, grounded theory consists of a range of methods and tools that support the analysis of data and the generation of theory. This defined process, loose though it may be, is often cited as the major difference between grounded theory and alternative qualitative approaches. A central requirement of the process is that the researcher maintain a rich set of research memos that document the process, allowing inspection by others and offering the means for the researcher to justify their interpretations and allow others to offer alternatives interpretations of their own. Borgatti (2009) holds that it is this rich and documented process that gives rise to useful theory from grounded theory studies, and sets this approach apart from others that seek to describe and explain data in context without having a defined method.

Grounded theory as a method is intended to be flexible and non-linear: it can be adapted to suit the needs of a specific study and the phases described in the literature are defined as guidelines, not prescriptive sequences for analysis.

Data collection in a grounded theory study begins with open sampling. In this phase, raw data are collected from the source without any preconceptions about what is important or relevant. After a period of *open sampling*, the researcher begins to code the data in the *open coding* phase. Open coding is where the researcher annotates the raw data with codes to describe what is seen in the data. Typically, this is done in a 'line-by-line' fashion for interview transcripts, or at an equivalent atomic level for other media. Open sampling may continue whilst open coding is being performed. Once a substantial set of *categories* (descriptive labels) have been developed from open coding, the researcher can begin *relational sampling*, modifying the data collection strategy to fit with the themes emerging from the coding. This leads to the collection of data that are specifically relevant to the ongoing analysis, and allows the start of *axial coding*, where the emerging categories can be grouped and the axes on which they can be organised can be developed. Subsequent coding is then organised around those categories. At this point, a grounded theory starts to emerge, and sampling can be theoretical, allowing the researcher to test their theory against newly collected data and determine if their categories and organisations thereof fit with observations. If the grounded theory needs to be modified because it does not fit the new data, this is done either by returning to the axial coding or even possibly open coding phases. Once a grounded theory has been developed that fits with all data collected, the researcher may proceed with the *final analysis*, preparing their organised categories and their theory that explains the collected data.

Giles (2002) offers a useful summary of the grounded theory process, summarised in the Figure 5 below.

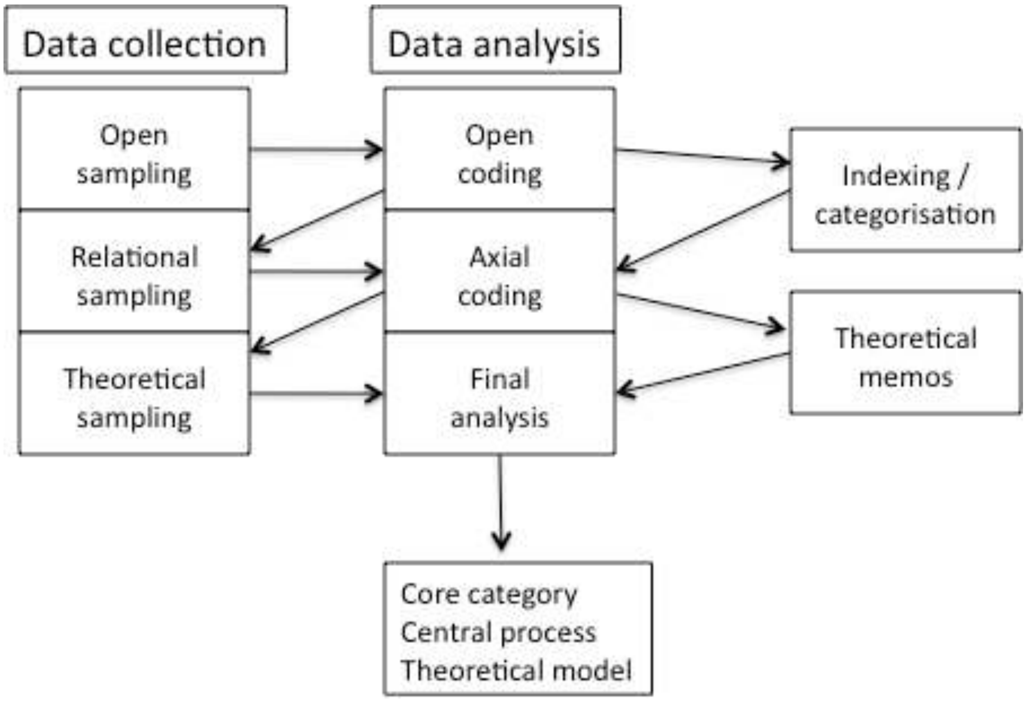

Figure 5: Stages in the grounded theory process (adapted from Giles, 2002)

In Figure 5, we see the three stages of data collection and associated three stages of data analysis, and how these relate to one another (adapted from Giles, 2002). The outcome of the data collection and analysis stages is an idea of the central category or concept to which all other categories or concepts relate, and from that a related theoretical model that explains the data in question. This model and the central category are supported by the researcher's memos and documentation showing how the categories were arrived at. In grounded theory, data collection and data analysis themselves do not occur as distinct phases – additional data collection may be informed by initial and later analysis, and new data may then go on to modify the analysis itself.

It is crucial to note that, like many other qualitative approaches, the use of grounded theory gives rise to a set of interpretations and explanations from the researcher's own perspective, and these may be challenged by others. The researcher must be related to the data being collected and analysed in order to complete a grounded theory analysis, and as such there is an inevitable loss of objectivity. This is fully acknowledged within the grounded theory literature and is part of the process itself; the researcher is expected to become immersed in the data and offer their own explanations for it, for the purposes of generating new theory and explanation that is not rooted in existing explanations and interpretations.

3.5.1.2 Applying Grounded Theory to this research

When applying grounded theory, the researcher can choose to work directly from the collected data, developing categories as they work, or they choose to begin with an established framework that describes a particular relevant set of phenomena. For example, when analysing Environmental Detectives, Squire & Klopfer (2007) use Gee's (1999) framework for discourse analysis.

We chose not to apply a specific framework because we wanted to understand the data on their own terms, and as we were not focusing on specifics such as language use we did not wish to be constrained by such a framework. In fact, we were more interested in the interactions between learners, the device, the environment, and the game, which meant we were observing their activities from a number of perspectives. We chose to use grounded theory without reference to any pre-existing frameworks to further enhance the 'grounded' nature of the work – no frameworks yet exist that adequately describe the interactions between learners, the environment, and mobile learning activities, and the intention of this research was to move towards just such a framework.

One of the tenets of grounded theory is that an analysis can continue indefinitely with ever increasing depth of description and explanation, and the researcher must *choose* a particular point at which to halt a particular analysis so that it can be written up and shared. We chose to halt our analysis when we discovered core categories and had some meaningful descriptions of how they related. This is an accepted point at which to stop a grounded theory analysis (Strauss and Corbin, 1998).

We do not assert that the interpretations presented in this thesis are complete or generalisable, but that they describe the activity we saw from the perspective of someone who was directly observing the activity. This work is presented with the intention of garnering criticism and alternative explanations, the aim being to further the conversation about how mobile learning can effectively integrate learner, environment, and learning, with supporting mechanisms such as games that can build bridges between these spaces.

The methods section in Chapter 7: Study 2 further describes the specific application of grounded theory method to this research.

3.6 Conclusion

This chapter has described the core research methods used for this thesis: *critical incident technique* and *grounded theory,* and has outlined the underlying quasi-experimental approach employed in the field trials that were conducted. Additional details of how these methods were applied to the specific studies described in this thesis are provided in the relevant chapters that describe each study.

Chapter 4

Design and development of a toolkit for building and deploying situated mobile learning games

This chapter describes the development and testing of a prototype toolkit for creating and deploying mobile participatory simulations that make use of the environment. We describe the high-level design goals, derived requirements, and the implementation of a combined authoring environment and game server, as well as client software for mobile devices.

The resulting combination of authoring toolkit, game server, and mobile client is referred to collectively as *PaSAT* – Participatory Simulation Authoring Toolkit.

The design and implementation of PaSAT was primarily informed by current practice, as observed in related projects and systems, and not by theory. This chapter thus describes the practical work involved in developing the PaSAT system. The theoretical influences on the design of the BuildIt learning game developed for Study 2 are described in Chapter 6.

An over-arching design goal for the authoring system was to determine whether it was possible to create a flexible toolkit that could be used by non-experts, such as teachers and other educators who do not have programming skills. This design goal is a key factor that differentiates the PaSAT toolkit from other authoring toolkits that have been developed over the past few years. Toolkits exist that allow designers to associate media with location-based activities (for example 'whereigo' from Groundspeak Inc, 2009), but adding more complex interactivity of the sort required for games requires programmatic design. This level of design has become available recently through the *mscape* package (Hewlett-Packard Development Company, 2009), but creating activities that involve complex interactions is still beyond the skills of a non-programmer when using these current toolkits.

4.1 Summary of the PaSAT conceptual architecture

We provide here a summary of the functional architecture of the completed system prior to describing its development in later sections.

PaSAT is implemented as a client-server system, with the server running a combined game authoring system and gameplay engine, and client software running on mobile devices that connects to the gameplay engine and allows players to take part in the game by displaying a dynamic map, game status, and allowing invocation of game events.

The underlying conceptual architecture of PaSAT is a state machine model. The game is represented as a number of states, with game events (including location change and invocation of game actions) triggering state changes and hence driving the game forward.

The details of how states and state changes are represented are given below in Section 4.6. We begin with a description of the development of requirements for the PaSAT software.

4.2 Development approach

The general approach for design and implementation was the *rapid prototyping method* (Isensee and Rudd, 1966). This approach, growing out of contemporary commercial software design, has been taken up by designers of educational activities and technologies (and Tripp and Bichelmeyer, 1990; in place of alternatives such as the ADDIE model – see Wilson *et al.*, 1993) due to its potential to save time and money in developing large scale systems. This approach has been used successfully in a range of educational technology development projects, with a recent relevant example being the Environmental Detectives platform (Klopfer and Squire, 2008).

Rapid prototyping involves building a small-scale, partly-working prototype early in the development cycle to test key features and to assess whether the chosen infrastructure is adequate and appropriate. Testing this first prototype allows designers to better understand the key requirements of the system and determine how well the initial designs meet the design goals.

We used this approach to test our first prototype against preliminary design requirements, and to feed into the development of more refined design goals in concert with a review of the literature (see Chapter 2).

4.3 Identifying Requirements

Our starting point for identifying requirements for a mobile game authoring toolkit was to review previous work and derive requirements based on the functionality and technical implementations seen elsewhere. We reviewed Virus Game, Savannah, and Environmental Detectives to derive our core requirements. These are key projects in the field, and provided examples of the kind of participatory simulations we wished to extend in the current research.

A core design goal was also to implement an authoring toolkit that allowed the creation and editing of situated mobile learning activities by users without programming skills. The number of location-based mobile learning projects that have appeared in recent years points to the popularity of these activities in the educational sector, but as yet creating interactive activities still requires a fair degree of programming knowledge, even using toolkits such as Hewlett-Packard's *mscape* (Hewlett-Packard Development Company, 2009). Basic activities that involve associating content with locations can be created without any programming skills, but activities that involve interactivity require at least some programming skills to set up the required rules, states, and variables. Our aim was to develop a system that allowed the creation of activities without the need for end users to write code.

4.3.1 Requirements

This section describes the primary design goal for each system component – the authoring toolkit, game server, and mobile client – as well as specific requirements derived from these primary goals.

4.3.1.1 Authoring toolkit

The primary goal for the authoring toolkit was: *Allow creation and editing of mobile activities through a non-programming interface, suitable for non-expert users such as teachers and other activity designers*.

To achieve this design objective we produced a number of specific requirements, by reviewing previous work and deriving specific features that would be required to recreate similar activities:

- An appropriate hierarchy of in game elements that maps on to conceptual concepts involved in creating interactive mobile activities
- Common descriptions for all objects allowing extensibility and flexibility
- Structured and appropriate representation of state for all in game elements
- Mechanisms for mapping of game structure elements on to a map of physical space
- Support for using customised maps of the local environment, provided as raw images rather than obtained from specific proprietary sources
- Mechanism for defining regions on map that could be used to trigger events

- Mechanisms for triggering state changes based on detection of specific game states (including player states)

- Mechanisms for defining and applying state changes

4.3.1.2 Game server

The primary goal of the game server was to provide a means for the authoring toolkit to allow mobile clients to connect to it and play the games by sending player location updates, invocations of actions initiated by players, and receiving game state information. The functions of the game server can be enumerated as:

- Provide a connection port for the mobile client to connect and send and receive data pertaining to the current game state.

- Provide a connection port for the mobile client to request the invocation of actions, and to return the results of those actions.

- Provide mechanisms for applying state changes configured by users using the authoring toolkit component.

4.3.1.3 Mobile Client

The primary goal of the mobile client was to provide a user interface on a mobile device that allowed a player to view the map used in the current game, their position on that map, the current game state, and the means to perform actions and receive feedback within the game.

We derived the following specific requirements to meet this primary goal for the mobile client:

1. Display of a custom map indicating position

2. Display salient game status information (including win/loss states, as well as ongoing status updates)

3. Display messages, prompts, and content items as required by the game

4. Display list of available game actions

5. Allow the player to select and invoke game actions

6. Allow the player to annotate the map through own movement and placement, and the movement and placement of other players

7. Communicate with server to send location information and receive game status updates

4.4 Development of the prototype

This section describes the technical implementation of the software components used to build the complete system for developing the location-based learning activities used in this research.

The PaSAT software comprises a desktop application *server* that allows the creation and playing of game-based tasks in physical locations, in combination with a software *client* that runs on a mobile device (such as a PDA). The mobile device is used by learners in the field to carry out a learning activity using the game facilitated by the mobile device connected to the game server.

4.4.1 Development Platform

All software development was carried out using the .NET platform and the Microsoft Visual Studio integrated development environment (IDE), using the C# language. The .NET platform is a development framework produced by Microsoft that is intended to allow rapid development of internet-based applications across a range of devices, using a standardised development platform.

Applications developed using Microsoft Visual Studio and .NET can be easily deployed on to Windows PCs and mobile devices that have a suitable version of the .NET Framework installed (this restricts the range of possible mobile devices to those running the Windows Mobile operating system).

4.4.2 Software architecture

It became clear from the outset that rolling the game server functionality into the authoring environment was practical and appropriate for a number of reasons. Firstly, this simplified the development process: since the game server component relied on data provided by the authoring environment it made sense to provide server functionality directly from the authoring environment. Secondly, it made conceptual sense from the user's perspective, especially in conjunction with the intention of providing real-time viewing and editing of the game-state at runtime. Separating the two components would have made the system harder to develop and less easy to understand for the user.

The PaSAT software was thus developed as two high-level components:

- A server and authoring application running on a desktop PC
- A client application running on a mobile device (a Windows Mobile device)

These two components communicate using Web Service calls. A Web Service is a server application that responds to incoming requests via the standard HTTP channel (port 80), using structured messages in XML (eXtensible Markup Language).

A Web Service was used for a number of reasons:

- Visual Studio includes native support for building, deploying, and consuming Web Services in .NET applications.

- Web Services offer stateless connections, i.e. they are more tolerant of interruptions in network connectivity than stateful connections such as sockets, because they do not require a continuous connection.

- Web Services allow the exchange of structured messages using XML documents. These documents can be easily parsed by applications that can reference the appropriate XML schema for the document. XML documents can include optional elements, which means that adding elements to include more data does not cause runtime errors because the original structure of the document is still viable.

However, the use of Web Services brings a number of limitations to the system:

1. Web Services are less efficient than custom, socket-based communications, and place greater demands on the system to interpret them.

2. Web Services only allow information PULL, that is to say they only respond to requests and do not allow for any PUSH to available clients.

These limitations were not significant factors for the development of PaSAT. Limitation (1) is not significant because the XML documents exchanged are simple and small, placing little demand on the software. Limitation (2) can be largely overcome by setting the client to poll the server at frequent intervals, simulating information Push by providing regular and frequent Pull.

In order for the two main components of the PaSAT system to communicate via Web Services, a Web Service application was developed as part of the desktop application. This application runs under Internet Information Services, the standard desktop web server application provided by Windows. The Web Service application listens for requests coming in via Web Service calls, and when an appropriate request is received the request is then forwarded to the desktop application. This forwarding is achieved through the use of an inter-application communication protocol called .NET remoting. The desktop application opens a communications port for listening to a designated other application, the Web Service server, and requests can be made via this mechanism. When the desktop application receives a request from the Web Service server via the remoting mechanism, it performs the required actions and, when appropriate, makes a response via the same channels.

Figure 6 below shows a diagrammatic representation of the architecture of the system.

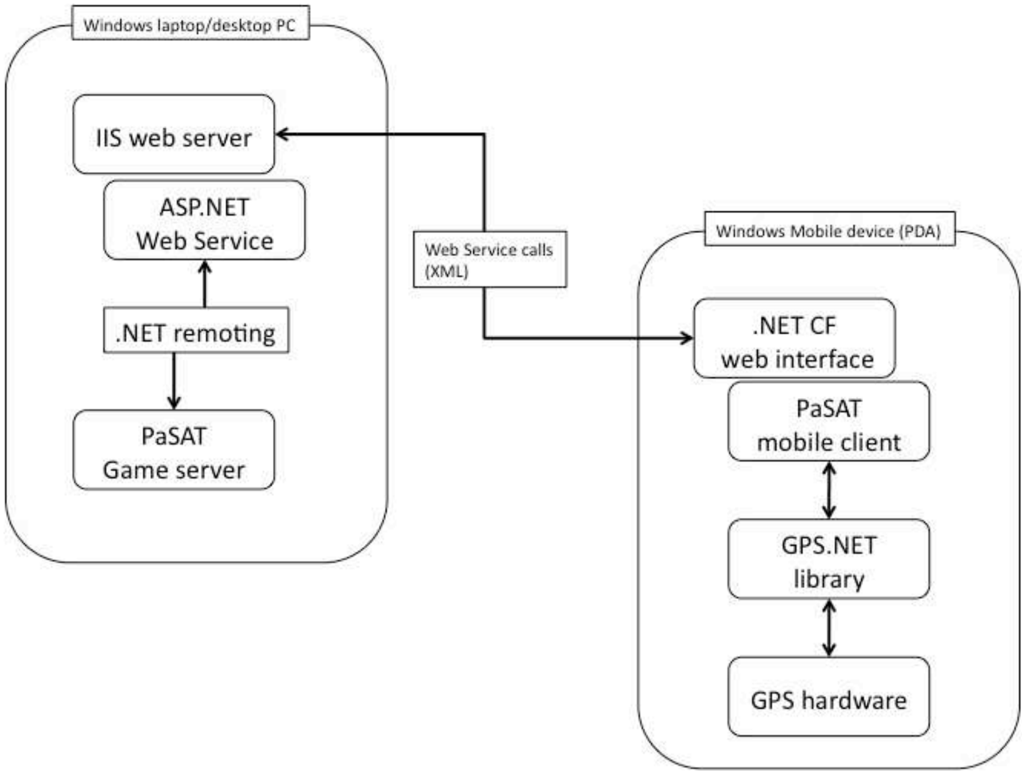

Figure 6: architecture of PaSAT system

4.4.3 Client-Server architecture

PaSAT employs what is known as a thin-client deployment strategy. The client software that runs on the PDA contains just enough functionality to allow users to connect to the game, see a map and their position, and to perform actions, and see results and other feedback. In addition, the client is responsible for using the mobile device's GPS hardware to calculate the physical position of the user. However, all of the data relating to the game's current state (including the current location of the user) is stored on the game server, and accessed periodically by the client. This means that the current game state and the handling of state change events is performed by the server and these changes are then immediately available to all connected clients.

A fat client strategy would store more (potentially all) of the game state data on the client, and the handling of the game state and state changes would be distributed, leading to potential conflicts and difficulties maintaining synchronisation between devices.

For the kinds of activities that PaSAT is intended to support, there are a number of advantages to the thin client approach. These include, but are not limited to, the following:

1. Crash resilience through session persistence: if a PDA crashes and loses local data the player can restore their session because this information is held on the server and not locally.

2. Speed of response: because the PDA software is lightweight it places a small burden on the limited processing capacity of the device and can respond more quickly to user input. This is especially important for simultaneous handling of continuous network and graphical events of the sort envisaged for the interactive mobile activities that PaSAT is intended to support.

3. Ease of deployment: because the game states and configuration are held on the server, deployment of a new game can be performed quickly via a log-in and synchronisation process rather than having to distribute new data or software files to each device

4. Multi-player interactivity: because the connected devices all connect to the server as a hub, multi-player interactivity can be handled easily on the server

rather than having to resolve conflicts arising from multiple devices trying to connect on an ad-hoc basis in the field

4.5 Related work

A number of related projects have either focused on or included work on implementing a toolkit for designing and deploying situated mobile activities. We present brief reviews of several of these below, outlining the core mechanisms they have used for presenting a toolkit to the authors and end-users. Other toolkits for creating mobile activities exist; we have selected key examples from the field that focus on creating dynamic interactive activities rather than simply situated content delivery. In particular, we describe *mscape* (Stenton *et al.*, 2007; Hewlett-Packard Development Company, 2009), an authoring toolkit that has been developed during the same timeframe as PaSAT and which now shares a number of features and design goals.

4.5.1 EQUIP2

EQUIP2 (Greenhalgh *et al.*, 2007) is a platform for developing interactive games that players can take part using mobile phones. EQUIP2 has been used to create and deploy a number of games, including MobiMissions (Grant *et al.*, 2007) and Day of the Figurines (Flintham *et al.*, 2007). These games have demonstrated the flexibility of EQUIP2 in catering for a range of phone handsets, and a variety of messaging protocols. Like PaSAT, EQUIP2 maintains a game engine on the server with handsets used primarily for game status display and action invocation. EQUIP2 is a flexible, extensible system, but does not appear to offer an authoring environment that can easily be used by educators to develop mobile learning activities.

4.5.2 WildMap, WildKey, and WildForms

WildMap, WildKey, and WildForms (WildKnowledge, 2009) are software packages comprising a mobile client for delivering multimedia content associated with specific locations, via handheld computers with GPS, and for collecting data based on that location using specific templates. This suite of applications from WildKnowledge allows the creation of situated activities using handheld devices. Interactivity is limited to responses from the device itself, and there is no framework for the creation of interactive, distributed activities. The emphasis is instead on lightweight applications, each of which focuses on a specific activity. Originally developed as bespoke applications, the software has now been ported to web-based delivery.

4.5.3 CAERUS

CAERUS (Naismith *et al.*, 2005) is a location-aware mobile guide system – intended for use with PDAs and GPS – that includes an authoring environment allowing users to import customised maps and configure content delivery and route prompts for specific locations. The client software runs on Windows Mobile devices, and uses GPS hardware to track users as they move around an area that has been set-up for a CAERUS activity. Users see a dynamic map indicating their current position, as well as possible routes that lead to new items of content. The CAERUS authoring tool allows users to import a map, overlay a custom sized grid, and define regions as groups of grid squares. Content and other display items can then be associated with these regions. CAERUS was designed to create tour guides, and as such has no representation of state other than what content items have been displayed.

4.5.4 Environmental Detectives

Klopfer & Squire (2008) describe the authoring toolkit developed to support the design and deployment of the Environmental Detectives participatory simulation (a subsequent trial of this simulation is described in Squire and Klopfer, 2007). This toolkit was developed originally to support the activity designed for the

Environmental Detectives game, specifically the taking of readings of toxin levels from the environment and viewing of media files associated with physical locations. The toolkit that was developed was extended to support different contexts of use, but the primary mechanisms of the task remained unchanged, and there is no way of modifying these other than by working with the source code.

4.5.5 Wherigo

Wherigo (Groundspeak Inc, 2009) is an authoring system for Windows Mobile devices that allows authors to create location-based games by defining hotspots on a map that trigger game events. The system is designed around a physical treasure hunt metaphor, with players expected to move around in the physical environment to find objects. The system is not designed expressly to support learning, but can be used to create learning activities. The mechanisms for defining and monitoring progress within a game are centred on making objects visible or invisible to the user, and there is no rich representation of the current game state.

4.5.6 'mscape'

'mscape' (Stenton *et al.*, 2007; Hewlett-Packard Development Company, 2009) is a software toolkit for creating interactive experiences that can be accessed using mobile devices in conjunction with sensors such as GPS to collect contextual information. 'mscape' (originally Mediascape) has been in development by HP since 2002, during the same timeframe that PaSAT has been developed, and was released as a public beta version in March 2007. Recent additions have included the inclusion of a StateMachine to handle state information, and the system uses a simple scripting language (similar to Adobe ActionScript) to allow experience designers to create rich interactive activities.

'mscape' shares a number of design goals with the PaSAT system described here, but came from different origins. PaSAT was originally conceived as a toolkit to specifically create mobile learning games, particularly participatory simulations. 'mscape' began as a tool to associate media files with physical locations, allowing users to access items of content provided by experience designers as they moved around a physical space. This core functionality has seen be extended to allow designers to add more interactivity and to represent state through the use of variables, and to create rules for action using a scripting language. A wide range of mscape activities – 'mscapes' – have been created by third party authors and are available on the mscape web site (www.mscapers.com). These activities focus on a wide range of domains, and there is no specific focus on either learning or games.

The most recent version of mscape appears to be suitable for recreating the BuildIt game as described in Chapters 6 and 7, as well as a range of other situated participatory simulations. However, as mscape was not available when development on PaSAT began, and has only recently offered support for the kind of state representation and interactivity envisaged for PaSAT, mscape was not a candidate platform for the activities described in this thesis. However, this parallel development of a system for authoring and deploying situated mobile activities does point to the relevance of the development of the PaSAT system.

4.6 Developing the software

This section describes the development of the functionality of the PaSAT software in relation to the requirements identified in Section 4.

4.6.1 Representing in-game objects

Given the object-oriented nature of the .NET platform, and especially the chosen development language C#, we decided to use a hierarchical, object-oriented representations for all in-game elements. This meant that in-game elements could inherit properties from other related elements, thus simplifying the development process and resulting in a structured internal representation that was easy to extend and modify.

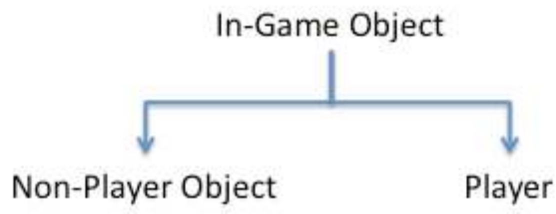

Figure 7: example hierarchy of in-game objects

We initially identified two types of objects that needed to be represented within a game, Players and Non-Player Objects. Player objects were intended to represent actual players during the game, and Non-Player Objects were intended to represent all other objects, real or virtual, that might be used during design or runtime. For example, a virtual object that players could pick up and carry somewhere to act as a key was a Non-Player Object. Similarly, an object in the physical world that we wished to interact with in the game world could be described as a Non-Player Object. Players and Non-Player Objects both inherit a set of properties in the source code and functions from the parent type In-Game Object. The use of this hierarchy meant that in many cases Players and Non-Player Objects could both be manipulated in the same ways within the PaSAT coding environment.

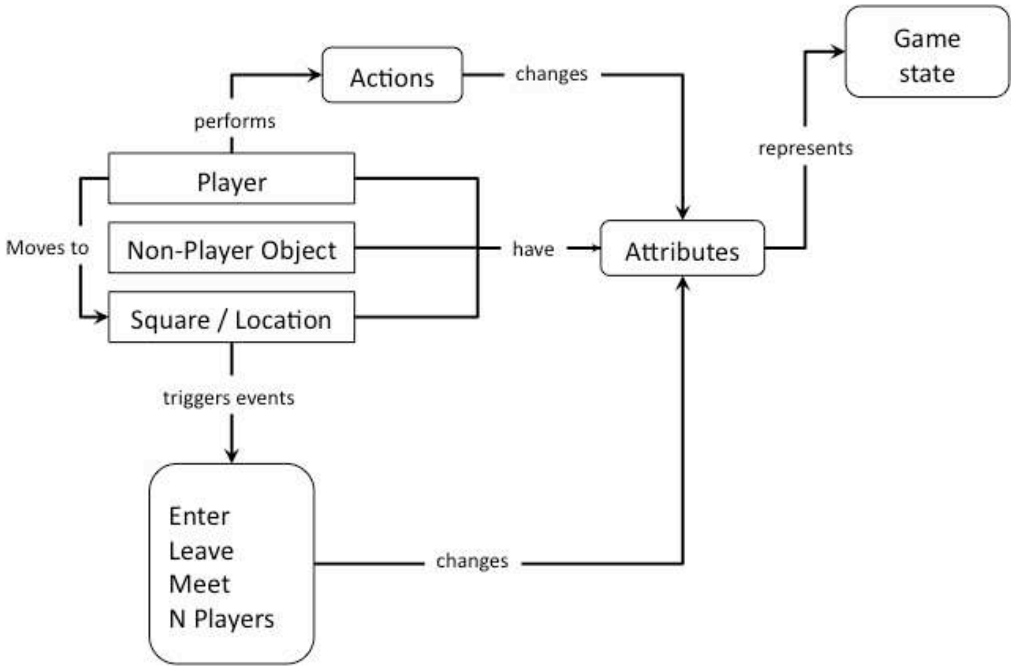

Figure 8: conceptual architecture of PaSAT, showing structural elements and relations

4.6.2 Representing in-game object states

To represent the current state of the game, including all players and other in-game objects, we required a way of representing state on all of these objects. For simplicity we chose to represent state as attributes composed of name and value pairs. For example, a Player could have the attribute Team = blue. To handle simple declarative states, we also allowed attributes to be name only types, for example a Player could have the attribute 'Dead'.

Since the primary mechanism for progressing the game was intended to be state-changes, the manipulation of these attributes on in-game objects was central to the operation of PaSAT, and forms the basis for the event-based triggers and Actions described below.

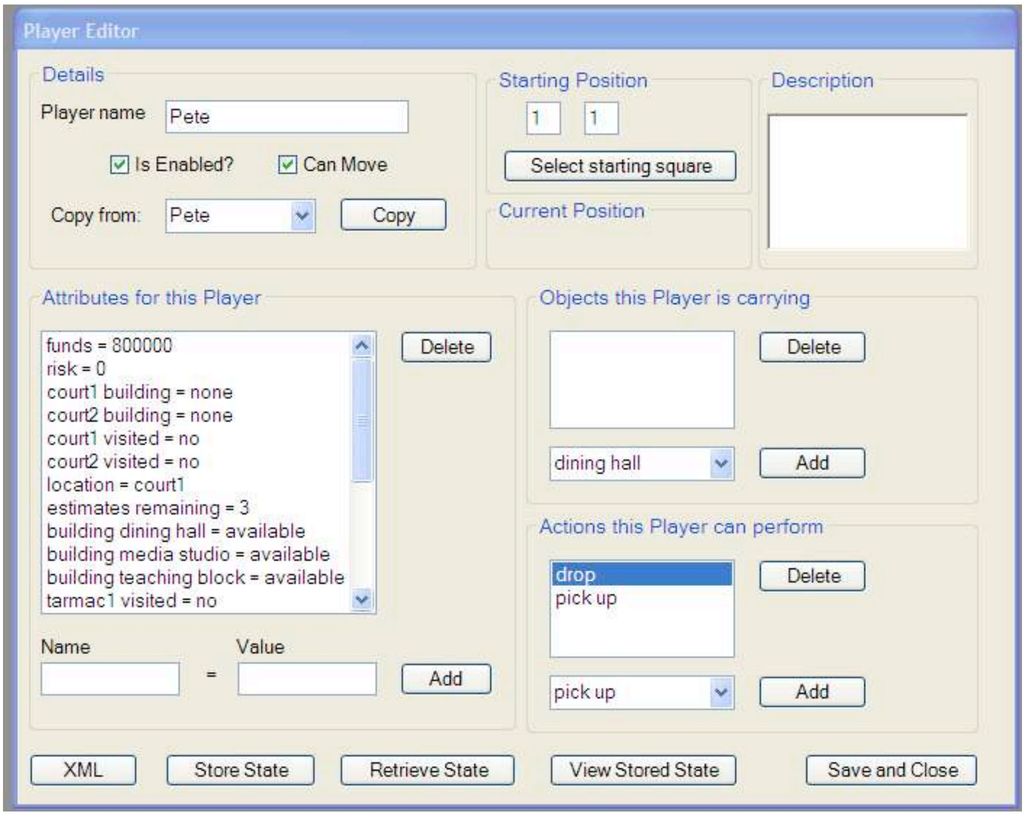

Figure 9: editing a Player object

As can be seen above, a Player object has a number of attributes defined on it, along with other values such as objects being carried and Actions that can be performed. This entire state is represented internally as a software object, and can be retrieved at any time as an XML document.

4.6.3 Representing actions

To allow Players to perform specific actions within the game, we included Action objects that could be configured to perform state changes on specified In-game Objects.

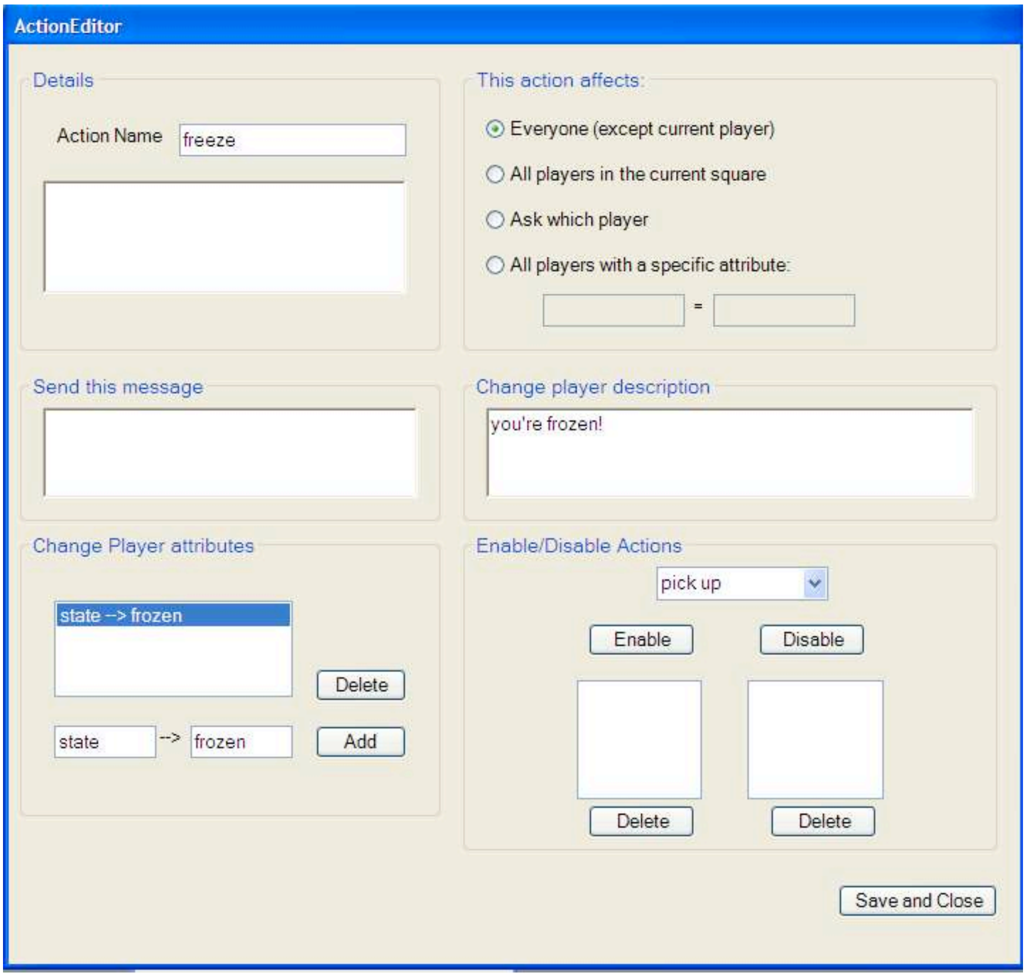

Figure 10: settings for an Action

As can be seen above (Figure 10), Action objects can be configured to enact state changes on specified Player objects by specifying the name of attributes to change. Messages can also be sent to Players, and the Actions that the target Player can perform can be modified. In the example shown in Figure 10, an Action called 'freeze' has been defined which acts on all Players, setting the attribute 'state' to the value 'frozen', and changing the Player's description to 'you're frozen'.

4.6.4 Representing maps and locations

A primary requirement of PaSAT was the ability to import maps of specific areas and overlay regions on those maps that could be set to trigger specific events or state changes within the game, thus allowing player movements to drive the game activity.

Having reviewed previous work such as CAERUS, and considering the benefits of a highly structured object-oriented representation, we opted for a grid-based system for describing locations on custom maps. In a grid-based system, the map is divided into regular grid squares, and regions can be defined as groups of those squares.

Alternatives to the grid-based method include systems that allow definitions of irregular regions. For example, both *mscape* (Hewlett-Packard Development Company, 2009) and *wherigo* (Groundspeak Inc, 2009) allow the creation of irregular regions. We felt that implementing such non-structured representations posed too much of a technical challenge for a first prototype, and would be harder for non-expert users to manipulate, so we opted for the established grid-based mechanism.

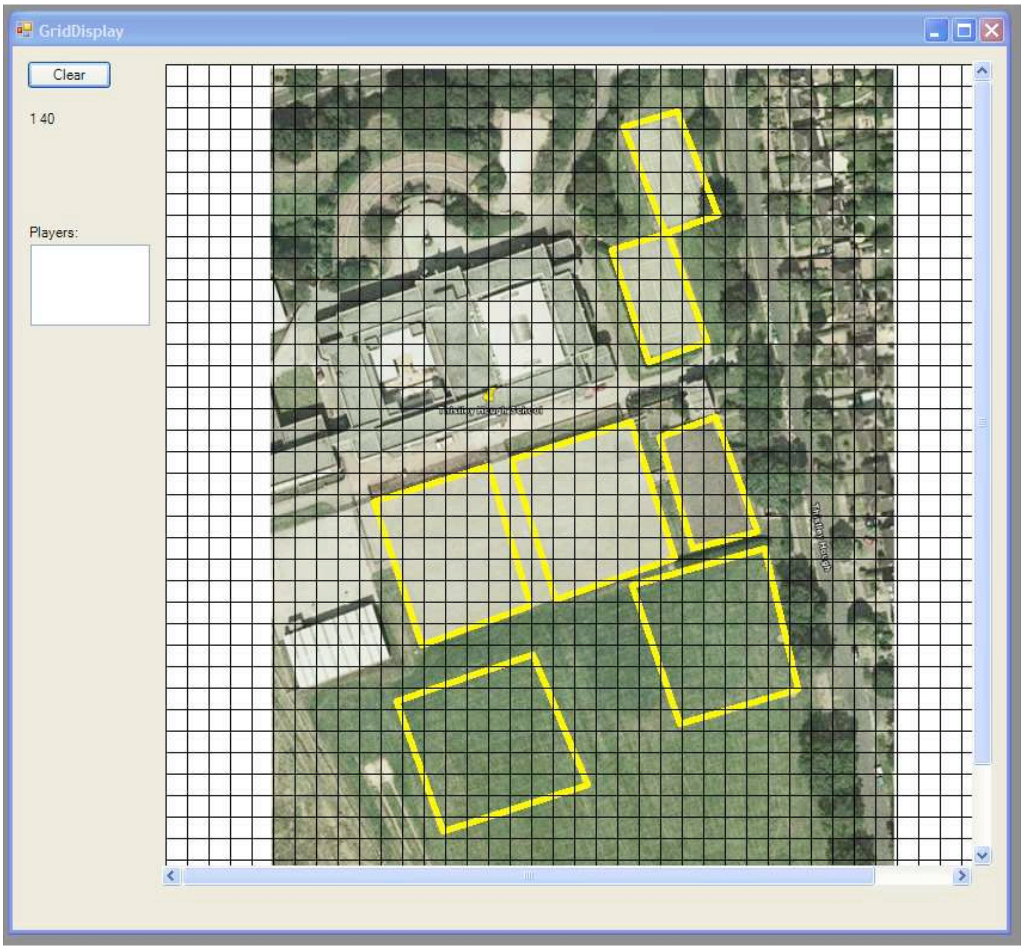

Figure 11: overlaying a grid on to a custom map

The software requires a scale map of the game space and a specification of the scale of the map in both x and y directions. Scale maps can be obtained from sources such as Google Maps, which provides aerial views of outdoor spaces along with a scale indicator. Maps from such sources do not always use the same scale for the x and y axes, so PaSAT supports maps with different scales in the x and y directions.

Once a map has been imported into PaSAT (from a JPEG or bitmap file), PaSAT draws the map onscreen and allows the user to choose the size of the grid to be used. Grids in PaSAT have the same number of squares in the x and y directions. By moving a sliding control on screen, the user can see how the chosen grid dimensions look when overlaid on the map. When the desired grid dimension has been chosen, it is locked and PaSAT creates an internal representation of the map using grid *squares* as the basic atomic unit of the representation. These squares form the basis of how interactive activities are created using PaSAT. Movement by players into and out of squares triggers events on those squares and gives rise to *state changes* within the game.

4.6.5 Representing map hotspots and regions

As described above, there was a need to be able to demarcate regions on the map that would act to trigger events within the game, or serve some other focus. PaSAT allows individual squares to be configured to trigger events and actions within a game. Also, groups of squares can be defined as a Location, which can be configured in exactly the same way as an individual Square. Location objects within PaSAT inherit directly from Square objects, and so can be manipulated in the same ways.

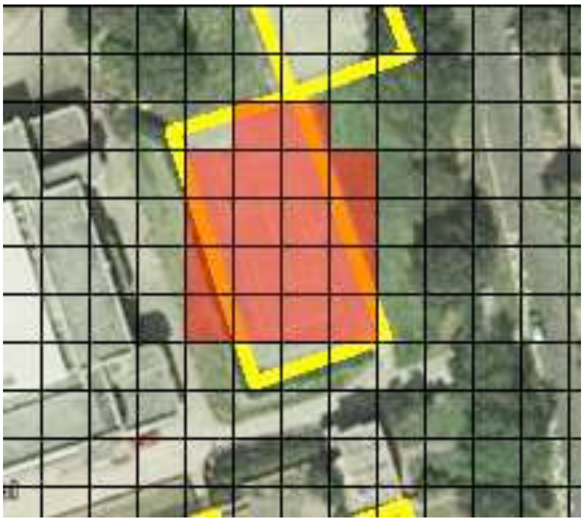

Figure 12: defining a group of Squares as a Location in PaSAT

4.6.5.1 Event triggers

In order to allow the game to be progressed, PaSAT needed to include a number of event triggers that could be configured to modify attributes on in-game objects and/or perform specific actions. Since the primary method of driving the game forward was envisaged as being movement, a set of event triggers were included on Square (and hence Location) objects that would react to Player movements:

1. Enter square/location: triggered when a Player enters this Square or Location
2. Exit square/location: triggered when a Player leaves this Square or Location
3. N players at a location: triggered when N number of Players are present in this Square or Location

When these events were triggered, they invoked the specific state changes as described by their individual settings – these were implemented in line with the settings offered by Actions (as described above):

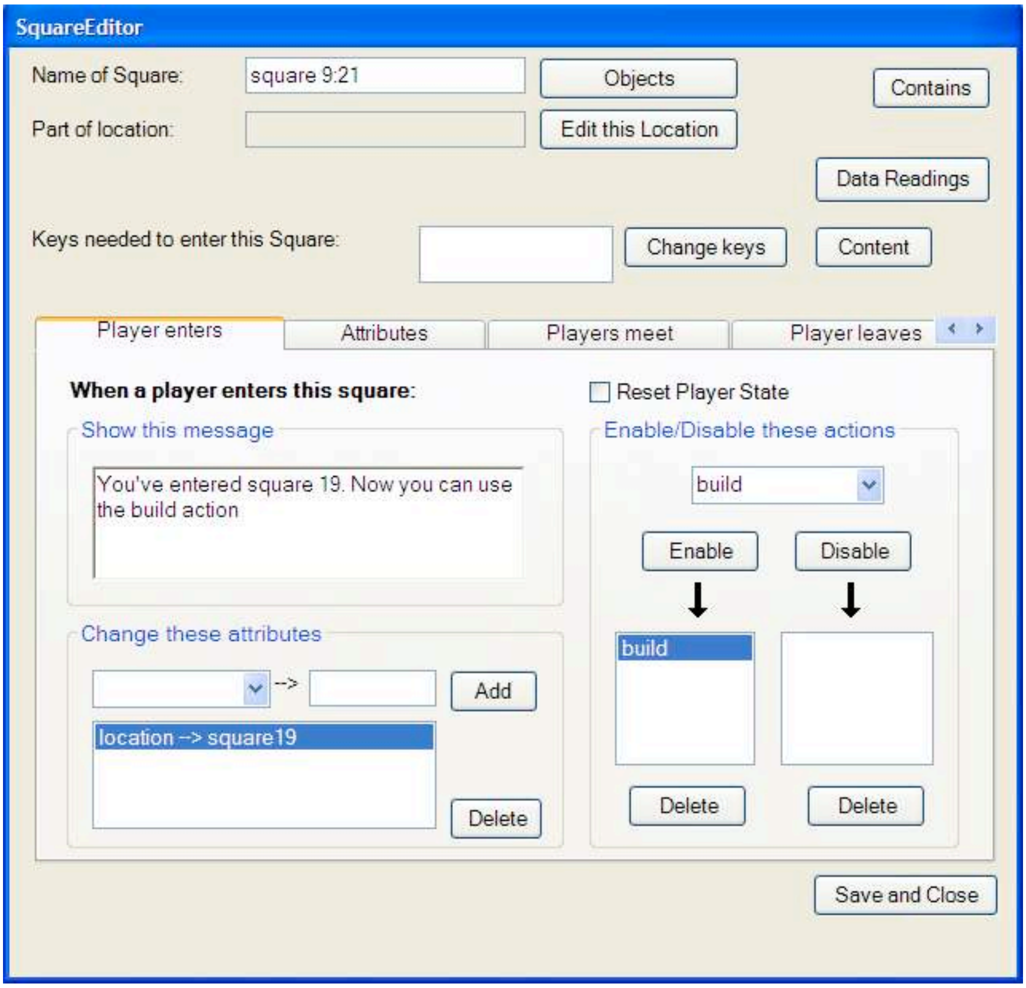

Figure 13: event settings for Square/Location object

In addition, we fulfilled the need to trigger content display for specific locations by allowing a Square (and Location) object to have a URL (entered by clicking on the Content button on the interface and entering the URL in a dialogue box) that would be displayed by the client whenever a Player entered that Square (or Location).

4.6.6 Desktop server/authoring environment

The PaSAT server and authoring environment, hereafter referred to as the PaSAT server, needed to provide a number of functions:

- The means to view and modify all of the object-based representations of a game at design time.

- The means to monitor the state of the game at runtime.
- The means to modify the state of the game at runtime, to correct errors and to facilitate progress.
- The means to record game states to a log for later inspection and reuse.

The PaSAT server was implemented primarily as a game server, responding directly to incoming requests from connected mobile clients, and allowing the inspection and modification of the game state and all associated internal objects through the provision of a range of Windows-style dialogue windows and palettes.

Since the internal representation of the game and all objects is maintained in XML, the coupling between the game representation and the user interface is loose, following the design pattern of Model-View-Controller and allowing flexibility in extending the system.

The PaSAT server software is modeless in that it responds immediately to connected clients whilst simultaneously providing the means to edit a game. It is not necessary to switch from authoring mode to runtime mode. However, the server must have the correct game data in memory for the client to connect.

The authoring toolkit/server allowed the user to edit all of the aspects of the game settings described above in Section 4.6.1 - 4.6.5. A simple list-based interface was provided that displayed all current objects in the game, which could be edited by clicking on them, and which allowed the creation of new objects from scratch or by copying existing objects.

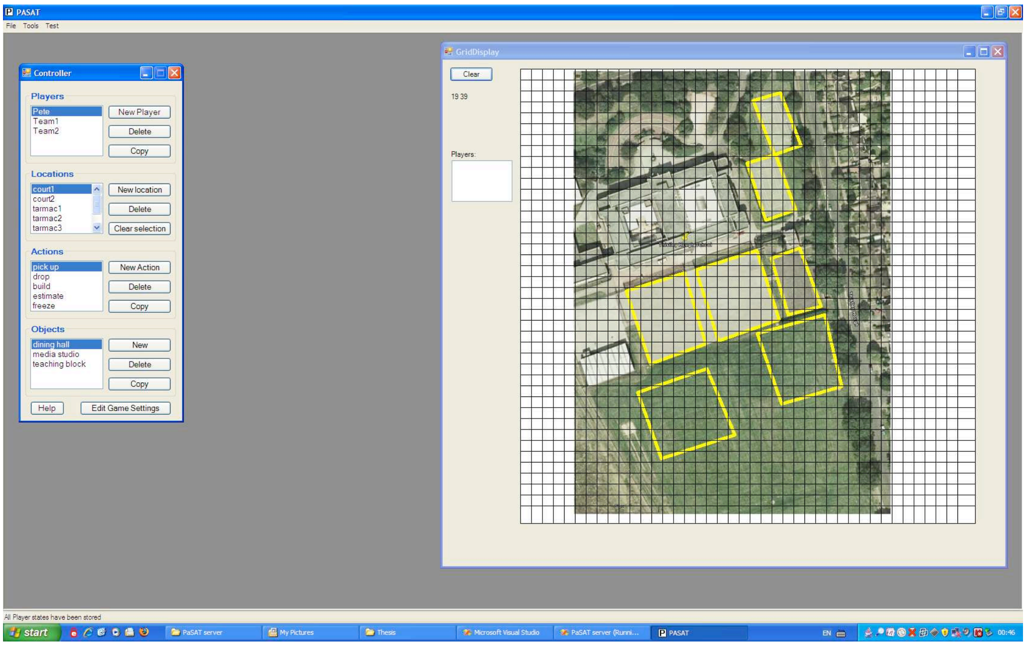

Figure 14: screen of PaSAT desktop authoring environment

As shown in Figure 14 above, the UI presented a number of listboxes showing existing Players, Locations, Actions, and Objects. Clicking on any of these objects opened the editor window for these objects, or new ones could be created.

When a game was being played by players using connected PDAs, the current object states would change dynamically onscreen in real-time, and could be edited if necessary. Player locations were also shown on the map.

4.6.7 PDA client

The client for PaSAT is the software that players use on the handheld device to play the game. The client was developed in C# using Visual Studio, and runs on any handheld device using the Windows Mobile 5 (or above) operating system. The .NET Compact Framework (a free download from Microsoft) is required for the client software to run.

The mobile client for PaSAT needed to display the custom map used to design the game, the Player's current location on that map, as well as allowing the user to view important game status factors, perform actions, and view content and the results of actions.

Achieving all of this on the small screen offered by the PDAs used during the development of PaSAT was quite a challenge, and we opted for a tabbed interface with the map display as the primary interface and other tabs available for performing actions and viewing content.

In line the with the loose coupling between underlying game data and representation in the UI of the PaSAT server, we followed a similar path for the client software, ensuring that data stored internally could be displayed in a number of ways without excessive re-development of the mobile client interface. The core functionalities of connecting to the PaSAT server, obtaining game status updates, and allowing invocation of game actions, were implemented as a separate layer underneath the UI. This meant that we were able to modify the mobile UI to fit specific needs, as became necessary when designing the BuildIt game (see Chapter 6).

4.6.7.1 General interface design

The interface on the mobile device used a tabbed interface to allow the player to switch easily between different screens displaying different information and options, whilst maximising the use of the viewable area of the screen. Initial tests showed that this tabbed interface was easy for players to understand and use, and no problems with players switching between tabs. The tabbed interface (as used in Study 1) is shown below in Figure 15.

Figure 15: screenshot of PaSAT mobile client as used in Study 1, showing main map display and tabbed interface

4.6.7.2 Displaying the map and player position

The primary interface tab displays a portion of the current map using the same resolution as the authoring environment. The current player's location is shown by a red dot, with other players shown as a blue dot. This is shown above in Figure 15.

Since the GPS hardware provides information about the accuracy of the current GPS fix, we initially intended to show this as a circle around the player dots to indicate the assumed accuracy of the position shown. However, initial tests with adult users showed that this was difficult to understand and appeared to clutter the screen rather than providing any useful information. This feature was removed.

4.6.7.3 Displaying status

Since most game status information is held on Player objects, with the current Player being the most salient source, the interface included a screen that could display the names and values of all attributes currently set for a particular player. This screen (shown below in Figure 16) also showed in-game objects present at the player's current location (which could be picked up) and the objects the player was currently carrying (which could be dropped).

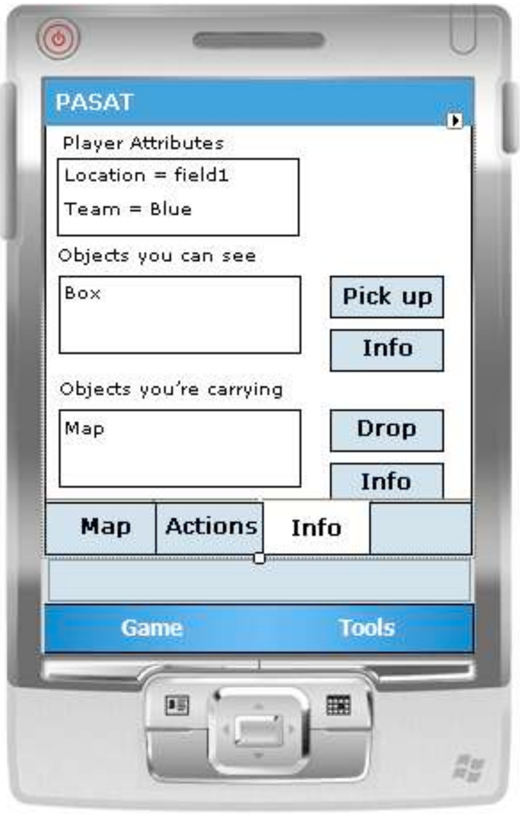

Figure 16: screenshot showing display of player state and available objects

In practice this approach was found to be impractical for both the Study 1 trials and the BuildIt game. For Study 1, players did not require this status display and so the tab was removed to avoid cluttering the display. For BuildIt, players needed to see only three specific attributes (Funds, Risk, and Estimates – for details see Chapter 7), whilst a large number of attributes were irrelevant for them since they were internal variables for the game itself. We added a feature to allow attributes to be hidden from players on the status screen, but it was still felt that the required attributes would be better placed on the main map display so that players could always see them without needing to navigate to a different screen. The main map display was customised for BuildIt to display the values of these three key attributes. This display queried the local Player object to obtain the current values, thus fitting in with the data representation used in the PaSAT system but indicating that more flexible ways of adding state display to the interface would be desirable in the long term.

4.6.7.4 Enabling invocation of actions

A primary mechanism for playing the games created using PaSAT was to allow players to invoke actions within the game. A tab was included that displayed a list of available actions (specific to the player's current location and state). When an action was selected, options specific to that action were displayed allowing the user to enter information such as on whom the action should be performed. When the user clicked on the "Do it!" button the game server performed this action and modified the game state accordingly.

Figure 17: screenshot showing the Actions tab on the PaSAT client

As shown in Figure 17 above, the player can select an Action from the drop-down list that then configures the options on the screen for that particular action. Here the Action 'freeze' requires the player to select a specific player as a target for the action. Other actions can be created that can act on all players, all players in the current location, or all players with a specific attribute. The Actions display changes accordingly for each Action type.

4.6.8 Use of GPS for location tracking

PaSAT uses data from a GPS (Global Positioning System) device (in the case of the studies run for this research the GPS device was built-in to the PDAs, but it can be a separate device) to determine the current location of the PDA, with reference to a customised map provided for the learning activity. GPS coordinates, specifying longitude and latitude on the Earth's surface, are translated into *xy* coordinates on the activity map.

4.6.8.1 Summary of GPS functionality

GPS provides positioning data by effectively triangulating a position using ranging signals received from a set of satellites. Under ideal conditions, GPS is able to provide position data to an accuracy of approximately ±3 metres. GPS accuracy can be affected by a number of factors, including weather (cloud cover can differentially slow down signals received), and the immediate environment. For example, built-up areas can result in false signals bouncing off building surfaces.

After initial work attempting to parse the raw data provided by the GPS hardware, we found that detection of the GPS hardware itself and parsing of the data were complex tasks that may be better handled by third-party solutions. We used the GPS.NET library (Person, 2008) that provided easy access to the GPS data on the mobile device[3].

The PaSAT mobile client software uses GPS.NET to interact with the GPS hardware on the PDA. GPS.NET is a class library for the .NET platform that provides easy access to the GPS device through the use of method calls to a documented set of classes. The GPS.NET component interprets the data from the GPS device and provides an event-driven architecture for integrating GPS data. In addition, there are a number of methods that provide calculations of range and bearing from one GPS point to another, which are used by PaSAT for determining position using a customised map.

4.6.8.2 Using GPS data with customised maps

The PaSAT system uses GPS data from the PDA's GPS device to determine the PDA's current location on a custom map that is produced for the physical space in which PaSAT is deployed. The map must be to scale, so that accurate calculations of location can be made using fixed reference points. The scale of the map is specified by calculating how many pixels on the map represent one metre in the real world. This can be determined from the scale indicated on sources such as Google Maps or Google Earth. This value is then provided to PaSAT's GPS component for use in location calculations.

To determine the PDA's location on a map for which we have no available GPS information (the bounds of the map are not specified as a GPS range), we can

[3] The GPS.NET library is commercial software, used in a range of GPS applications globally. It was provided free of charge for this research by the original developer, Jon Person.

determine the GPS coordinates of a fixed reference point on the map, and then calculate position relative to this point.

A reference point can be determined in a number of ways. A point can be recorded by moving to the actual physical location and invoking the reference point function on the PDA. This stores the current GPS coordinates along with the xy coordinates of the point on the map as a reference point. However, due to the errors inherent in the GPS signal, it is possible to record an inaccurate reference point that may give rise to later inaccurate position readings. A more reliable method is to use a third-party system to determine the actual GPS coordinates of a point on the map. Google Earth is one such system that provides GPS coordinates for specified points on the Earth's surface. Using Google Earth, we can click on an actual point on a map and see the GPS coordinates for that point. By using this as a reference point, we have an accurate point from which to calculate position on our custom map. This reference point can be entered manually on the game authoring software, associating an xy position on the map with GPS coordinates, or by marking a position in the environment as described above.

During operation, the PaSAT software receives updates from its GPS component, which in turn receives GPS data from the GPS.NET library that is interacting with the actual GPS device. The GPS.NET library allows us to calculate range and bearing to a specified point. By requesting the range and bearing to the previously specified reference point, we can determine our position on the custom map. Once we have obtained position and bearing, we use trigonometry (along with the map scale as already specified) to determine our actual xy coordinates on the map. There are a number of different conditions that require a range of different (but similar) trigonometric calculations.

4.6.8.3 Increasing accuracy with differential GPS

Differential GPS uses GPS receivers with known positions to calculate error correction data in real-time. The difference between the GPS position calculated by a receiver and its actual known position provide corrections that can be used by other receivers in the area to correct their own GPS calculations. Commercial GPS receivers can make use of differential GPS correction signals that are broadcast via radio transmissions from fixed receiving stations in the area. Alternatively, if we have a number of GPS receivers that can share information locally, and we can determine the absolute position of one or more receivers, then those receivers with known positions can act as local sources of correction data.

The PaSAT client software on the PDA was modified to include a mode whereby a PDA could be placed at a known point, and set to broadcast the observed differences between its known position and the information supplied by its GPS hardware to the PaSAT server. These corrections could then be used by other PaSAT clients to correct their own GPS readings.

This method was developed and tested for the PaSAT software following Study 1, prior to running trials for Study 2. We found that this method was effective in providing higher accuracy GPS readings, but the results were not consistent, with accuracy being improved on some occasions but not on others. The differential GPS functionality was only used on two occasions when GPS readings were particularly problematic, and it is unclear what impact this functionality had on the GPS accuracy in the field. We did not have the resources to further explore this issue.

4.6.9 Wireless network set-up

We conducted a number of trials to determine the feasibility of using wireless LAN outdoors to provide the client-server functionality implemented in PaSAT. For initial trials at prior to Study 1, we used a single consumer grade wireless access point. We found that this configuration was unable to provide coverage over a large enough area, with the signal degrading towards the edges of the intended play area. This effect was exacerbated when players turned so they had their body between the PDA and the access point. To provide enhanced coverage, we upgraded the antenna on the access point to one providing 9db signal strength; this was sufficient to provide coverage for the play area in Study 1.

For Study 2, we wished to use a much larger area with one area out of line-of-sight coverage. This meant that regardless of signal strength we were unable to use a single access point. We used three commercial grade access points that offered roaming between their coverage areas. These access points supported connection to a backbone network via either Ethernet or WLAN connection. We opted for wired Ethernet connections, due to the line-of-sight problems with the site. This solution provided adequate wireless coverage for the areas of the school grounds used for Study 2. Figure 18 below shows the approximate coverage provided by the placement of the access points. This diagram is a representation of the optimal coverage experienced after several experimental placements of the access points.

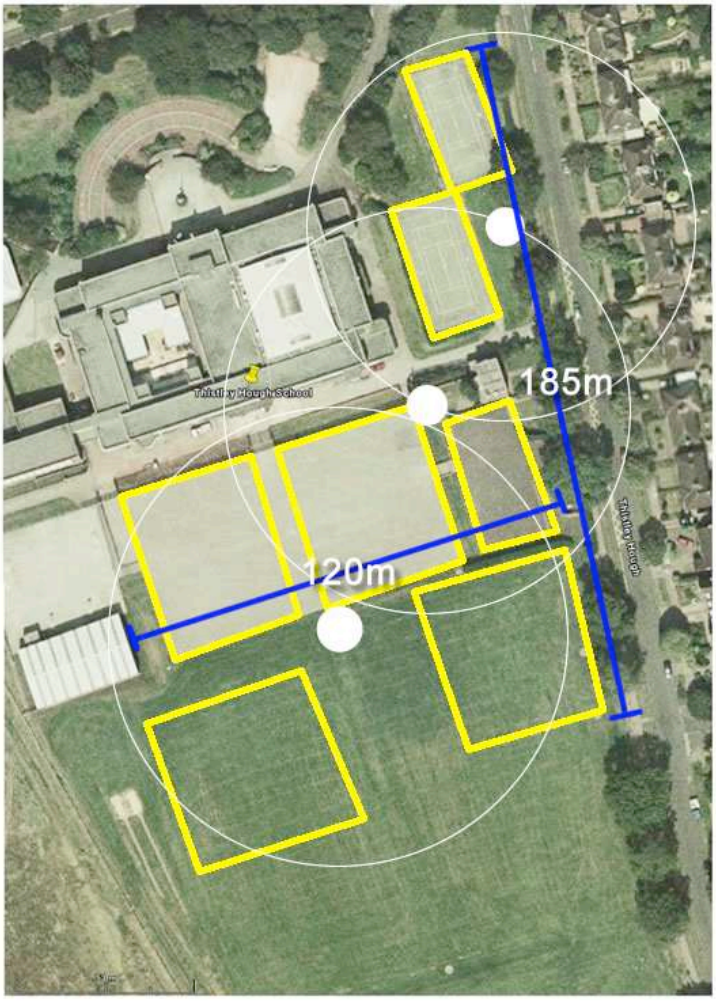

Figure 18: approximate wireless coverage provided by access points in the school grounds for Study 2

4.6.10 Standalone mode support

Although the original intention was to use a thin client design, we found that in practice there were significant problems with supporting this architecture in the field. Towards the end of trials for Study 2, numerous technical problems with the wireless networks (primarily caused by physical damage to the cables connecting the wireless access points from vehicles passing over them) necessitated the inclusion of support for a standalone mode that meant the PDAs could operate even when not connected to the network. The system was reconfigured to cache the XML data files on each device and to use these when the network was unavailable. This meant that we lost the ability to monitor players' activities on the server, but ensured that we were able to complete the studies as intended.

4.7 Implemented system vs ideal system

The ideal authoring system for creating and deploying situated mobile learning games would meet all of the design goals specified above for PaSAT, with some key additional extensions:

- Extensibility: the representations used in PaSAT and the associated mechanisms for handling those representations (and hence for effecting state changes within the system), were limited to the original format devised for PaSAT as described above. Whilst we found this approach to be adequate for the activities we have implemented and tested using PaSAT, it is likely that more complex activities would require more complex representations that are not constrained by the system and which can be extended, perhaps using self-describing formats such as XML

- Programmability: further to the need for extensibility to representations, we found that whilst the event triggers and Actions framework built into PaSAT were adequate for our needs, these functions would quickly require updating for more complex activities. The Actions framework in particular, whilst allowing simple state changes, did not allow us to fully express the actions required for the BuildIt game, and these had to be extended in the source code. In practice it would be ideal if such interactivity could be achieved without having to edit the source code. This could be achieved in two ways. First, the set of available mechanisms for configuring Actions and their effects within the game could be extended to provide a comprehensive set that could be used within the form-filling UI of the PaSAT authoring system. Alternatively, the system could use its own internal language for querying and manipulating object states. This latter approach would provide the maximum flexibility, but at the expense of the user-friendly interface that PaSAT provides. A hybrid approach would likely be the best option, providing a form-filling or graphical means for end-users to create and edit games with the underlying scripting language being generated from the configuration of elements in the UI. Users could then edit the script for more complex requirements.

In summary, an ideal system would include flexible representations that allow for the minimum of code changes for different games and game types, with the ultimate ideal system requiring no modifications to source code at all and providing a truly flexible and generic language for describing mobile games, but with a user-friendly graphical interface for 'building' activities non-programmatically.

In many respects the 'mscape' authoring toolkit, developed in parallel with this work by Hewlett Packard, represents many aspects of the ideal system envisaged for this research. Both 'mscape' and PaSAT use state representations with mechanisms for applying state changes, and allow the use of customised maps for specific locations. PaSAT includes a number of pre-defined trigger events and a constrained syntax for describing actions, their scope, and their results. 'mscape' does not provide such a structure, instead it allows designers to use a scripting language to detect events and states and manipulate internal variables accordingly. 'mscape' thus offers the maximum flexibility, but at the expense of user-friendliness that PaSAT is intended to provide.

4.8 Conclusion

This chapter has described the work conducted to design and develop the PaSAT software, intended to support the creation and deployment of location-based mobile learning games. This software was used to create and deploy the mobile activities used in Studies 1 and 2, and for a range of testing activities before each study. The PaSAT software remains an alpha release, and has been developed solely for the research presented in this thesis.

Chapter 5

Study 1: Exploring the benefits and problems of an outdoor, location-based mobile learning activity compared to an indoor activity

This chapter describes Study 1, a comparison of an outdoor, location-based learning activity with a similar fixed location activity based indoors using the same technology. The PaSAT toolkit (as described in Chapter 3) was used to develop and deploy the learning activity on handheld devices for both activities. The students' activities in both the indoor and outdoor condition were evaluated using outcome measures and the critical incident technique to derive recommendations for the design of subsequent studies of learning using location-based mobile learning games.

5.1 Scope of the study

5.1.1 Motivation and goals

Previous studies have demonstrated how location-based activities, using handheld computers with GPS, can deliver engaging mobile learning activities. Environmental Detectives (Squire and Klopfer, 2007), Savannah (Facer *et al.*, 2004), and Frequency 1550 (Huizenga *et al.*, 2009) are exemplary projects that have all shown that mobile game-based learning activities have the power to engage learners and enable innovative learning activities using physical spaces as learning environments.

However, a lack of comparative evaluations means it is difficult for us to determine the exact source of this engagement, and how the use of mobile learning provides specific benefits beyond traditional interactive learning activities.

Dede and Dunleavy (2007), who describe the use of handhelds to deliver an interactive learning activity that requires learners to explore a physical space and gather information, state that it is unclear where the engagement comes from in these learning activities – is it the location-based activity, the use of the physical environment, or just the novelty factor of being outdoors with a PDA? In a recent review of the field, Frohberg *et al.* (2009) have also highlighted the need for comparative studies to help explore the issues pertaining specifically to mobile and location-based learning.

Crucially, some aspects of these outdoor mobile learning activities might actually hinder learners in their performance of the underlying learning activity. Again, without studies comparing outdoor, mobile learning with more traditional activities indoors, it is difficult if not impossible to state what these factors might be. Some previous studies, such as Savannah (Facer *et al.*, 2004), have identified pragmatic issues and specific aspects of the learning activity used in their study that were detrimental to the performance of the activity as a whole (see Section 2.4.6.1), but these findings cannot easily be generalised.

To design the next generation of mobile learning activities that exploit location-based, handheld technologies, we need to build a clearer picture of what it is in these activities that learners find appealing, so that we can better exploit it. We must also include in this picture some indicators of what aspects of these tasks, as currently implemented, can *detract* from the learning activity. This latter point has so far gone relatively unaddressed in the field (Dede *et al.*, 2005; Frohberg *et al.*, 2009); the novelty of these technologies means that researchers and practitioners alike are prone to a high degree of enthusiasm with regard to their use so evaluation tends to be biased towards searching out the positives rather the negatives.

5.1.2 Aims

This study aims to compare an outdoor, location-based learning activity, enabled using mobile devices, with an indoor learning activity using the same technological support. By using this direct comparative design, we aim to identify those aspects of being outdoors with mobile, location-based technologies that can actively engage and support learners, and those aspects that actually hinder the learning process.

Additionally, Study 1 is intended as a first exploratory use of the PaSAT system to determine its suitability for deploying location-based learning games and to assess whether this type of system can deliver tangible benefits for learners. Findings from this study were fed into the development of the PaSAT toolkit to help refine the technical, pedagogical and ludic aspects of its functionality.

Since this was an exploratory study, there are no specific experimental or research hypotheses, however we developed several expectations during the course of reviewing previous work that helped to focus our attention during task observation and analysis. Our intention was not to determine whether the outdoor mobile learning activity was superior or inferior to the indoor version, since we did not optimise the activity for either environment. Instead, we focused on identifying issues that either helped or hindered in both cases. Before designing activities intended to support learners in a field condition, it was essential to gain first-hand experience of the problems faced by learners and teachers alike. Reports in the literature tend to focus on the positive aspects brought about by location-based learning, and we wished to see directly what *problems* could arise as well as what benefits.

We expected the outdoor condition to engage because we were giving them the PDA, but with the indoor condition allowing us to identify the aspects that came only from the presence of the technology itself we aimed to identify factors that arose from the combination of handheld computer, location-based activity, and direct coupling with the physical environment.

However, we are more concerned with what problems may arise as a result of learners using the PDAs outside, away from the classroom, so that we can determine how to support situated enquiry learning. Problems that were expected to arise from outdoor use include:

1. Moving around outside takes more time: exploring a space and map through physical movement will take longer than performing the same task using a point-and-click interface (as in the control condition). It is expected that learners will take longer to complete even simple tasks using the PaSAT system outdoors.

2. Distractions: there are far more potential distractions outdoors, both in terms of physical artefacts and also the activity of other learners. It is expected that, at times, learners using PaSAT outside may be more distracted and be less focused on the task.

3. Dissonance between physical world and informatic space: the layering of a virtual informatic space on top of a physical space is the central premise behind PaSAT, however, this layering could lead to problems if there is too much of a mismatch between what learners see on the screen and what they see in the physical world.

To evaluate the impact of the device and the environment on the learning process, compared to the indoor version, our evaluation was structured around several core questions:

Do any observed benefits arise from the additional, situated functionality provided by the system, or are they due to the novelty and engaging nature of the task itself?

It is important to ask whether any observed benefits of interactive educational technology can be attributed to the actual functionality of the system or whether they arise simply from the novelty of the technology itself and hence increased engagement from the learners. This issue has been raised for participatory simulations, most recently by Dede & Dunleavy (2007). This study attempts to begin to answer this question by using an experimental design that controls for the use of movement-based interactions. The novelty factor of being outside will be removed for the control condition, indicating whether or not this is a major factor in the engaging power of the system. If the novelty factor remains for the control condition this will suggest that the use of the technology itself is novel enough to lead to increased engagement. The only way to control for that would be to run longitudinal studies where learners were given long term access to this kind of technology, thus eliminating the novelty factor. Such longitudinal studies will be possible with future versions of PaSAT.

Does the use of PaSAT to learn about flooding lead to a richer learning process than the indoor condition?

Rogers *et al.* (2002) found that the coupling of a familiar action with an unfamiliar digital response was effective in getting children to talk about and reflect upon their experience. It is expected that children using PaSAT outside will talk more about what they are doing and display more reflective activity than those in the control condition, because of the coupling of movement with information display and trail making. The act of movement is coupled with content display and trail making in the outdoor condition; in the indoor version the initial act is always a click on the screen, to which any computer-based response will be familiar.

We can relate this reaction to an unfamiliar response to Kolb's cycle of engagement and reflection (Kolb and Fry, 1975), whereby a learner who is actively engaged in concrete experience is then cued to reflect on that experience, form a conceptualisation of what they have seen, and then to engage again in active experimentation. Considering this in the context of movement-based learning activities, an obvious question is how to support the learner in this cycle and how to cue reflection in appropriate circumstances. One of the major advantages of using mobile technology such as PDAs to facilitate learning activities is that the PDA can be used to prompt and guide the learner in a context-sensitive way, directing them to engage and reflect at suitable times. This kind of support could be built-in to later versions of PaSAT, so this present study aims to identify where this kind of support could be given, and how it might be provided.

Do the design of the task and the available functions lend themselves to a gameplay style of activity? What aspects can be exploited and improved to make the most of students' tendency to 'play' the activity?

Games have been shown to be effective motivating activities for learning, and interactive activities that incorporate one or more of the core elements of gameplay as identified by Malone (Malone, 1980) are likely to give rise to a fun, game-like experience.

Malone has identified *fantasy, curiosity,* and *challenge* as the key elements for a compelling gaming experience. The use of physical movement and interaction with a physical space is expected to lead to the activity seeming more game-like, with a clearer sense of the goal (*challenge*) and also a stronger notion of the *fantasy* aspect of being engaged in a role-playing activity. Curiosity is also expected to be greater in the outside environment than using a screen-based system, because of the coupling of familiar actions with unfamiliar results (cf. Rogers *et al.*, 2002; Rogers and Price, 2004). It is expected that motivation and engagement will be increased by virtue of the outside condition being more game-like than the indoor version: learners take on roles and have tasks to perform in collaboration with other learners. Increased motivation and engagement are expected to lead to observable changes in learning outcome and process.

However, what is not clear is how the different elements of gameplay map on to students' behaviours when engaged in an outdoor learning experience. Many previous projects have cited 'game-like' activities without actually making use of the full range of popular gaming mechanisms (for example Environmental Detectives – see discussion in Chapter 2, Section 2.4.6.3). By observing the students' activities with the PDAs both indoors and out, we will be able to determine which aspects of the learning activities are supported by game elements, and in what way. In particular, we are interested in what aspects of the system capture the students' interests, and any behaviours they exhibit that indicate they are engaged in the task as a fun activity.

Where do breakdowns occur in the use of the system and what gives rise to them?

A range of problems with the system is expected, both technical and practical in nature. These were recorded by the observers and in video logs and with the intention being to use these observations to improve the design of PaSAT and to inform the design of subsequent mobile learning activities to be used in this thesis.

Where do breakthroughs (unexpected successes) occur in the use of the system and what gives rise to them?

It was expected that there will be a number of 'eureka moments' when learners discover that they are able to perform particular functions using the system that lead to specific instances of engagement or understanding.

5.2 *Materials and Methods*

5.2.1 Design

This study was a between groups comparison of learning process and outcomes between 2 conditions:

1. Outdoors: learners used the PaSAT system running on PDAs to perform the learning activities outside the school. They then completed the post-task assessments inside using printed materials.

2. Indoors: learners used the PaSAT system running on PDAs indoors, navigating around the map by clicking on the screen. They had access to the same content as students in the outdoor condition. They then completed the post-task assessments inside using printed materials.

Further details of the differences between the conditions are given below where appropriate.

5.2.2 Participants

The participants for this study were Year 7 students at an academy in Nottingham. The students who took part were selected for the study by a teacher at the academy. They represented a mix of gender and abilities. Five pairs of students took part in each condition. Pairs were self-selected. We asked students to work in pairs so that i) they could help each other with technical or other issues, ii) to encourage them to discuss their actions to make their activity more observable.

Students each used a PDA in both the outdoor and indoor versions, but were asked to work in pairs so that i) they could provide support to each other, and ii) there would be a greater likelihood of them talking to each other about the task thus making their activities and understandings more visible to the observers.

5.2.3 Consent

All students were provided with written information about the study prior to taking part, for themselves and for their parents. Written consent forms were obtained from each student and their parents confirming that they understood the nature of the study and that they were happy to take part and for data to be gathered, including video recordings. The consent forms used for this study are included an Appendices A and B.

5.2.4 Recording, observation, and facilitation

For the outdoor condition, each pair of students was followed by an observer who recorded their activity with a video camera, and provided assistance if they required it. The researcher and class teacher were also present to observe the activity from a more general perspective and to provide assistance.

For the indoor condition, the researcher set up three fixed cameras to record the room, observed and took notes on learner activity during the task, and provided assistance. The teacher was not present during the indoor activity.

5.2.5 Task

The task for Study 1 was designed to fit with the opportunities and interests of the learners and teachers for whom it was built. We began the design of the task following initial consultations with staff at the school. After exploring broad ideas relating to the use of the environment in mobile learning activities, the school grounds were chosen as a focus for the task due to the practical difficulties of taking students out of school during the school day. This was followed by a survey of the school grounds to determine opportunities and constraints for the outdoor task.

The indoor task was intended to be as similar as possible to the outdoor task, so the outdoor task was designed first, but with constraints in mind to ensure that nothing implemented outdoors could not reproduced in a similar format indoors.

5.2.5.1 School grounds

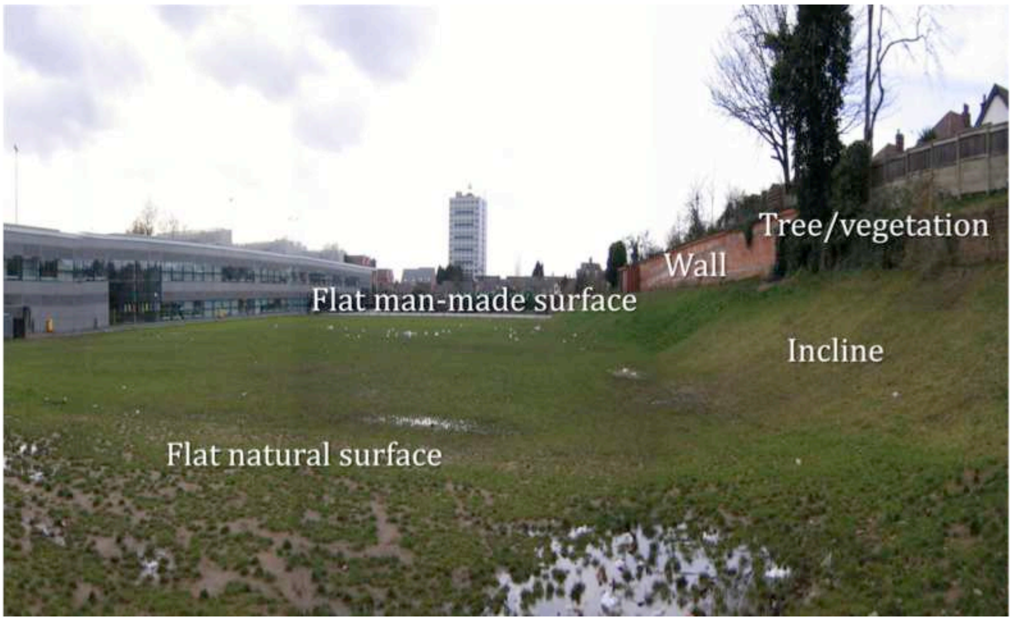

Figure 19: grounds at the school used for Study 1

We began the process of designing the location-based activity by surveying the school grounds (see Figure 19) to identify potential features of the environment that could be used within the activity. The aim was to find features that were i) distributed around the grounds (so that learners would have to move around the space to visit them) and ii) directly observable by the learners during the course of the task.

We identified five features present in the environment that met these criteria:

1. Flat, natural surface.
2. Flat, man-made surface.
3. Incline.
4. Tree and vegetation.
5. Wall.

A scaled aerial map of the school grounds was obtained from the local council website (Figure 20 below), and modified for use with the PaSAT software.

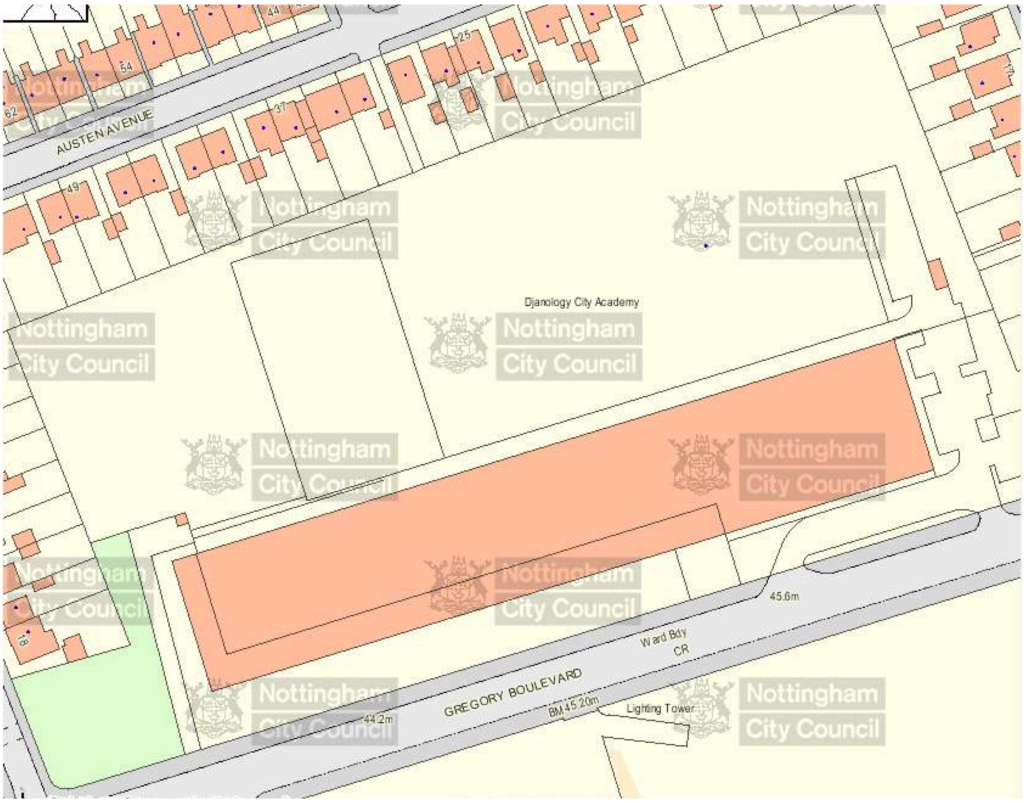

Figure 20: original aerial map obtained for the school site

A number of GPS calibration points were obtained from the site and used to calibrate the GPS code to ensure accurate position tracking.

Figure 21: satellite photo of the school site

A satellite photo obtained from Google Earth is shown in Figure 21 to further indicate the layout of the school grounds. However, this photo was not available at the time of conducting Study 1 and so could not be used to generate the maps for the activity.

5.2.5.2 Learning Topic

We wanted the learning topic to be meaningful to the students so we looked to a number of sources to identify potential candidate topics. At the time of designing this study, there had been widespread flooding in the UK and this was a topic featured prominently in the news and we discovered from discussions with the teacher at the school that this topic had been featured in lessons. The teacher agreed that this topic would be a suitable area to engage the students' interest. We decided to base the learning activities designed for this study on learning about the causes of flooding and how to build flood defences. We reviewed the National Curriculum and found that these factors were included in the Geography section. We reviewed BBC learning materials (BBC Scotland, 2009) related to flooding and then set out to determine how we could use features of the environment to address specific topics in the curriculum.

The next step was to identify how the physical features of the environment could be mapped on to issues relating to flooding and the building of flood defences. This topic provides an opportunity for children to see how natural processes and environments interact with manmade artefacts, and the factors involved in making decisions about how to cope with these interactions. Flooding can be affected by a number of factors including land level, inclines, impermeable/man-made surfaces, permeable/natural surfaces, and growth of vegetation. Examples of all of these are present in the school's immediate environment, and a learning activity was designed using PaSAT to draw students' attention to these features in the context of flooding.

Following a review of materials relating to flood risks and the building of flood defences, we were able to map six specific physical features of the school grounds on to salient aspects of flooding and flood defences.

- Wall: walls can be built adjacent to rivers and the sea as a hard defence against flooding. The physical barrier of the wall prevents the water from flowing beyond (BBC GCSE Bitesize, 2009).

- Tree: vegetation can be allowed to grow to form a soft defence against low level flooding. Vegetation takes up the water and allows the ground to absorb flood water by preventing the water flowing away too quickly (BBC Scotland, 2009).

- Manmade surface: manmade surfaces increase the risk of local flooding because they render the ground impermeable, leading to large run-offs and no chance for water to be absorbed by the ground (BBC Scotland, 2009).

- Natural surface: natural surfaces allow water to be absorbed because they are porous (BBC Scotland, 2009).

- Slope: slopes increase run-off and can contribute to local flooding. However, this can be mitigated by slopes being natural surfaces and covered in vegetation (Environment Agency, 2009).

- Potential floodplain area: an alternative to building defences can be allowing areas to flood deliberately, creating expanses where large amounts of vegetation can grow and reduce the impact of tidal surges (BBC News, 2006; Environment Agency, 2009).

Content hotspots (locations with short textual items of information) were created for the locations listed above. For example, when learners moved to the wall, they saw the following text (Figure 22) displayed on the screen:

> *Walls as Flood Defences*
>
> *To stop high levels of water reaching areas we want to keep safe, we can build walls to hold back the water. For example we might built walls along the coast, or along a stretch of river prone to flooding.*
>
> *Q: Look at the wall here and think of some reasons why building walls might not always be the best thing to do.*
>
> *Clue: is the wall in good condition?*

Figure 22: text from Walls content hotspot

As can be seen in the example above, hotspot content was not just informative text, there were questions and activities embedded within the text as well. Another example of this can be found in the hotspot for the hill shown in Figure 23.

Hills and Slopes

Steep slopes can cause problems because water will tend to run down them quickly without having time to be absorbed into the ground. If the water ends up running on to a problem area like one with impermeable surfaces, there is likely to be a flood.

Where there are steep slopes that run on to flat areas, flood defences could help to slow the water down so it has time to be absorbed, or divert the water so that it goes somewhere else.

Q: Take a look around. What could we do to this slope to help slow the water down?

Figure 23: text from Hills & Slopes hotspot

An additional hotspot was added to allow learners to access information about a fictional river located just behind the school. Students were prompted to discover the reason why their school might be at imminent risk of flooding. This element was included as part of the *fantasy* part of the task – we wanted the students to see the content and features pointed out to them as meaningful to them, and so we created a backstory that featured a river behind the school that was about to burst its banks.

Note that the aim of this learning activity was not to provide any form of comprehensive information about flooding, this topic was chosen simply as a relevant focus for the activity (by virtue of its links to current lesson content, the curriculum, and news coverage) and the intention was to explore the impact of the location-based technology (or lack of it for the indoor condition) on the process of performing the relatively simple learning activity.

5.2.5.3 Learning Task

The intention was to use PaSAT and the handheld devices to facilitate an exploratory activity using game aspects to provide a meaningful context. The primary task goal was to locate the hotspots and review the content available at each, and to determine what aspects of the school environment could be identified as flood risks and which aspects could be co-opted in building flood defences. This task was designed in consultation with the school ICT teacher Mr Frearson.

Students were given two tasks, to be performed in sequence. Instructions for these tasks were delivered via Task Hotspots that they had to locate in the environment, using the map on the PDA. This was done to maintain the link between the learning activity, the environment, and the device.

Task instructions:

- Explore the school grounds using the map and hotspots on the PDA as a guide.
- Locate each hotspot and find out about what is there.
- Carry out any of the activities mentioned at the hotspot.

For the survey task, students sometimes required some assistance to use the functions on the PDA, and this was provided either by the researcher, the teacher, or by the observer who was following each pair of students.

5.2.5.4 Functionality of PaSAT for Study 1

Using the version of PaSAT made available for this study, learners could:

- Move around in physical space with a real-time map on the PDA (all players' real-time locations are shown (Figure 25). (If players are 'offscreen' then they could be viewed by selecting Big Map in the Tools menu)

- View content for specific locations, displayed automatically when a location was reached for the first time (Figure 26).

- Retrieve content already viewed for earlier locations.

- Save/view notes attached to specific locations (Figure 27).

Students were asked to make use of all of these functions to complete the tasks set. They were verbally introduced to the topic of flooding and flood defences, and shown the map (Figure 24) to be used during the learning activity. This map is an outline map of the school's field, with the rear staff car park removed and an imaginary river included at the top (North) of the map.

Several hotspots on the map provide information about key features of the terrain (such as soft natural surfaces versus hard manmade surfaces). Students were asked to use PaSAT to explore the space and to take notes about the information. These instructions were given verbally to all students at the beginning of the task, and were told to go to the Task 1 hotspot to begin the activity. The content at the Task hotspot provided clear instructions (see Section 5.2.5.3).

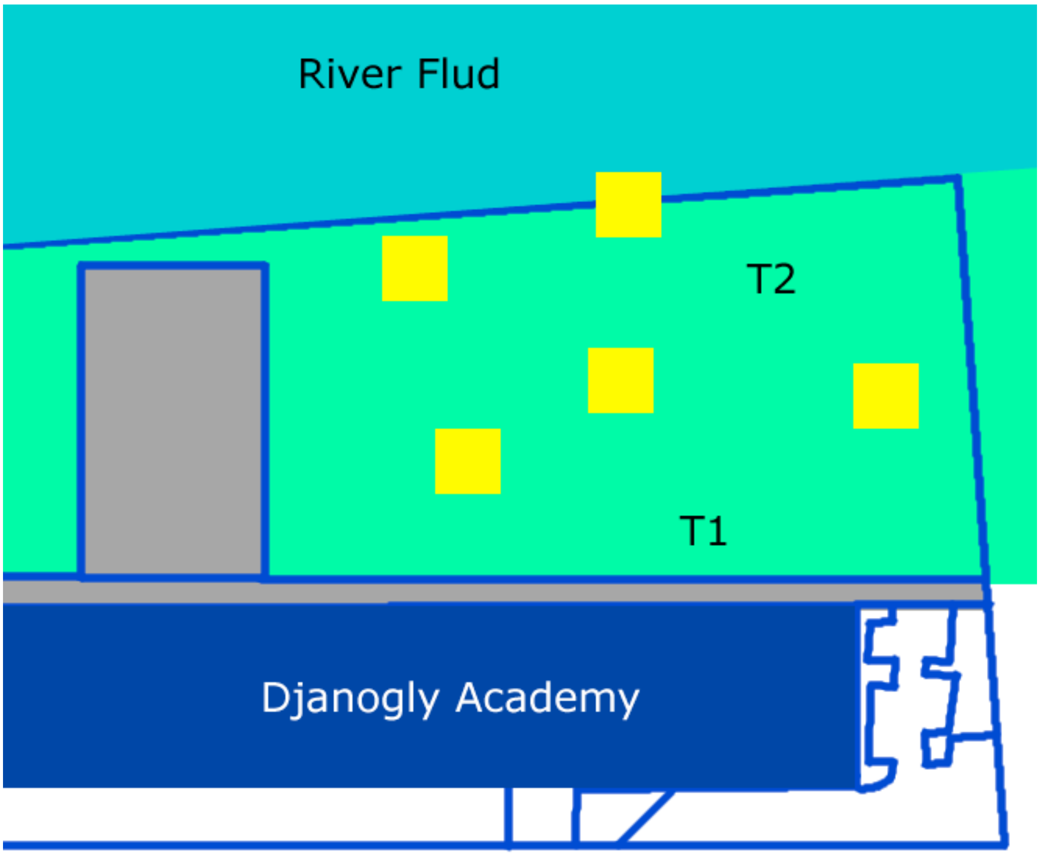

Figure 24: map of the school site with imaginary river and content hotspots

Figure 25: PaSAT client showing location of hotspots and learners

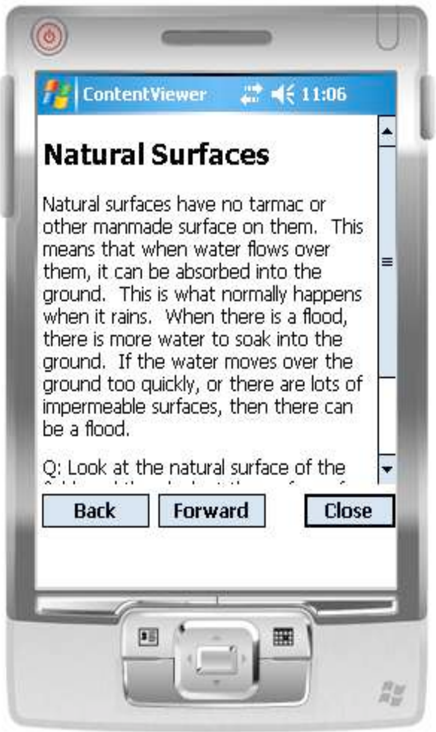

Figure 26: PaSAT client showing content for hotspot location

Figure 27: PaSAT client note-taking screen

5.2.5.4.1 Indoor version

For the indoor version, students used the same PaSAT software on the handhelds, but instead of using physical movement and GPS to move around the map, they navigated by clicking on the screen.

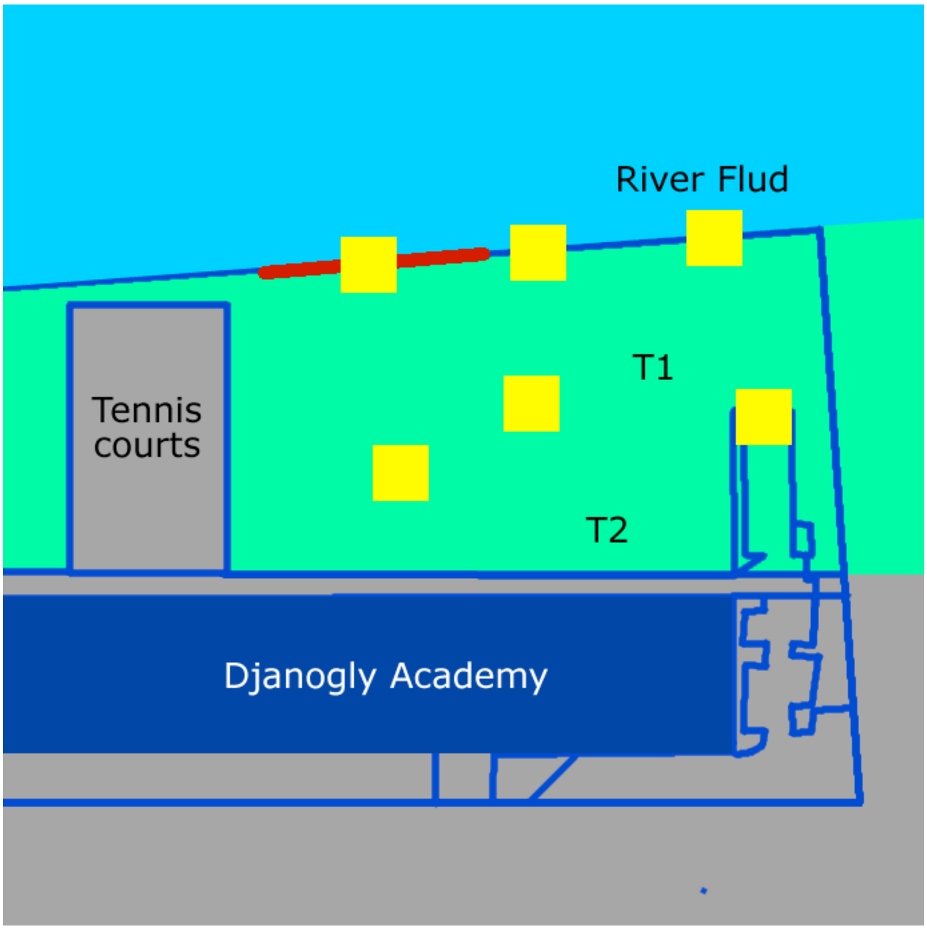

Figure 28: map used for the indoor condition (with features marked)

5.2.6 Technical Setup

For both conditions used in this study, students used PaSAT client software running on Mio Pocket PC PDAs with built-in GPS for location tracking. As described in Chapter 4, the client software on the PDA connected to a server application running on a laptop via a wireless network connection. The PaSAT server laptop was connected to a dedicated wireless router to provide wireless coverage in the learning space. The connection was via Web Services and hence stateless – if the connection is dropped temporarily there is no immediate impact on learner activity (see Chapter 4). The system also used a thin-client design whereby all session data is stored on the server and not on the PDA – if the PDA needed to be restarted no data is lost for that session.

5.2.6.1 Outdoor Condition

For the outdoor condition, the PaSAT server was deployed on a laptop connected to a wireless access point, with power provided to both from inside the school building via a 50m extension cable. Following initial trials that had indicated problems with extending wireless coverage to the area required for the learning activity, the access point was fitted with an additional antenna to boost its range.

5.2.6.2 Indoor Condition

Students used the same PaSAT software running on PDAs connected to the server via a wireless network, but they used the PDAs indoors and indicated their location by clicking on the screen and not by moving around. The same server-client setup was used, with the laptop server located indoors in the same room as the students.

5.2.7 Evaluation

We used a number of different methods to observe, explore and explain the activity of the learners during Study 1.

5.2.7.1 Video recording and direct observation

In line with studies of similar PDA-based learning activities (for example, Facer *et al.*, 2004; Squire and Klopfer, 2007), we used an observational approach and then reviewed video data to look for evidence that related to the research issues outlined in Section 3 above. In particular, in line with Squire & Klopfer (2007), we focused our attention on unexpected factors.

The observation notes and video footage were reviewed for episodes related to the issues being investigated. Any other significant episodes that were not related to the research questions were also flagged for further analysis, in line with the critical incident technique (see Chapter 4).

5.2.7.1.1 Outdoor condition

The students' activities and behaviour during the session were analysed using video recordings made during the session and the direct observations made by the observers. Students each had a PDA to use during the task, but were asked to work in pairs and to stay as close as possible to one another. An observer with a video camera followed each pair and observed and recorded their activity.

Observers were also requested to flag any notable critical incidents by moving their hand in front of the camera, and to report any significant events after the session.

Unfortunately two of the five cameras malfunctioned (one hardware failure, one battery failure) during the session, so only three tapes were available for analysis.

5.2.7.1.2 Indoor condition

For the indoor condition, students worked in a classroom, each using their own PDA. For the purposes of video recording, they were grouped into three groups (two groups of three and one group of four students). The analysis was based on reviewing the footage from these three tapes (only three cameras were available for this condition following the camera malfunctions in the outdoor condition).

5.2.7.1.3 Critical Incident Technique as used for this study

To identify specific aspects of the outdoor location-based activity that led to either breakdowns or breakthroughs in learning (Sharples, 1993), we employed a modified version of the critical incident technique (Flanagan, 1954). The critical incident technique (CIT), and its applicability to this work, is described in detail in Chapter 4.

We modified the technique to fit with the limited time we had to work with the students. Instead of reviewing each critical incident with the participants, we used the video footage to perform an in-depth analysis of each critical incident. After a critical incident had been identified, it was reviewed on the footage, taking note of the context, causes of the incident and any impact it had on the task activity.

This process was started before the focus group with the students took place, so that we were able to structure the questions in the focus group to probe specific incidents. This particular modification of CIT has been employed before in exploratory studies of learning technology, for example Anastopoulou *et al.* (2008).

5.2.7.2 Pre- and post-task quizzes

Students were asked to complete pre- and post-task quizzes (see Appendix C) to assess their recall of the content encountered during the task. The quiz comprised a series of questions relating to flooding and flood defences, with an open answer format. An open answer format was necessary because of the limited amount of content presented during the task: it would have been impossible to produce pre- and post-task quizzes that used different questions.

The questions were devised to test students' knowledge of types of flood defences, both before and after completing the learning activity. Students were asked to provide examples of types of flood defences along with advantages and disadvantages for each. This mapped on to the content provided during the activity.

The aim of the quizzes was to provide an indication of whether there were any directly observable differences between the students' learning in the outdoor condition compared to the indoor version.

5.2.7.3 Post-task map drawing and annotation

Students were each asked to draw on a map of the area with the locations of content hotspots and with notes describing what each hotspot related to. The students were also asked to describe (in note form) any memorable incidents from the task, for example “we made a joke here about what the tree looked like”.

The purpose of these maps was twofold. Firstly, we wanted a quantitative measure of how well the students recalled the layout of the map and the features on it, compared between the two conditions. Secondly, we used the maps as a way of determining whether the students had any underlying conceptual misunderstandings arising from the task. By asking the students to make notes about what they had found, we gained some insight into their understanding of the task over and above the pre- and post-task quizzes. The intention was also to determine what aspects of the task were memorable for the students, and to provide them with a way of feeding back narrative descriptions of what they did.

5.2.7.4 Changes to chosen evaluation methods following field trials

After conducting the indoor learning activity and reviewing the footage, it became clear that it was difficult to identify critical incidents for the indoor version, as had been possible for the outdoor condition.

This was due to a number of factors:

- Low visibility of student activity: students were seated at a table each using a PDA. Video footage was from the front of each student, which meant that their actual activity was not as visible as was the case outdoors.
- The task was not as engaging, leading to fewer observable events in general.
- The activity was conducted within a single room.
- Low levels of activity compared to the outdoor version.

Following this observation, we decided instead to focus primarily on the critical incidents identified for the outdoor condition, and for each of these to then review the footage from the indoor version to see if we could compare directly between the conditions. Where direct comparisons were possible, this is shown in the analysis of the critical incidents shown in 5.3.2. Where this was not possible, we instead reflected in general terms on the nature of the indoor condition compared to the outdoor one.

5.2.7.5 Post-task interviews

As well as completing the post-task quiz materials described above, all of the students who took part in the outdoor activity were interviewed in a group to gather their opinions on the activity. They were encouraged to express both positive and negative opinions, and it was emphasised that their input would contribute to improving the system for subsequent use. The interviews used open-ended, semi-structured questions to identify key issues related to the task and explore them with the participants. In some cases critical incidents identified from the task activity were related to the participants to prompt discussion. The researcher took notes during this session.

5.3 Analysis of results

5.3.1 Learning outcomes

5.3.1.1 Pre- and post-task quiz

An analysis of the post-task quiz results in comparison to the pre-test answers indicated no significant difference in learning gains between the two conditions. Non-parametric tests were used to compare the actual scores and the improvements.

The results of the post-task quiz were coded in two distinct ways to allow for two analyses:

1. to compare the results in relation to the task;
2. and also in relation to any improvement from the pre-task quiz.

A comparison of the scores in the pre-task quiz showed no significant difference between the groups. However, looking at the actual data, it can be seen that several students in the experimental condition did not answer any of the questions, and those that did scored very highly. In the control condition, the students all attempted to answer the questions, and obtained a much more even spread of scores. So the statistical results cannot be used as an indication of the similarity of the groups. The differences between the two groups is most likely due to the quiz being administered by the teacher for the experimental condition, and by the researcher for the control condition.

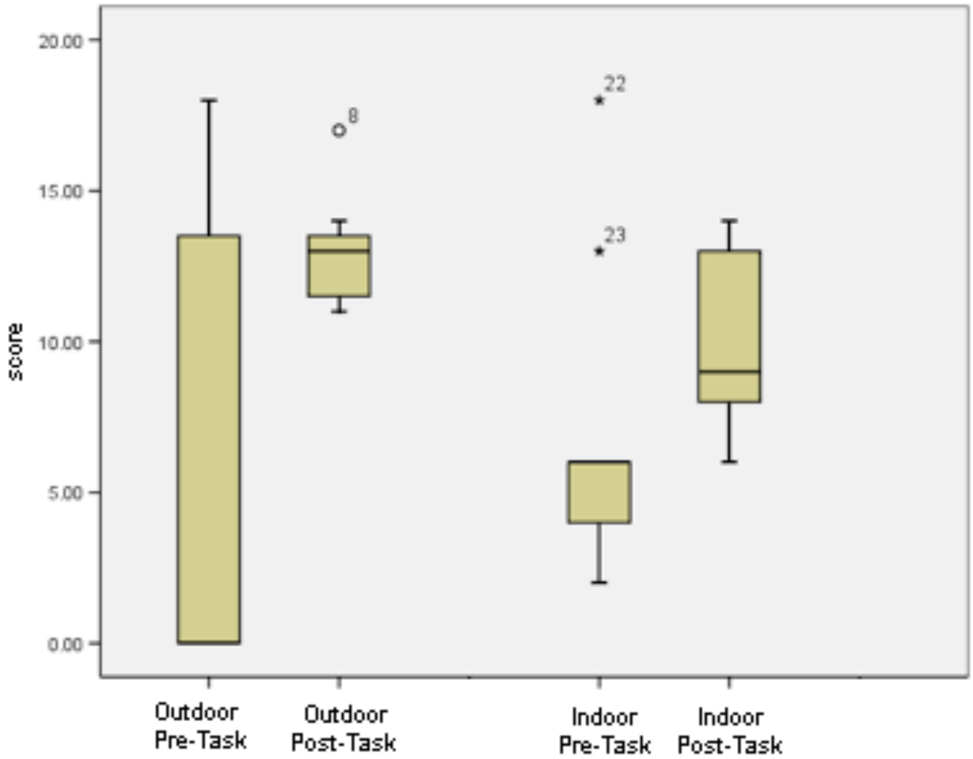

Figure 29: box plot showing scores on pre- and post-task quizzes for outdoor and indoor groups

Figure 29 above shows a boxplot showing the scores from the pre- and post-task quizzes for the outdoor and indoor groups (raw data are included in Appendix K). A comparison of the scores obtained by students in the indoor condition showed that there was a significant difference between their scores before and after the task. There was no significant difference for students in the outdoor condition.

At face value, this suggests that students in the indoor condition demonstrated learning gains not demonstrated by those in the outdoor condition.

However, in considering these results it should be noted that the sample sizes (N=8 for each group, after outliers have been removed) are small, and that several students in the outdoor group simply chose not to answer any questions on the pre-task quiz, which resulted in high 'improvement' scores. However this in itself is an interesting finding: students who were previously not motivated to even attempt any answer to any question did so after engaging in the task. All of the students in the indoor condition attempted at least some of the questions in the pre-task quiz, so it is not possible to compare the two groups on this aspect.

5.3.1.2 Post-task map drawing and annotation

Students were given a map of the school site with the content locations (hotspots) removed. They were asked to draw squares on the map to show where they thought the hotspots had been, and to annotate these squares with a short note about what they had found there.

A simple score for how many items each student placed on the map was used to assess their recall of the task. The scores indicated no significant difference between the two groups. However, all students did recall at least six of a possible nine items, suggesting that despite the technical and practical problems in the outside condition they were able to recall the nature and location of the hotspots.

5.3.2 Critical incidents from the outdoor activity

Criteria for identifying critical incident were as follows:

1. The learners(s) should be demonstrating a positive reaction to an event

2. The learner(s) should be demonstrating a negative reaction to an event

3. The learner(s) should be demonstrating significant engagement with the task or device

4. The learner(s) should be demonstrating significant disengagement from the task or device

5. The learner(s) should be demonstrating an interesting and/or unexpected behaviour directly related to the learning activity, the use of the PDA, or the environment

Applying these criteria to the video footage resulted in the identification of 21 distinct critical incidents (Table 1, below). These are summarised below, and used in combination with an analysis of learner behaviour to produce the discussion in section 5.3.3 below.

These critical incidents were validated by selecting ten of them at random and showing the surrounding segment of video in which they were found to an independent rater (approximately three minutes for each). The independent rater was also shown an additional 10 clips where no critical incident had been identified. In 15 out of the 20 segments (75%) shown to the independent rater the independent rater agreed with the researcher's analysis, identifying either or stating that there was no critical incident present (there were eight agreements from clips with critical incidents, seven from clips with no incidents). We deemed this to an acceptable level of conformity between the researcher and the independent rater.

Far more evidence for the points made in the conclusion section is available in the footage, but we highlight just the indicative critical incidents here for clarity. In drawing our conclusions, we have examined the critical incidents, the context in which they occur, and the task activity as a whole.

Table 1: critical incidents from the outdoor condition

• **Two students sharing the PDA**	Breakthrough
The students are engaged with the device, and use it successfully to find out about their task.	
• **One girl points something out to partner on screen**	Breakthrough
The students use the PDA as a shared learning resource, with one student using it to show something to her partner.	
• **Reading from the screen, with partner**	Breakthrough
The students respond positively to the appearance of content on the screen, and look at the content together, ensuring they have understood it.	
• **Student reads through content on screen apparently for herself**	Breakthrough
Evidence of motivation, as the student reads through the content even though her partner is doing something else. However, this could also be an indication that the observer with a video camera is impacting on the learner's normal activity.	
• **Need prompt – inaction**	Breakdown
Students are unsure what to do, but do not actively seek a prompt, they wait for one instead.	
• **Know what should be doing, but aren't moving:**	Breakdown
The students are aware that they should be continuing with the task, but do not do so.	

<table>
<tr><td>• Pre-occupied with onscreen display, scrolling, clicking, rather than moving to hotspot:</td><td>Breakdown</td></tr>
<tr><td colspan="2">The device appears to be too distracting for them, or they have lost interest in the task, or both.</td></tr>
<tr><td>• Waiting for change</td><td>Breakdown</td></tr>
<tr><td colspan="2">The students are prevented from completing their task because the GPS coordinates are clearly inaccurate and they are waiting for the them to change so that their on screen map position matches their physical location.</td></tr>
<tr><td>• Checking actual locations of friends against screen seemed a valuable activity:</td><td>Breakdown +
Breakthrough</td></tr>
<tr><td colspan="2">The students are highly engaged (breakthrough) with the device and checking the onscreen locations of their friends, but not with the learning (breakdown).</td></tr>
<tr><td>• Students start sitting down after about 20 minutes</td><td>Breakdown</td></tr>
<tr><td colspan="2">There appears to be nothing to prompt the students to continue, and they start to sit down to play with the PDAs. When two pairs have done this, more quickly follow and require prompting to continue.</td></tr>
<tr><td>• Students not moving</td><td>Breakdown</td></tr>
<tr><td colspan="2">The onscreen map is frozen, and the students do not move or do anything else until they resume working again.</td></tr>
<tr><td>• Students bored, playing with UI, not moving around.</td><td>Breakdown</td></tr>
<tr><td colspan="2">The students have become disengaged with the task and are looking for distractions by playing with the PDA.</td></tr>
</table>

• **PDA upside down.**	Breakthrough
The students find a novel solution to orienting themselves to the map by turning the PDA upside down to navigate.	
• **Victory moment**	Breakthrough
Girl takes small steps to locate a hotspot and is happy when she finds it	
• **Pointing to indicate action**	Breakthrough + Breakdown
One girl points, links the environment with map display, indicates action, other says "but I'm not there" – the dissonance between the 2 PDAs causes them to pause.	
• **Engagement with surface level only**	Breakdown
Observer asks "Do you know what Task 1 is?" they say "yeah we went to it, something about hotspots". They are looking for hotspots, but seem fixated on this activity, and are unclear that this is actually what they should be doing (in part), and are clearly not engaged in finding out what is at the hotspots.	
• **Map as a shared artefact**	Breakthrough
The students use the map display as a shared artefact for discussion, one shows it to their partner and asks have we done that one there. Also indicates lack of feedback	

• **Wall**	Breakthrough + Breakdown
They are looking for the hotspot and immediately assume they have to go over the wall: this shows the power of the device to command action, but also that they can become inappropriately fixated on specific aspects and actions.	
• **Creating landmarks**	Breakthrough
The students use the location of other players as landmarks to navigate with. This highlights the need to provide ways to orient themselves to the blank map. Indicates a need for more landmarks to be visible to help them reconcile the map and environment	
• **See what happens**	Breakthrough
They move various directions in an attempt to orient themselves to the map. But they don't walk very far. They are happy to try stuff and 'see what happens'	
• **Building**	Breakthrough
"The building looks so long from outside" the task has brought them to the back of the field and one girl comments on the appearance of the building, suggesting that this kind of activity might have given an opportunity to see their environment in a new way. Serendipitous learning	

5.3.3 Group interview

Students were interviewed as a group to get their general reactions to the activity and ideas for future versions. A number of open-ended questions were asked, and students were encouraged to provide both positive and negative responses.

Highlights of the activity identified by the students included the freedom of movement (outdoor condition) and awareness of the location of others (both conditions).

The students were quite insightful about the use of content, and stated that whilst they were keen to use the PDAs for similar activities, they were more interested in actively doing things rather than reading any content on the screen. However, all the students enjoyed the practical nature of the task, and even the students in the indoor condition described the task as more 'hands on' than other learning activities, and enjoyed the ability to move around a space with other players.

5.3.4 Analysis of task performance

This section provides a summary of the analysis of the video footage obtained during the trials, drawing on the critical incidents identified for the outdoor condition (above) and the observations of the students in the indoor condition. It is organised according to categories that arose during analysis, with a comparison between each condition provided for each issue.

For each category, the video footage was reviewed for critical incidents relating to that category. The set of identified critical incidents were then grouped and reviewed on a per category basis.

5.3.4.1 Goal-awareness

Students indoors appeared, on the whole, to be much more aware of what the tasks were that they needed to perform, and when to move on from Task 1 to Task 2. Whilst this was not true for all students, only a small number of the indoor students asked questions of the type "What should we do now?" and as a group they required far less encouragement and prompting to complete the set tasks.

By contrast, the students in the outdoor condition required a much higher degree of prompting and frequently asked what they should be doing. There are numerous examples of students not engaged in any particular activity, apparently distracted by either the device itself or the environment.

Students in both conditions responded very positively to the PDAs displaying the location of their co-players, and there were frequent remarks on this throughout the task. Some students used it to play ‘practical’ jokes by following, ‘jumping on’, and ‘hiding from’ their friends (this was possible due to the colours used in some areas of the map being similar to the colours used to mark player positions). In particular, students outdoors often compared the displayed locations of their friends to their actual positions, without any apparent need for this in relation to the task they were performing.

5.3.4.2 Use of content

The students were clearly aware of the primary goal of the activity, which was to visit each of the available content hotspots and make notes on what they found. They also displayed a high degree of engagement in the ‘find’ aspect of the task. However, they did not demonstrate any real engagement with the content that they found, nor did they relate the content to the physical location where it was presented. There were no examples of students referring to the physical environment after reading the content, or vice versa.

5.3.4.3 Game behaviour

There was evidence that students stopped and read the content that they saw in the hotspots. However, there was also evidence that even those same students who read the content did not then recall it in the post-task quiz. Students outdoors made a show of reading the content, standing still and reading it aloud to the camera. Students indoors did not exhibit the same behaviour, suggesting that they were perhaps less aware of being filmed. However, this can also be interpreted as evidence for the surface engagement hypothesis, whereby the students are engaged in the process of locating and gathering the information, albeit in a very superficial manner, but are not engaged with the actual content itself.

The inherent lack of accuracy present in the GPS tracking appeared to lend itself well to a challenging, game-like interpretation of the task. Several students were seen closely monitoring their position on the screen in relation to the visible hotspot, and were audibly triumphant when they succeeded in navigating to the correct position. Again, whilst this is evidence of a high degree of engagement with the first-order task, it did not appear to translate into any enhanced engagement with the content that was available at each hotspot.

One particular hotspot proved exceedingly difficult to move into due to its position at the extreme edge of the playing area. With the GPS providing inaccurate fixes, none of the players were able reach this hotspot and some became fixated on it, beginning to climb over the tree at the edge of the field in an effort to move closer to the hotspot.

Since the students in the indoor condition did not experience the same problems with the GPS, they consequently did not struggle to find any of the hotspots, and were not seen to exhibit any similar triumphant behaviours. Only one student in the indoor condition expressed any positive reaction to a particular event in the task, remarking that the note about the imaginary river that could flood the school as “awesome”. No other similar reactions were observed in the indoor condition.

5.3.4.4 Motivation and engagement

It is useful to start with general characterisations of the students’ behaviour in each condition. In the outdoor condition, despite numerous technical problems, they appeared to remain engaged and interested for the best part of an hour, continuing to move around the space and try out the functions on the PDA. By contrast, whilst the students indoors were quite willing to continue using the PDAs for as long as possible (to avoid returning to lessons) they appeared less engaged with the task after initial exploration, and in most cases did not engage in any meaningful collaborative activity.

A significant contrast was the apparent lack of any ‘victorious’ moments in the indoor condition in comparison with the outdoor condition, which yielded a number of occasions where students displayed triumphant behaviours when they had successfully located a hotspot or completed a task using one of the functions on the PDA.

One group of boys in the indoor condition became quite fascinated with the function for drawing shapes and lines using the trails function, and entertained themselves for some time drawing shapes both individually and collaboratively.

Engagement in the outdoor condition seemed to be simultaneously a benefit and disadvantage. This came about because students appeared to be highly engaged in the first order task of ‘find the hotpots’ but not in the second order task of ‘read the content’. Students were seen to be moving quickly from one hotspot to another, without apparently taking the time to stop and take note of what they were seeing. All students were given clear instructions about taking notes at each hotspot, but these instructions were quickly forgotten (or ignored) as they engaged in the task of simply locating the hotspots. Performing the subtasks mentioned in the content was something that required specific prompting from the facilitators; no students spontaneously followed these instructions.

It is important to note that despite high levels of engagement, this was followed by a period of fatigue whereby many students became bored with moving around the space and sat down to play with the PDAs. They then required specific prompting to get them to continue.

5.4 Conclusions and Implications for subsequent studies

5.4.1 Technical issues to overcome

5.4.1.1 Wireless LAN coverage

For this trial, a single wireless router was used to provide connectivity to the PDAs used in the field. Although the router was equipped with an improved antenna to boost the signal gain, there were still gaps in the coverage, particularly when students moved far away from the router and turned away from it, blocking the signal with their bodies. For subsequent trials over even small areas, enhanced wireless coverage will be required, using two or more wireless base stations that can act as signal repeaters. This functionality is now available in many consumer grade models so should not be difficult to implement.

5.4.1.2 GPS accuracy

The use of GPS for location tracking inevitably led to some inaccurate tracking of the students' movements in the field. GPS at best can provide accuracy to within 3 metres, and under normal working conditions an accuracy of 10 metres is a better estimate of its real-world accuracy. Systems such as car navigation systems are able to use assumptions to further refine and constrain the possible positions calculated from the satellite signals (such as ignoring slight lateral deviations from the course of the road). In an open space such as the school grounds, tracking learners on foot, there is much more scope of GPS errors to lead to inaccurate results.

Due to the positioning of some hotspots near the edge of the space where the students were working, problems with the GPS led to it being very difficult for some students to visit all of the hotspots, because they simply unable to move beyond the bounds of the school grounds to overcome the discrepancies in the GPS readings. This was an important finding that did not arise during testing of the system, and will be used to constrain the design of subsequent tasks using PaSAT to ensure that similar problems are not encountered again.

A number of methods exist for improving the accuracy of GPS positioning systems, including the use of multiple fixed reference points to calculate local offsets (differential GPS) and the use of independent, high capacity systems to perform higher accuracy calculations (assisted GPS). These solutions will be explored for subsequent trials. There are also practical measures that could be used, such as ensuring that the layout of hotspots fits with an estimated ten metre accuracy from the GPS system, and not positioning hotspots near the edge of the outdoor space., where GPS inaccuracies are more likely to render that hotspot unreachable.

5.4.2 Task design

Since our intention for subsequent studies is to employ games to create engaging and structured activities, it is significant to see that learners react to even the simplest of location-based activities in game-playing terms. It is apparent that we can easily engage learners in an activity, but the challenge is to ensure that they engaged with all of the activity and not just surface level aspects of it.

In particular, students seem to be fascinated with location, and co-location, and how their movements can form part of an ongoing activity. This accords with Dewey's principles of experiential learning (Dewey, 1916), and also Papert's notion of linking dead learning in the classroom into something more live and meaningful away from the classroom (Papert, 1980).

Location was a key part of the activity because the students had to locate the hotspots, which meant they had to be able to navigate to them by locating themselves on the map, relating this to the environment, and choosing the correct direction to travel in. This caused numerous problems for several students. The primary problem was that the map had a fixed, north-pointing orientation. As students turned, the map remained static, apart from small fluctuations due to the GPS signal – GPS receivers cannot provide cardinal direction information when stationary. Because we had simplified the map and removed the smaller features, the students often saw only a screen containing one or more hotspots and their own location marker. This was insufficient for them to determine which way to head in order to reach a target hotspot. Students were instructed to face away from the school with the PDA pointing towards the rear of the field to orient themselves, but few heeded this advice, instead making many experimental movements in order to find out which way they should go. For hotspots anchored to specific features, such as the wall or tree, the students knew which way to go, highlighting that was particularly an issue related to placing target hotspots away from recognizable environmental features. This suggests that more closely associating target locations with recognizable environmental features will help learners to navigate the space more successfully.

Another challenge we face is how to support the applied cycle of learning as proposed by Kolb (1975), expanding on Dewey's (1916; 1938) experiential foundation. Kolb's model (Kolb, 1984) includes *engagement* and *action* (as active experimentation and concrete experience), and *reflection* (as reflective observation and abstract conceptualisation), with the latter leading to more *engagement*. Engagement and action are easy, they are almost unavoidable when presenting learners with an appealing activity, but how can we promote reflection? Admittedly in the present study there was little to reflect on, but we saw that *over-engagement* in particular aspects of a task may interfere with the engagement in other aspects that was intended by the designers of the activity.

The challenge therefore appears to be one of how to effectively couple or integrate the learning content into the interactive experience. The concept of extrinsic versus intrinsic motivation is important here. Malone (1980) identified that for the motivational effects of games to be maximized, the motivation must be intrinsic to the game. In other words, players must want to play the game for its own sake, and not because of some external reason. This concept is highly salient for the use of games to deliver learning; it is not sufficient to 'bolt-on' learning to a gaming activity, we must instead try to integrate the learning into the game and have the two things serve as one unified experience. This importance of intrinsic motivation in learning has been acknowledged, for example by Lepper & Malone (1987) and Habgood (2005). Game theorists such as Koster (2005) have further suggested that pleasure may be derived from the activity of solving puzzles within a game.

Learners appeared to be highly engaged by the 'doing' aspects of the activity, and were quick to latch on to goals such as 'find the hotspots'. The related goals, read the content and respond to questions, were largely ignored, or required prompting. When questioned about this, the students stated that they enjoyed being outdoors and being involved in doing things, but did not want to have to read any content on the screen. This implies that we should minimize the display of content and focus on making the PDA a tool with which to perform an activity. It may be acceptable to display status information to inform learners of their current distance from their goals and offer them options, but trying to embed content within the context of outdoor, location-based activity appears to be difficult.

We were successful in using the environment to provide a focus for the task, and using real features of the physical space did appear to be a draw for students. Using features that were clearly visible meant that they had something to focus their shared discussions (minimal though these were) and they were able to orient themselves to the map and decide on what to look at next. It seems we can exploit the immediate engagement of being outdoors with a mobile device to kick-start learners into beginning a task. However, we saw that this initial engagement could wear off without further feedback from the activity. The exploratory activity in this study gave students no feedback about what they had done or what they could do next, and many students appeared to struggle with this, asking what they should do or just doing nothing at all.

All of this highlights the difficulties of conducting an outdoor learning activity where we are relying on handheld devices to engage and motivate the learners. This engagement and motivation is present at the beginning, but after that it becomes difficult to coordinate the learners' activities and they find it difficult to do this themselves. Discussions with the teacher involved with these trials further cemented this view: there are a vast number of opportunities for learning outdoors, but the primary problems of coordination and being able to deliver an activity that is at least as structured as one in the classroom are paramount.

Frohberg *et al.* (2009) comment on this issue of giving learners too much control over their own learning, and suggest that, while giving over more control to the students themselves can be beneficial, it can be detrimental if they are given too much, with students becoming uncoordinated and distracted. In attempting to move away from the classroom activity, this study appears to have moved too far towards the other extreme, and subsequent activities will need to be carefully designed in order to provide a more optimal level of control.

Another factor that may have led to lower engagement is the fact that after a while the students appeared to realize that there was nothing more to the task than could be observed initially. They enjoyed finding the imaginary river, but once they had located a few hot spots they realized that the remainder of the task would yield few surprises and hence they were perhaps aware that there were no further rewards to be had. The implication here is that initial engagement needs to be followed by a structured task that keeps providing rewards.

The task therefore very quickly became a treasure hunt for the students. They fixated on finding the hotspots, often at the exclusion of paying attention to other goals. One pair demonstrated this to the extreme, taking great lengths to locate a hotspot that, due to GPS errors, was temporarily beyond their reach at the back of the field. This demonstrates the power of the location-based activity to engage, but perhaps only at the surface level. It may prove more difficult to engage the learners in the underlying learning process that we are trying to promote. All of this implies that games are a highly promising direction to follow in terms of wanting to provide in situ support for field-based enquiry learning. Students readily treat the activity as a game, respond well to challenge, look for feedback, and want to be *doing* rather than *reading*.

5.4.3 Evaluation

We employed a mixed-methods approach in the evaluation of this study, and found that this was a rewarding and effective approach that allowed us a rich exploration of the behaviour of learners both in the field and in the classroom. However, it became apparent that what was of most interest was the processes that learners were engaged in, and what mediated and impacted on those processes. The outcome of the learning was less interesting from the point of view of understanding how to support learners with mobile technologies.

This fits with current calls to approach learning more as a 'doing' activity rather than an 'acquiring knowledge' activity. The richness of the learner activity suggested that it is much more valuable to explore how and why they are learning rather than just whether they are learning at all. Granted, outcome measures give us an indication of success, but as we saw it can be difficult to set up evaluations so that differences between groups can be observed when trying to support this kind of activity-based learning.

For subsequent studies, this implies that we should further adopt a process-centric approach to evaluation, and look for methods that allow us to understand learner activity on its own terms, in the context in which it arises. This means that we need to use enhanced tools to both record and analyse learner activity. Critical incidents were useful in this first study to identify salient issues, but for evaluating subsequent designs of location-based learning activities we will need to explore how different factors relate to one another and what are the core processes involved in learners' activities.

Reflecting on the post-task interviews conducted with the students, it seems that although the students were able to provide helpful suggestions about future versions of the activity and were open to creative thinking about the task, they found it difficult to provide detailed information about their own activities and motivations. This further contributed to our decision to focus on process-centric evaluation, with much more in-depth analysis of field data rather than relying on post-hoc data gathering.

5.4.4 Summary

This study has provided insights into the factors that impact on students using a location-based mobile learning activity to explore the grounds of their school. We saw first-hand how such an activity compared with a similar activity indoors, and although there are some apparent benefits or at least aspects of being outdoors than can be exploited, there remain significant problems to overcome in terms of maintaining engagement, coordinating activity, and keeping students on task. These findings will be helpful in designing further studies using the PaSAT toolkit, and the overall indication appears to be that structured activities such as games, which can provide motivation, structure and ongoing reward, are a strong candidate for attempting to support field-based learning, but there are specific and significant issues to overcome relating to ongoing motivation, deep engagement, and coordination of learner activity.

Chapter 6

Design of BuildIt: a situated mobile learning game to support active enquiry learning outdoors

This chapter describes the design of a mobile learning game called BuildIt that was developed using the PaSAT software (Chapter 4) for use in Study 2 (Chapter 7). Drawing on our review of the literature in Chapter 2, we describe a set of requirements derived from related work, Study 1, learning theory, curricular goals, and game design principles. We then describe the design of the game, and highlight how the key design elements are intended to meet the requirements that are identified. Where appropriate, in both the requirements and design sections, we refer to how the features used in the BuildIt game were implemented to address the requirements. These requirements in many cases are complementary rather than distinct, and there are several areas that overlap (for example, the requirements for situated learning environments and those for creating engaging games).

6.1 Research question and problems identified in Study 1

Our touchstone at the start of the design process was our primary research question: "How can situated mobile learning games be used to support active enquiry learning in the field?" Embedded within this question there are already several requirements for our learning game. Firstly, it must be mobile: the activity must make meaningful use of mobile devices and technologies. Secondly, it must be situated, in that it should take place within a specific environment that is relevant and meaningful for the learning activity. Thirdly, the game must in some way encourage active enquiry and reflection as part of the activity. Fourthly, the activity must be a game: it should be fun to take part in and provide an appropriate level of challenge so that learners are intrinsically motivated to play. These high level requirements can be broken down into a number of lower level ones:

- Situated learning
- Experiential learning
- Enquiry learning
- Game design
- Curriculum and learning objectives

We explore these areas below.

6.2 Aims for the design process

We aimed to build on previous work by designing and implementing a mobile learning game that incorporated the core features of situated, experiential and enquiry learning models. We did not seek to exhaustively implement features that would ensure a fit with every requirement that has been discussed for these approaches. Instead we sought to use these instructional models as guidelines for the design of the mobile learning game described in this chapter. It became clear that we could not start from the identified requirements and work forwards, because this would lead to simply expanding the requirements and not generating a creative core idea for the game. Instead we drew our inspiration from examples of the approaches we were following and after a period of design we re-visited the requirements and modified our designs to ensure a better fit with the identified approaches, where necessary. Our initial starting point was the problems and opportunities that we had observed in Study 1 (Chapter 4) and in previous related work (see Chapter 2 for a review).

6.3 *Reviewing previous work and Study 1*

Our review of related work in Chapter 2 and the results from Study 1 (Chapter 4) suggested that there were a number of specific problems that arise in situated mobile learning activities, as well as a number of specific areas that appear to offer opportunities for supporting the learning process but which have not yet been specifically addressed.

6.3.1 Problems to address

6.3.1.1 Surface engagement – the treasure hunt problem

The 'treasure hunt problem' – the tendency for learners to focus on surface level activities at the expense of engaging with the underlying learning – has been referred to in related projects such as Environmental Detectives (Klopfer *et al.*, 2002; Squire and Klopfer, 2007) and was seen to be a problem in Study 1 (see results of Study 1, Chapter 5, section 5.4.2). We observed learners being highly engaged in the general task of locating hotspots, but apparently ignorant of the deeper task, to "find out about the hotspot". Similar problems were observed in Environmental Detectives. Squire & Klopfer (2007) remark that the students appeared to be "exclusively" focused on the collection of data samples (p400), without being engaged in any kind of interpretation of them. These problems formed the basis of a requirement to engage the students in the underlying learning activity by encouraging (perhaps requiring) them to reflect on their actions and the results they obtained. This requirement is also closely related to the goal of including reflection as a core part of the learning process (see 6.3.1.3).

6.3.1.2 Lack of coordination of action, shared locus of control and guided enquiry activities

The locus of control of the learning activity is an important issue for mobile learning, even more so for mobile learning that takes place outside with learners away from the support of their classroom and teacher. It has been identified as a core component of a proposed theory for mobile learning (Sharples *et al.*, 2005; Sharples *et al.*, 2007) and has been used as part of a framework for exploring the current state of the art in the field (Frohberg *et al.*, 2009). Few projects explicitly discuss the issue of control, yet it is an important issue in the design of mobile learning activities (more so than for traditional learning activities) because having learners in the field away from the classroom exacerbates the problems associated with the locus of control.

Most mobile learning projects (approximately 73% according to Frohberg *et al.*'s (2009) survey) feature control that is either fully or mainly held by the teacher. This is appropriate for activities conducted in the classroom that are based on established learning strategies. But it is not so relevant out in the field, especially when we are trying to engage learners in authentic, situated, self-directed enquiry activities. There is an inherent tension between the need to maintain control of the activity and the need to cede control at least partially to the learners who we wish to direct their own learning. Learners who are given too much control may not know what to do with it (Lawless and Brown, 1997), but learners who are given too little cannot explore and apply knowledge (Ploetzner *et al.*, 1999).

The requirement is therefore to provide an appropriate degree of control to the learner, so that he or she can drive the activity and find their own path, but not so much that they lose track of what it is they should be doing and lose motivation. This could be implemented in a number of ways. Explicit prompts could be given at specific points to guide their activities. A more subtle approach, which is perhaps more desirable from a design point of view, is that the task and activity itself could be structured so that there are clear affordances for action, giving learners the means to see what they *can* do and decide from those available options what they *should* do.

This requirement can be addressed by aiming for a level of control whereby learners can make their own choices yet still determine their options and be guided in their activities. We should therefore aim for a balance of learner and teacher control in the form of a guided enquiry activity such as that implemented for *MyArtSpace* (Vavoula *et al.*, 2009) or *Mad City Mystery* (Squire and Jan, 2007).

6.3.1.3 Lack of reflection on action

Reflection has been identified as an essential component of active, reflective learning. For example, Ackermann (1996) stresses that, in order to engage in exploration and discovery, and enquiry in the environment, learners need to step back from the activity and reflect on it before diving back in. It appears that whilst situated mobile learning activities can be very successful in engaging learners in an activity, learners do not tend to form hypotheses about phenomena they observe. This was observed in several projects, including Frequency 1550 (Huizenga *et al.*, 2009), Ambient Wood (Rogers and Price, 2004) and Savannah (Facer *et al.*, 2004). Facer *et al.* (2004) reflect on the tasks given to the learners in Savannah and remark that they appeared to lack sufficient focus and challenge to really give rise to learners having to generate hypotheses about what was going on. Squire & Klopfer (2007) also indicate that mobile learning games could use specific structuring in order to encourage reflection.

A requirement for a game to support reflection on action is therefore to include specific, focussed tasks that give a clear indication of how to complete them, and to make them challenging enough so that learners have to reflect on what they are doing. This also accords with our aims of using failure (see 6.3.2.3) and challenge within the game design (see 6.5) as mechanisms to support enquiry learning.

6.3.2 Opportunities observed

As well as the problems and issues described above, we discovered several opportunities and aspects mentioned in the literature and observed during Study 1 that have not as yet been fully exploited for enabling mobile enquiry learning activities. The opportunities described here are far from exhaustive, but represent the salient aspects that helped inspire the design of the BuildIt game.

6.3.2.1 Coupling movement, location and the physical environment

The capacity for mobile devices to fuse the virtual and physical worlds together effectively has been demonstrated across a broad range of projects, including entertainment (for example *Can You See Me Now?* Benford *et al.*, 2006), conveying information (for example *CAERUS*, Naismith *et al.*, 2005), and for enabling active, participatory learning (for example, Colella's Virus Game, Colella, 2000). Roschelle (2003) lists "augmenting physical spaces with information exchanges" as one of the key affordances of mobile technologies that can support learning. Squire & Klopfer (2007) describe the use of the physical environment as part of the learning activity as "[possibly] the strongest pedagogical value of Environmental Detectives" (p403). In Study 1 we observed students highly engaged with the environment, trying to climb walls and tree to reach virtual hotspots, and fascinated by the relative location of their friends.

We therefore included use of the physical environment as a direct part of the learning activity as a core requirement for the mobile learning game for Study 2.

6.3.2.2 Challenge and 'wicked problems'

Challenge is important for games. A game needs to be difficult so that players are motivated to try, and when they fail, they try again. If a game is too easy, players will be bored, and will not be motivated to continue, because the intrinsic reward of gameplay comes from overcoming the difficulties of the game (Crawford, 1982; Squire, 2005).

This applies equally to situated mobile learning games. As found in Savannah (Facer *et al.*, 2004), learners who are not given a sufficient challenge are not prompted to reflect on their actions, and their activities may lack focus. Similarly, in Environmental Detectives (Squire and Klopfer, 2007) the challenge was to 'solve the mystery', but there were few immediate constraints on learners' actions. They thus attempted to perform as much activity as possible, and they became focused on performing the only action available to them (collecting data samples) at the exclusion of reflecting on why they were doing so.

The engaging challenge of discovering the rules in situated games has been demonstrated in Colella's Virus Game (Colella, 1998), as well as in more recent examples, particularly *Mad City Mystery* (Squire and Jan, 2007) and *Frequency 1550* (Huizenga *et al.*, 2009) where students are asked to solve a mystery-based puzzle. Squire's studies of the use of *Civilization 3* to explore world history have also demonstrated how learners can thrive on the process of discovering and conquering the rules of a game (Squire, 2004).

There is also some indication that particular types of challenge may be appropriate for encouraging hypothesis generation, testing, and reflection. According to Facer *et al.* (2004), for games to encourage problem solving and hypothesis generation and testing they need to be based on 'wicked problems'. Such problems, as described by Kirschner *et al.* (2004), need to feature challenges that have ambiguous or ill-defined structures, with no obvious or fixed solution, so that learners have to explore and find multiple explanations and answers.

So making things too easy does not work, and incorporating an appropriate level of challenge into a learning game is important to maintain interest and motivation. Open-ended problems, or at least problems where there are a number of solutions, may be particularly suitable. As described below, we produced an initial design based on these principles and play-tested it with students to assess its suitability.

6.3.2.3 Failure as an unexplored aspect of games

In reviewing previous work, we found that failure is i) cited as a central feature and learning mechanism for games (for example Squire, 2004), ii) has been identified as an effective mechanism for learning (for example VanLehn *et al.*, 2003; Kapur, 2008), and iii) learning theorists have argued that unstructured events that allow failure are desirable from a pedagogical perspective (Dillenbourg, 2002; Kirschner *et al.*, 2006). In fact failure, through the process of a learner recognising that their conceptions of the world need to modified, is central to Piaget's original explanations of learning, and formed a core aspect of his description of constructivism (Piaget, 1970; Pimentel, 1999).

However, there have been no examples so far of including failure states in mobile learning games to prompt reflection. A requirement derived from this lack of the use of explicit failure states in situated mobile games is therefore that we should include direct and clear failure, and ways to determine how close players are to possible failure, into the game design.

6.4 Requirements derived from learning theory

In Chapter 2 we identified two learning theories that have informed the design of previous work on mobile situated learning games. Since our aim is to build on these previous projects we have also chosen to focus the design of our game on these learning theories. We describe below requirements for our mobile learning game derived from situated and experiential learning perspectives. There is not a set of requirements that we can operationalise or objectify, rather it is more a case of adopting an approach, and identifying the core aspects of it and ensuring that these aspects are embodied in the design of the game.

6.4.1 Situated learning

To follow a situated learning approach, our aim was to find authentic activities performed within an authentic setting: students should be situated in an environment that has direct relevance to the learning activity and they should be given the means to perform actions and conduct activities within that environment that again are directly relevant to the learning topic. A particular requirement is that the learning process should be participatory, so that the students actually get to take part in an activity they can learn from.

In emphasising the role of the environment and adopting the situated learning approach, we are also seeking to overcome what has been called the "focus problem" in mobile learning. This problem, as described by Goth *et al.* (2006) refers to the tendency for learners to become over-engaged with the device that is being used: they stare at the screen instead of engaging with the environment. We were mindful of this and sought to minimise interactions with the device, seeking instead to maximise references to the environment and aiming to encourage (if not force) learners to attend to the environment in order to play the game.

Situated learning has been described and re-described many times since its origins in Lave and Wenger's original paper (Lave and Wenger, 1991). It is a general approach to modelling learning and designing instructional activities. A number of core characteristics of the approach have been described, for example Herrington and Oliver (1995) identify nine key characteristics of situated learning environments. These are shown below in Figure 30.

Key characteristics for a situated learning environment:

- Authentic contexts that reflect the way knowledge will be used in real-life
- Authentic activities
- Access to expert performances and the modelling of processes
- Multiple roles and perspectives
- Support for collaborative construction of knowledge
- Provision of coaching and scaffolding at critical times
- Promotion of reflection to enable abstractions to be formed
- Promotion of articulation to enable tacit knowledge to be made explicit
- Provision for integrated assessment of learning within the task

(adapted from Herrington & Oliver 1995)

Figure 30: key characteristics of situated learning environments, adapted from Herrington & Oliver (1995)

Herrington ad Oliver's paper has been widely cited in the field (for example Lonchamp, 2006) and specifically with regard to the use of mobile technologies to support learning (for example Kurti *et al.*, 2007). We identified several core aspects from Herrington and Oliver's characteristics that we viewed as both critical and feasible for the mobile activity envisaged for Study 2:

1. Use of an authentic context to enable authentic activities.

2. Inclusion of multiple factors to necessitate multiple perspective-taking.

3. Support for collaboration through shared tools and references.

4. Support and prompts for reflection.

We describe the key game features intended to support these requirements in the design and implementation sections below.

6.4.2 Experiential learning

As identified in Chapter 2, experiential learning is complementary to situated learning and has also been cited as a core approach for several mobile learning projects, including participatory simulations (such as Colella's Virus Game – Colella, 2002), learning games (such as Frequency 1550 - Huizenga *et al.*, 2009), and other enquiry activities (for example Ambient Wood - Rogers and Price, 2004).

The key principles of experiential learning are rooted in the constructivist learning paradigm, which holds that children construct their own understandings of the world through experience. The experiential learning paradigm has been cited as the basis for several exemplary mobile learning activities (including Colella, 2002; Facer *et al.*, 2004). Dewey (1916) asserted that the more direct the experience, the better – we were thus mindful of this in creating the BuildIt game, seeking to provide as direct a link as possible between the learners' activities and the environment in which they were conducting the task. This was primarily achieved through incorporating features of the environment into the gameplay, and by using learner movement as a required part of the task.

Meaningful activities have been described as more engaging and motivating for learners. We were also mindful of how meaningful the task would be for the learners, seeking to ensure that it was as personally relevant for them as possible.

Kolb (1984), building on Dewey's original philosophy of experiential learning, identifies six core characteristics of the experiential learning approach:

1. Learning is best conceived as a process, not in terms of outcomes.
2. All learning is relearning. Learning is best facilitated by a process that draws out the students' beliefs and ideas about a topic so that they can be examined, tested, and integrated with new, more refined ideas.
3. Learning requires the resolution of conflicts between dialectically opposed modes of adaptation to the world, i.e. reflection and action - and feeling and thinking.
4. Learning is a holistic process of adaptation to the world, not just cognition but also feeling, perceiving, and behaving.
5. Learning results from synergetic transactions between the person and the environment.
6. Learning is the process of creating knowledge.

(adapted from Kolb 1984)

Figure 31: key characteristics of experiential learning (adapted from Kolb,

We derived a number of core requirements for the BuildIt game from these characteristics:

- Emphasis on learning as process, with knowledge created through engagement in that process.
- Relearning: re-examination and re-conceptualisation.
- Resolution of conflicts, adaptation to the world: learning through recognising and dealing with observations and held beliefs.

How these requirements were embodied in the BuildIt game is discussed below in the Design section.

6.4.2.1 Problems with experiential learning

As identified in Chapter 2, there are specific problems with creating experiential learning activities that may be addressed (at least partially) through the appropriate use of scaffolding technologies. One specific problem is that experiential learning environments often lack an appropriate mechanism to focus learners' attention, with the result being that learners may not reflect on their actions (Vince, 1998).

Whilst this research did not aim to explore how a mobile learning game could in itself help address these problems related to experiential learning in general, we kept these issues in mind when designing the BuildIt game to attempt to alleviate any negative impact of these problems on the learning activity we wished to create. In particular, the identification of these problems highlighted the need to provide a clear focus for learner's attention and activities, and provide appropriate prompts for reflection within the activity itself.

6.4.3 Enquiry learning

The research question for this thesis focuses on the use of mobile technology to support enquiry learning in the field, hence we needed to ensure that the mobile learning game implemented for Study 2 was based around an enquiry and could support the range of activities expected in an enquiry learning activity.

Our initial touchstone for this was a basic model of enquiry learning, as described by McFarlane & Sakelleriou (2002), shown below in Figure 32.

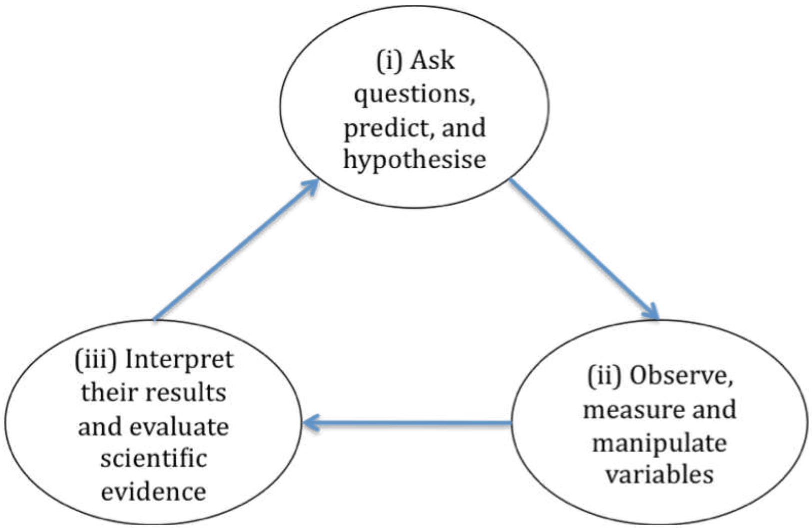

Figure 32: a model of enquiry learning (adapted from McFarlane & Sakelleriou 2002)

The key requirements derived from this model were that the game needed to include:

1. Some means to collect data and to manipulate variables in some way.
2. A reason to interpret those data and draw conclusions.
3. A way to test hypotheses formed about the data collected.

In line with the view that the processes in enquiry learning should not follow a strict sequential path (for example Reiff *et al.*, 2002), we also included the requirement to support relatively free-form activity, i.e. not being overly prescriptive in terms of what the learners had to do next.

6.5 Requirements derived from game design principles

As well designing the activity to incorporate salient features that enable learning, we also wanted it to be, like any good game, fun to take part. Creating good games is an art rather than a science, but a number of heuristics have been developed to aid in the development of engaging activities, particularly learning games.

Prensky (2001) lists six structural elements that combine to form an engaging game:

- rules
- goals and objectives
- outcomes and feedback
- conflict/opposition
- interaction
- representation or story

Malone & Lepper (1987), building on earlier work studying games, identified *challenge*, *curiosity*, *control*, and *fantasy* as the core requirements for games that incorporate intrinsic motivation – required for a engaging and fun learning activities.

Challenge refers to any features of a game that make it difficult to play. This can be achieved in a number of ways, including physical challenge (such as requiring the player perform a skill that requires manual dexterity), or cognitive challenge (such as requiring the player to solve a riddle or puzzle). What is important to note about challenge is that it must be appropriate: games that are too hard or too easy are no fun for players, and they will quickly give up if the level of challenge is inappropriate.

Curiosity refers to the capacity for games to prompt questioning in the minds of the players, so that they are motivated to discover the underlying mechanics of the game and determine what gives rise to particular phenomena. If learners are not motivated to discover the nature of the game in this way, they will not learn to play it.

Control refers to who is in control of the action that takes place within a game. Like challenge, there must be an appropriate level of control for both the player and the game itself. The game should respond to the player, and hence have some control over events and states, but the player's actions must ultimately be seen to be the driving force behind the game otherwise the player will perceive the game as less interactive and hence not as much fun.

Fantasy is common to every game and refers to the abstracted reality that games present for the game-world itself, be that the fictional battleground of chess or the fully immersive 3D virtual reality of modern video games such as World of Warcraft. Fantasy can be achieved in simple ways: a player controlling a marble rolling over a surface is already engaged in the fantasy of being in control of that object in that particular environment.

Since we were concerned primarily with creating a learning activity that used game elements to support enquiry processes, the design of our activity did not require extensive reliance on game design patterns or guidelines. We were concerned mainly with ensuring that there were no major omissions from Prensky's structural elements, that we had an appropriate level of challenge, that we could encourage curiosity, that players had the right level of control, and the context of the game lent itself to the fantasy involved in imagining the game as real in relation to the physical environment. It is interesting to note how easily these aspects can be mapped on to the goals of the situated learning paradigm.

6.6 Learning objectives and links to the curriculum

As well as being designed to meet the needs of an enquiry learning activity, we also consulted the relevant sections of the National Curriculum so that we could identify appropriate learning objectives and operationalise them for inclusion in the game. The BuildIt game was intended to fit with the existing curriculum for Year 7 and to provide support for that curriculum. In reviewing the Key Stage 3 curriculum, we found two areas that were good candidates for outdoor learning activities supported by location-based systems.

6.6.1.1 Choosing a domain

The most natural candidate was Geography, since this topic would link directly to the physical environment we intended to use as the learning space. However, because we did not wish the results of this trial to focus on specific topics, rather on learning processes in general, we opted instead to base the game on the curriculum for Key Stage 3 Scientific Enquiry, which is based much more on general processes for performing science enquiry learning.

This choice also accords with the current calls for the learning of science to be more like the 'doing' of science, as identified in Chapter 2.

6.6.1.2 Learning objectives

The learning objectives for the task are based on the Key Stage 3 Curriculum for Scientific Enquiry, and are intended to support the following core activities from that curriculum:

1. Turn the problem into a plan: students will need to make a plan of their activity after they have been introduced to the task and the tools they will be using, so their plan will relate to the game activity

2. Use tools to take appropriate measurements: students will use the in-game functions to obtain information

3. Form hypotheses: students will use the information obtained from the game and observations of the physical environment to form hypotheses about what factors are affecting the costs and risks of the different buildings and sites

4. Use tools to test hypotheses: students will then test their hypotheses by gathering more information and by enacting solutions to the problem.

We can operationalise these objectives as follows:

- Turn a problem into a plan: decide on next course of action, what they should do next, what information they need to solve the problem, what information they need for the next step. Planning will be both pre-task (global) and during the task (immediate).

- Use tools to take measurements: measurements will be obtained through the use of the PDA game to obtain information at specific sites.

- Form hypotheses that explain the data they are gathering, and make predictions by applying these hypotheses.

- Use of tools to test and confirm or refute hypotheses.

- Refine hypotheses.

In addition, the activity is intended to increase awareness of:

- The physical environment

- The interaction of multiple variables

- The need to refine hypotheses in response to data

The game is designed to support this process through offering:

1. Tools to collect and understand information

2. Tools to test hypotheses

3. Feedback mechanisms to indicate the accuracy of hypotheses

4. Failure as motivation to reflect on hypotheses and actions

The game is not intended to directly support learning about planning or environmental factors. The intention is to use this as a context to demonstrate the potential for physical, environment-based activities to support the process of enquiry learning. The actual factors used for the underlying game mechanics were intentionally exaggerated for effect, but were based on observable features of the environment.

6.7 Game design

In this section we describe the actual design of the BuildIt game including the physical setting of the game, the actions that players can perform, the mechanics underlying the game constraints, and win/lose situations. Where appropriate we refer back to the requirements described above to demonstrate how we fulfilled those requirements.

We do not present the exact details of the design process or the numerous iterations that were developed in the process of designing the game, instead we present the initial designs, a discussion of how these met with the aims of the research, followed by details of the finalised version, and finally a discussion of how this version met with the requirements identified above in Sections 6.3, 6.4 and 6.5.

6.7.1 Initial design

We set out to design a mobile learning activity to meet as many of the requirements identified above, as fully as possible. This process was a creative one and involved a number of initial ideas that were developed to assess their suitability. The eventual design was found to meet the majority of the core requirements

To start with, we knew that we needed an activity that used failure as a prompt in enquiry learning. So the first step was to identify an enquiry learning activity that we could feasibly design using PaSAT. At the same time, we knew that we wanted the activity to be meaningful and relevant to the learners. We wanted an activity that was relevant to them and which used the grounds of their school in a meaningful way.

We also chose to base the game on a 'wicked problem', following remarks in the literature that such challenges can present appropriate activities for encouraging reflection and enquiry (for example Facer *et al.*, 2004). This meant that we started our designs for the task by focusing on problems that could have more than one solution, where those solutions would not be immediately apparent, and the factors influencing whether or not particular states were correct solutions or not had complex interactions. This immediately led us to select a design-based task, where we would ask learners to propose solutions to a particular problem by selecting multiple options in the hope of arriving at a 'best fit' solution.

We began by surveying the grounds at the school, and noting the observable characteristics. We observed a range of features, including multiple surface types and the location of the school relative to nearby residents. Inspired by previous work that has successfully used SimCity (a simulation-type game where players construct and manage a city and its services) our initial idea was to create something similar, albeit much more simple, that featured the construction of buildings as the primary activity. We consulted with a teacher at the school, and discussed these initial ideas, and we discovered that the school was due to be demolished and a new academy built in its place under the Building Schools for the Future programme. This reinforced our choice of focus: the activity of exploring where to put buildings was highly relevant to the students.

Having selected the primary focus for the activity, we set about determining exactly what the game should entail. Our touchstone at this point was the Key Stage 3 Scientific Enquiry curriculum, as we wanted to create a game that would support this curriculum.

With the intention being to keep the game as simple as possible, we decided that finding suitable locations for new buildings would be the core game activity. To ensure that the task made use of the physical environment, we decided that the suitability of a particular location should be determined by factors that were physically observable in the environment. Returning to our earlier survey of the school site, we determined that surface type, inclination, and proximity to residential properties were all highly visible aspects, and we set out to develop a game using these.

We also wished to include factors introduced by the type of buildings erected, to allow for an interaction between the physical and virtual aspects of the game. We devised three building types that had characteristics that interacted with the characteristics of the physical environment to produce costings and risk assessments for each building in each location. This was done by combining the results of the grounds survey with the characteristics of the buildings in a matrix and generating plausible results for each combination. The aim was not to produce figures that were accurate in terms of the real world, but to construct a believable game fiction that was consistent and could be understood in terms of the interactions of multiple factors.

We started out having a range of characteristics for the buildings, some of which were unique to individual buildings (for example, a dining room with a glass roof which meant it could not be sited near trees for safety reasons). In reviewing these options it was apparent that a smaller set of characteristics that were consistent across buildings would be clearer to understand and easier to quantify for the required look-up tables.

The obvious 'data' for students to collect was the price of buildings in particular locations. However, this single-factor approach did not allow us to allow for multiple perspectives and multiple variables, so we decided to include risk factors in the game as well. This meant that students had to look at two sources of information and evaluate them, a much richer process than just collecting a single figure. This also fit well with our aim to encourage students to discuss what they found. Our reasoning was that if we provided more than one source of information, and left students themselves to determine which was more important (if any) then this would prompt more discussion than if we just provided a single indicative data point for each result.

6.7.2 Final design and implementation of the game using PaSAT software

6.7.2.1 Summary

The object of the game is to find suitable sites on the school grounds for three new buildings. There are seven potential building sites occupying areas where there are currently tennis courts, tarmac, playgrounds, and fields.

Players have fixed budgets for cost and risk, and must successfully place all three buildings on three different sites without exceeding either of their budgets.

Buildings incur different costs and risks depending on where they are placed. For example, a tall building placed close to nearby houses (on one of the tennis courts) will be low cost because, in the game, building on existing concrete surfaces is cheaper than building on grass, but it will be high risk because of the risk of complaints from local residents. A building that is less tall will still incur higher costs for building on the court site, but will incur a lower risk of complaints.

Players play the game by moving around the grounds, taking Estimates and Building buildings. Estimates tell them what the costs and risks will be for a particular building at a particular site, whilst Building something provides the same information but at the same actually erects the building and adjusts the remaining budgets for cost and risk accordingly. Players can only take six estimates.

The game is won by successfully placing all three buildings on three different sites without exceeding the limits of either the cost or risk budgets. The game is lost if either budget is exceeded at any time.

6.7.2.2 Setting

The setting for the game was the school grounds at a secondary school in Stoke-on-Trent, Staffordshire.

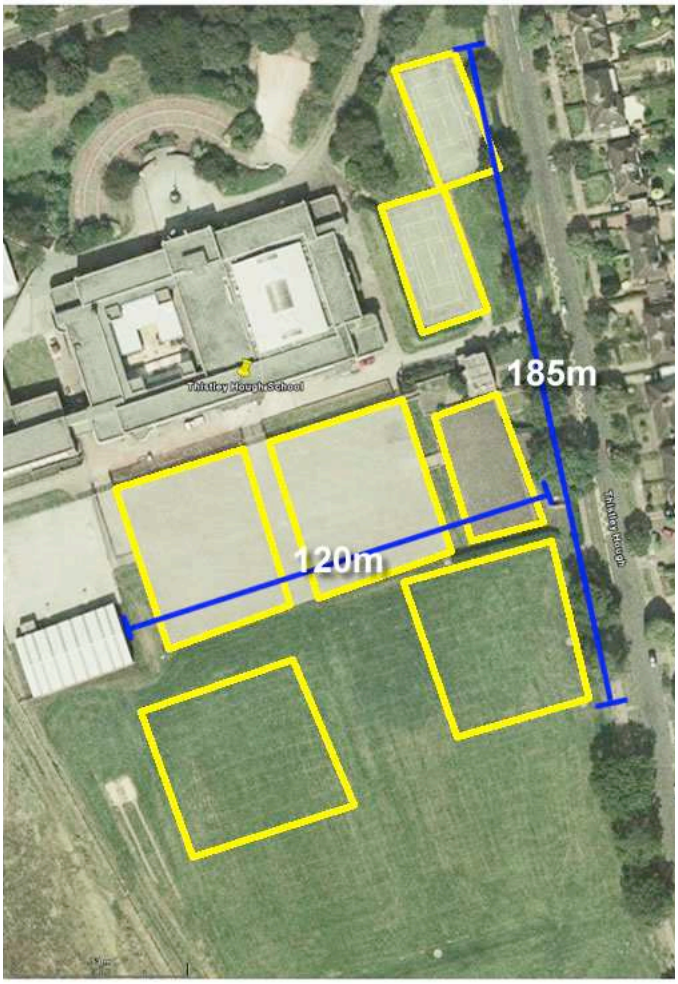

Figure 33: aerial photograph of school grounds used for BuildIt, with approximate dimensions in metres

Figure 33 (above) shows an aerial view of the buildings and school grounds for which the BuildIt game was designed and where Study 2 was carried out. The areas used for the activity are the rectangular areas marked out in yellow. These areas are located in a space approximately 185 x 120 metres in size, but not all of that area was used (specifically, the school buildings and the front parking area were not used). This meant that all of the salient locations for the learning activity were within the area normally used by the students during recreational periods, or during Physical Education classes.

The school grounds comprise a number of tarmac areas that serve as parking areas, all weather pitches, and tennis courts. There is also a large grassy field used as a sports pitch. The north and east side of the grounds are adjacent to residential properties, whilst the south and west sides are elevated in relation to the surrounding area and are not as close to neighbouring properties. The main tarmac area adjacent to the school, and the field adjacent to it, have an observable incline, descending to the west. These observable features of the physical environment were used as the basis for the design of the learning activity for Study 2.

6.7.2.3 Map display

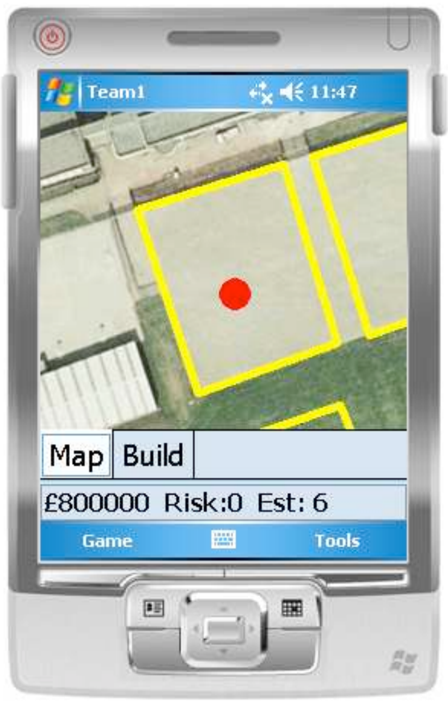

Figure 34: main display for the BuildIt game

The main display of the mobile client shows a dynamic map that indicates player position in relation to the map and the building sites drawn on it in yellow (see Figure 34). This display also shows current game status information in the form of current remaining funds, risk points incurred, and remaining estimates.

6.7.2.4 Actions

Players can perform two actions, Build and Estimate. To perform these actions, they must be located within a designated building site. When invoking the action, the player selects a building type for which they wish to perform the action.

To perform a Build action, a player must:

1. Be within a designated building site that does not already have a building erected on it
2. Not have previously gone over budget for cost or risk

To perform an Estimate action, a player must:

1. Be within a designated building site that does not already have a building erected on it
2. Not have previously gone over budget for cost or risk
3. Have at least one remaining Estimate

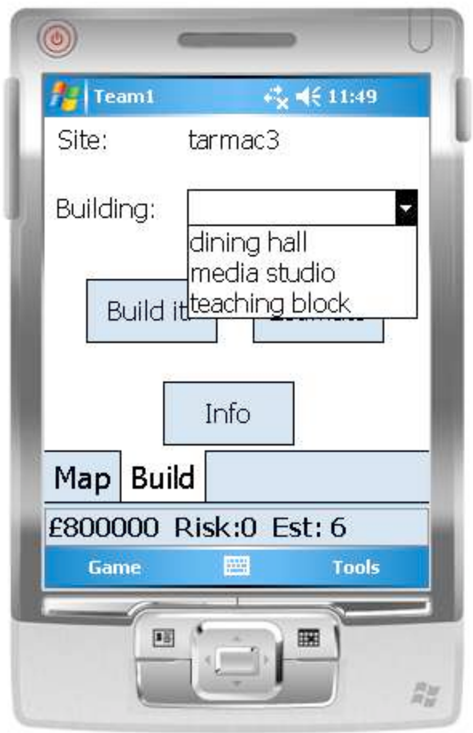

Figure 35: the action screen for BuildIt

6.7.2.5 Results of actions

After invoking either a Build or Estimate action, players then see a Report (Figure Figure 36) showing the costs and risks associated with erecting the selected building type in the current location. The only difference between these two actions is that Build returns a report and then modifies the Player's state to reflect them having actually erected the chosen building at the chosen site, whereas Estimate only returns the report. However, Estimate does decrement the Player's remaining Estimate counter, to enforce the limit on the number of Estimates that each Player can perform.

Figure 36: a report from an Estimate action

This building report is generated by the game server from the results of several lookup operations against attributes on non-player objects representing the possible Building types in the game. These lookup operations return the costs and risks of erecting each building at each possible location. The results are thus identical if the same action is invoked again for the same building type in the same location.

6.7.2.6 Constraints on action

Players have a fixed budget of £800,000 and a maximum risk allowance of 160 risk points. They also have a limit of six estimates.

To perform a Build or Estimate action, Players must be within a Building site that does not already have a building erected on it. Players can only Build or Estimate for the site that they are within, so to Build something on Court 1 they must be on Court 1. They cannot Build or obtain Estimates for another site without physically moving to that site.

These constraints are intended to the contribute to the challenge aspects of the game, encouraging careful planning and decision making by giving players limited resources that they have to be mindful of spending.

6.7.2.7 Winning and losing

The game is won by erecting all three buildings on different sites, without going over the limits for budget or risk.

If a Build action results in the Player exceeding either the budget or risk limit, they will be shown a Game Over screen that indicates which limit they exceeded, and they are prevented from taking any further actions within the game.

Figure 37: screen shown when players exceed the cost limit

Figure 38:screen shown when players exceed the risk limit

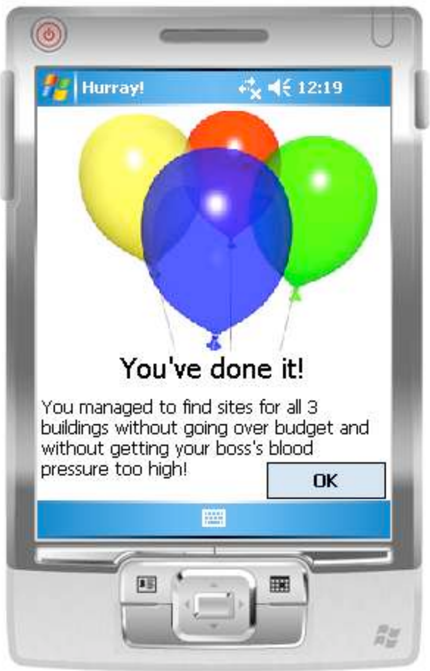

Figure 39: screen shown when players successfully complete the game

6.7.2.8 Costs and risks

Cost: this was the cost of erecting the building, and was the combination of the building's base cost and additional funds required for foundation. Tarmac areas, being hard surfaces, were assumed within the game to require less foundation work as the existing hard surface would serve as part of the foundations. This is contrary to the actual work that would be required, but it was felt that this option was more visible and simpler to understand than the technically correct explanation of tarmac areas requiring more work to clear the existing surface before foundations could be dug. This was borne out by initial play testing, which showed that students quickly arrived at the conclusion that hard surfaces were cheaper to build on.

Planning risk: this was the risk of residents objecting to the erection of the building, and was based on a combination of the height of the building and its proximity to nearby houses

Flood risk: this was risk of a building suffering from flooding in the event of heavy rain. This was based on the surface type and surrounding slope, meaning that a tarmac area with a surrounding slope was prone to flooding, but a grassed area would be less so.

6.7.2.9 Building types & attributes

There were three building types, represented as non-player objects within PaSAT, with *attributes* (see Chapter 4) indicating their base costs, risks, and weightings. Building sites were also represented using the PaSAT system as Locations, again each with a set of attributes indicating weightings that affected costs and risks for buildings erected on them. During play, the game server used these attributes to calculate the costs and risks of buildings placed at particular sites.

The three building types were:

1. Dining hall

2. Media studio

3. Teaching block

Each of these was represented as a non-player object within PaSAT, with three attributes:

1. Base cost: the ‘list price’ of the building, the minimum cost to build it

2. Planning weighting: the impact the building had on any planning risk associated with a building site. Since planning risk was intended to reflect the likelihood of complaints from local residents on aesthetic grounds, this directly related to the height of the building

3. Flood risk: we had initially planned on having different flood risks for different buildings, hence the use of an attribute to represent this factor. However, following initial internal testing we decided to have flood risk as a constant for all building types (but varying between locations – see below).

Table 2: building types and associated attributes

	Base cost	Planning weighting	Flood risk
Dining Hall	100000	2	10
Media Studio	150000	6	10
Teaching Block	250000	10	10

Building sites were represented as Locations within PaSAT, and also had attributes that held weightings used to calculate the costs and risks for buildings erected on them:

- Foundation weighting: this the extent to which the base cost of the building will be affected by additional work required for foundations at the site. This was either 1 for hard surfaces (less impact), or 3 for soft surfaces (high impact)

- Flood weighting: this was the risk due to rainwater collecting at a site and impacting on a building placed there. This was based on whether the site had a hard (high risk) or soft surface (lower risk) and also whether there was a slope leading to the site (the presence of a slope was higher risk, especially if the slope itself was a hard surface that could lead to high levels of water run-off).

- Planning weighting: this was proximity of the site to nearby houses, indicating the increased likelihood of complains from residents the closer the site was to the houses.

The weightings for each building site are shown below in Table 3.

Table 3: building sites and associated attributes

	Foundation	Flood weighting	Planning weighting
Court 1	1	2	5
Court 2	1	2	4
Tarmac 1	1	3	4
Tarmac 2	1	2	2
Tarmac 3	1	5	1
Field 1	3	1	3
Field 2	3	1	1

The attributes held on the Building and Site objects were used to calculate the costs and risks for a given building on a given site.

For example, the costs and risks for building the Teaching Block on Court 1 were calculated as follows:

Base cost (as shown) = 250000

Total cost = base cost * foundation weighting = 250000 * 1 = 250000

Planning risk = site planning weighting * building planning weighting

= 5 x 10 = 50

Flood risk = site flood weighting x building flood risk

= 2 x 10 = 20

Table 4 below shows the costs and risks for each building type at each possible building site.

Table 4: costs and risks for every building type at each building site

	build cost	planning	flood	total cost	total risk
teaching block					
court1	250000	50	20	250000	70
court2	250000	40	20	250000	60
tarmac1	250000	40	30	250000	70
tarmac2	250000	20	20	250000	40
tarmac3	250000	10	50	250000	60
field1	750000	30	10	750000	40
field2	750000	10	10	750000	20
media studio					
court1	150000	30	20	150000	50
court2	150000	24	20	150000	44
tarmac1	150000	24	30	150000	54
tarmac2	150000	12	20	150000	32
tarmac3	150000	6	50	150000	56
field1	450000	18	10	450000	28
field2	450000	6	10	450000	16
dining hall					
court1	100000	10	20	100000	30
court2	100000	8	20	100000	28
tarmac1	100000	8	30	100000	38
tarmac2	100000	4	20	100000	24
tarmac3	100000	2	50	100000	52
field1	300000	6	10	300000	16
field2	300000	2	10	300000	12

As can be seen from Table 4 (above) by looking at the total cost and total risk entries for the different building types, each building had a site where it was very cheap and a site where it very low risk, but these two did not coincide. This meant that players had to find the best fit and decide how they wanted to optimise the placement of buildings. To have a building at low cost, they had to accept high risk, or to have it with low risk they had to accept higher costs. This tendency was present from the initial combination of survey results with the first ideas for the different building types, and required only a slight modification to the values of the cost and risk weightings to produce a set of situations that provided this distribution.

6.7.3 Play testing

After the initial prototype of the game had been implemented using the PaSAT software, we play tested the game with students and staff at the University of Nottingham. This testing indicated that players were able to grasp the underlying mechanics of the game easily, and were able to perform actions in order to progress the game. Even more importantly, we found that the game posed a challenge to the players, and that they were not able to complete it easily without stopping to think about what was giving rise to the feedback they received from their Build and Estimate actions.

To determine the playability of the game, a set of basic testing algorithms were written for the game authoring software that systematically tested all possible solutions for win/lose outcomes, in order to ensure that the chances of winning by random play were significantly lower than winning by intentional actions.

Using the results of this testing, the game parameters were adjusted so that there was approximately a 0.3 chance of winning through chance alone. There were 210 possible ways in which to site the buildings; 62 of these were winning states, 148 were losing states. There are no specific guidelines for adjusting playability at this level;

we aimed to ensure that winning by chance was less likely than winning through intentional action, and then assessed general playability through play-testing.

The game was play-tested with students at the school and with postgraduate students at the University of Nottingham prior to the trials to determine how playable it was and to identify any significant problems the students had with the system. The play tests indicated that the design of the game, the difficulty level, and the interface, were all suitable for the trials. No significant problems were found with the design; minor usability issues relating to placement of onscreen items and sequence of operations were addressed. Following feedback, we made small modifications to the weightings used in the game to emphasise the differences between the riskiest and cheapest sites. Again the weightings were adjusted to maintain the 0.3 probability of winning through chance.

6.7.4 Modifications to PaSAT software

The PaSAT software allowed us to import an aerial photograph of the school grounds and create Locations corresponding to the available building sites. The GPS functionality on main map display proved to be suitable for the game.

We were able to implement the representations required for the BuildIt game by using attributes of objects for Players, Buildings, and Sites. These attributes and their values used for the game are described above.

To implement the Actions available within the game – Build and Estimate – we found that whilst it was possible to use the generic Actions tab on the client interface, this was not the best option for providing optimum usability. We decided instead to use a customised actions screen for the BuildIt game. This was achieved through modification of the source code for the mobile client.

Additionally, we found that instead of having game and player state information available on a separate screen, it was more desirable to have salient status indicators (for funds, risk, and estimates) displayed on the main map screen. This was again achieved by modifying the source code of the mobile client to include onscreen elements that displayed the value of specific attributes.

6.8 Assessing the fit with the identified requirements

6.8.1 Game requirements

The game described above includes all the structural elements described by Prensky (2001):

- Rules: players have limited resources, can only act in specific locations, and can only build one building per site.
- Goals: players must find a way of erecting all three buildings without exceeding their budgets.
- Feedback: the game provides clear feedback on player actions (Build and Estimate reports) and displays the current game state (Costs, Risks, and Estimates remaining).
- Opposition: the opposition is the representation itself, in that only certain combinations of buildings and sites will lead to a win state. The challenge is to discover which ones.
- Interaction: players perform actions that lead to results which are meaningful within the game.
- Story/Representation: players are given the backstory of having to act as project managers to find sites for new buildings at the school.

In addition, we ensured that the core elements of fantasy, curiosity, control, and challenge were addressed. The game has a fantasy backstory by requiring players to act as project managers in a fictional planning exercise. Their curiosity is piqued by the results they receive in response to their actions. They experience control by moving around the grounds and choosing which options to explore, but they are controlled by the game because of the constraints it places on their actions. The challenge posed by the game was carefully assessed during play testing and found to be appropriate for the Year 7 students for whom it was designed (although older players – including teachers – also found it difficult!).

In Chapter 2 we identified explicit failure states as a key component of games that has so far not been used in situated mobile games. Failure was included in the BuildIt game by giving players specific resource limits and by linking game actions to the spending of those resources: players had to think and act carefully otherwise they ran out of resources and lost the game. This constrained resource model is a common game design pattern (for example see Bjork, 2004) and provided us with a clear means to present the players with clear failure states which could not only be seen when they occurred but also predicted by observing when failure was a risk. In this way we used failure and fear of failure as core factors in the gameplay for this BuildIt game.

6.8.2 Situated Learning

Our assessment of the fit with the key characteristics of situated learning environments is based on our identification of four core characteristics in Section 6.4.1:

- Use of an authentic activity and authentic activities: The use of the school grounds for the planning activity in the game provided an authentic environment for the learning experience. In addition, because of the close integration of the game with the physical environment itself, the learner's activities were authentic for that environment. The current context of the school's imminent demolition to make way for a new academy also lent an air of authenticity to the activity.

- Perspective-taking: We designed the game task to require learners to examine multiple factors in interpreting the results of their actions to encourage multiple perspective taking. Specifically, we setup the cost and risk factors so that learners needed to look at both of these aspects before making decisions. Focusing on one factor alone would quickly lead to failure.

- Collaboration: To support collaboration, we required learners to work together and to share a PDA. This meant that any actions they performed and results they received were the results of joint decision making and the PDA itself could act as a focus of their attention.

- Prompting reflection: Providing prompts for reflection was a core goal of this game and of this thesis in general. We designed the game to prompt reflection through failure, the intention being that learners would have to reflect on their actions and determine the underlying causes of the results they obtained in the field in order to complete the game successfully.

6.8.3 Experiential Learning

The requirements for experiential learning identified in Section 6.4.2 are somewhat more general than for either situated or enquiry-based learning. To maintain the experiential nature of the game we tried to focus on the 'all learning is relearning' premise, and designed the game so that learners would receive information that caused them to re-evaluate their understanding of what was going on and to re-assess their explanations of it. The focus of the task to was to discover why certain sites were cheap but risky, and why others were the reverse. Since the reasons for these results were based on the observable, physical environment, this meant that learners had to adapt their understandings to fit with the world, a key part of experiential learning. We also sought to make the experience as direct as possible (in line with Dewey's (1916) assertion that direct learning is better learning) by requiring learners to physically move around the space and by making game results directly linked to the observable characteristics of the physical environment.

6.8.4 Enquiry learning

The core requirements to support enquiry learning were:

1. Some means to collect data and to manipulate variables in some way
2. A reason to interpret those data and draw conclusions
3. A way to test hypotheses formed about the data collected

These requirements were easily fulfilled by the BuildIt game, which offered Build and Estimate actions as a way of gathering data and verifying hypotheses, and a plausible reason for needing to interpret those results in a meaningful framework: learners had to understand the causes of high risks and high costs in order to win the game.

Manipulation of variables was provided by allowing learners to choose where to place buildings and where to collect estimates; this process was the way in which they could affect the state of the game and thus see the results of those manipulations.

6.8.5 Summary: meeting the requirements

Having reviewed the design of the BuildIt game against the requirements derived from the results of related work, learning theory, and game design principles, we were satisfied that the BuildIt game met the requirements described and that it would serve as an appropriate platform for assessing whether a situated mobile learning game could provide specific support for reflection in the field, through the mechanism of game failure states.

6.9 Conclusion

This chapter has described requirements for a situated mobile learning game derived from previous work, learning theory, and the results of Study 1 (described in Chapter 5). We then described the details of the implementation of a mobile learning game, BuildIt, tailored for the setting of the school used for Study 2. We found that in general the PaSAT software as described in Chapter 5 was adequate for the intended game, but some modifications were made to enhance the usability of the game client software for the learners.

This mobile learning game was used as the basis for Study 2, described in Chapter 7.

Chapter 7

Study 2: Exploring the impact of a location-based mobile game on a grounded, field-based learning activity

This chapter describes the second field study, which explored the potential for an interactive mobile game to scaffold students' learning in the field and provided the basis for the development of a grounded theory derived from learner activity in the field.

7.1 Scope of the study

7.1.1 Motivation and goals

We considered the previous study, as described in Chapter 4, as a preliminary investigation of the impact of location-based, interactive learning technologies on students' learning. The results of Study 1 – in line with related work such as Environmental Detectives (Squire and Klopfer, 2007) and Savannah (Facer *et al.*, 2004) – showed that, despite some apparent advantages to being outdoors using the physical environment as a learning space, there were also specific problems that need to be addressed to maximise the potential of outdoor spaces for enabling mobile learning.

In particular, we saw evidence of problems arising from:

i) Lack of coordination of action, and low awareness of goals

ii) Lack of reflection in situ

iii) Tendency towards engagement in surface level task aspects, rather than underlying learning aspects

Using the results of Study 1 as a guide, we designed, implemented, and evaluated a location-based learning game called 'BuildIt' that used the physical environment as a learning resource. The design and rationale for BuildIt is described in Chapter 6.

The intention was to design the game and learning activity to address the specific problems we observed during Study 1. As well as basing the design of this learning game on the results of Study 1, we also drew on previous related work, most notably the Environmental Detectives project (Squire and Klopfer, 2007). In particular, we incorporated characteristics of the physical environment as part of the game based on observations from Environmental Detectives that showed learners were willing and able to integrate observations of the physical environment into their reasoning. We also followed the approach of Dewey (1916) – who asserted that the more direct the learning experience the better – by designing the task to include direct physical interaction with the environment through movement and the collection of data that was directly linked to the learners' current physical location. The intention was to better engage the learners with the actual learning aspects of the task, rather than the surface level features such as movement and performing actions. This approach of tightly coupling the activities required by the game with the activities required by the learning activity map on to the idea of intrinsic motivation and intrinsic fantasy in gameplay, which has been shown to lead to enhanced engagement and learning (for example Malone, 1980; Malone, 1981; Habgood, 2005).

By using the environment as part of the game we are presenting learners with a tangible artefact that maps on to the informatic layer of the game, rather than using the environment as a blank canvas such as in other projects such as Savannah (Facer *et al.*, 2004). Having the physical environment span both the learners' actual field of attention as well as their attention on the virtual game means that affordances for action are immediately more visible: learners can see what is possible because it is all around them, and when they reason about aspects of the game they can see those aspects in the physical environment as well as in the virtual environment of the game.

We wanted to investigate whether incorporating more game-like aspects into the task would enhance the activity and provide additional scaffolds for learners. To date, a number of mobile learning projects have described 'games' that do not actually fit with definitions of games put forward by Crawford (1982), Malone (1980), Prensky (2001), and others (see Chapter 2). In contrast, many projects concerned with delivering games for entertainment, rather than education, have shown great success in attracting and maintaining the attention of learners and in engendering structured, meaningful activity.

The first aim of this study then is to determine whether an interactive game-based learning activity can actually support (scaffold) learning in the field, overcoming problems such as coordination, motivation, and task drift through lack of engagement.

We have also been motivated by a lack of studies in the field seeking to compare situated mobile learning activities with equivalent, non-mobile activities (as noted, for example, by Frohberg *et al.*, 2009). As identified in Chapter 2, theories of mobile learning are still in the nascent phase, and we have relatively little understanding of how learners may behave in rich environments such as school grounds when engaged with technology-enhanced learning activities.

The second aim is therefore to explore the impact on the learning process of the use of handheld PDAs in the field, to indicate areas of success and failure, to guide future development of similar learning using outdoor mobile games, and to generate a grounded theory describing the activity of learners in the location-based game (grounded theory is explained in Chapter 3, and the details of how it was applied to this study are presented in this chapter, section 7.4.2)

7.1.2 Research aims

We adopted a mixed methods approach, leaning towards qualitative exploration of the learning process, so we do not present specific hypotheses but rather open questions to be explored. Mobile learning is arguably a complex field where little is yet known about the phenomena and factors underlying observed behaviour (Cook *et al.*, 2008). Following our difficulties in evaluating the rich and complex behaviour of the learners in Study 1, we reviewed potential research methods and found that grounded theory (Strauss and Corbin, 1998) would offer us the means to explore the behaviour and events arising from a location-based game. This approach fits well with the research methods employed on related projects Savannah (Facer *et al.*, 2004) (episodic, ethnographic analysis) and Environmental Detectives (Squire and Klopfer, 2007) (constant comparative, discourse analysis, grounded theory approach).

Our aims were to explore the potential for an interactive mobile learning game to support learners in the field, and to explain and understand how they came to use that game in combination with the physical environment to complete the game task. These research questions are deliberately open-ended to fit with the nature of grounded theory work; we make some predictions about how we expect the location-based game to enhance the learners' activities, but we do not rely on these predictions or quantitative analysis for substantial findings. Instead, we seek to evaluate the use of the BuildIt game at a number of levels, each of which contributes to our understanding gained from the other levels:

1. Usability and fitness for purpose of the game development and deployment platform: conducted through observation and performance of heuristic evaluations.

2. Observed behaviour and interactions: conducted by coding video footage of learners using the BuildIt game.

3. Grounded theory analysis of behaviour: conducted by following the grounded theory approach to video footage of learners using the BuildIt game.

7.1.3 Rationale

To explore the questions described above, and to progress the work started in Study 1, we designed and implemented a location-based game using the PaSAT system and trialled it at a local secondary school. To provide a means of determining the impact of the location-based game, we also designed a paper-based version of the activity and had a second group of students use this version instead of the PDA version. The paper version was designed to be equivalent to the kind of field-based learning activity that a school would employ rather than the PDAs, not simply an impoverished version the PDA condition. Learners were given the same task but the method of collecting information was different: in the paper version they had booklets which they could use to 'look-up' the relevant information rather than playing the game and obtaining information through game actions (this is covered in detail in section 7.2.4.2).

We employed a mixed-methods approach in the evaluation of this field trial, with an emphasis on qualitative evaluation in the form of grounded theory study of learner activity during the task. Some basic quantitative measures and metrics were also used to provide summary and comparative information for the two conditions, and also to provide an initial guide for the grounded theory analysis.

7.2 Materials and methods

7.2.1 Participants

Participants for this study were students at a secondary school in Stoke on Trent. All students were from Year 7, aged 11-12, and were of mixed ability and gender. All students were highly familiar with the school grounds, having been at the school for the entire school year prior to the trials. Each trial took approximately one hour, and was conducted during normal school hours. A member of staff from the school was present during all trials, and occasionally assisted with data collection by filming the participants using a video camera.

Students completed the activity in self-selected pairs. After exclusions (see below), there were 10 pairs (20 students) in the PDA version, and 8 pairs (16 students) in the paper version.

7.2.1.1 Consent

All participants and their parents were provided with written information about the study and were asked to give written consent prior to taking part. It was emphasised that the study was an investigation into the use of learning technology and not a study of their learning abilities. They were told that they could withdraw from the study at any time without having to give a reason, and that no personal information would be stored without their consent. Specific permission was requested for the storage and use of audio and video recordings for the study, which was stated to include the use of such materials at meetings and conferences, but would not include public use of such materials, for example placing video material on a web site. The information and consent forms are included in Appendix E, F, G, and H.

7.2.1.2 Excluded participants

A number of participants were excluded from the analysis after having taken part in the trials for a number of specific reasons.

Participants (or more accurately pairs of participants) in the PDA condition were excluded on the following grounds:

- Pair 6: rain, technical problems with wireless network
- Pair 7: rain, technical problems with GPS
- Pair 9: technical problems with network connectivity

- Pair 21: no audio, microphone problem
- Pair 14: audio receiver problem
- Pair 15: audio receiver problem

None of the participants in the Paper version were excluded from the analysis.

7.2.2 Design

A between-groups comparative design was used to study the differences between a game-based learning activity facilitated by handheld computers, and a paper-based activity based on the same learning topic but without any technology support.

Students took part in one of the two conditions. All students were initially selected for participation by teachers, and were then given the opportunity to opt-in to the activity (see Consent, above).

Students worked in pairs to complete either the PDA or Paper-based version of the activity. For the PDA version, only a single pair of students took part at any one time. For the Paper-based version, one or two pairs took part at any one time.

Students worked in pairs because we wanted to prompt discussions between them that we could observe. To do this, we asked them to share a PDA, thus forcing them to discuss what they saw. This approach has been found to be successful in a number of recent projects; Cole (2003), and Frohberg (2009) have noted the success of 'tight pairs' in similar projects.

7.2.3 Learning Environment

We describe here the actual physical environment of the school grounds in which the learning activity for both the PDA and paper versions took place. We identify the features of the environment that were significant for the learning activity itself.

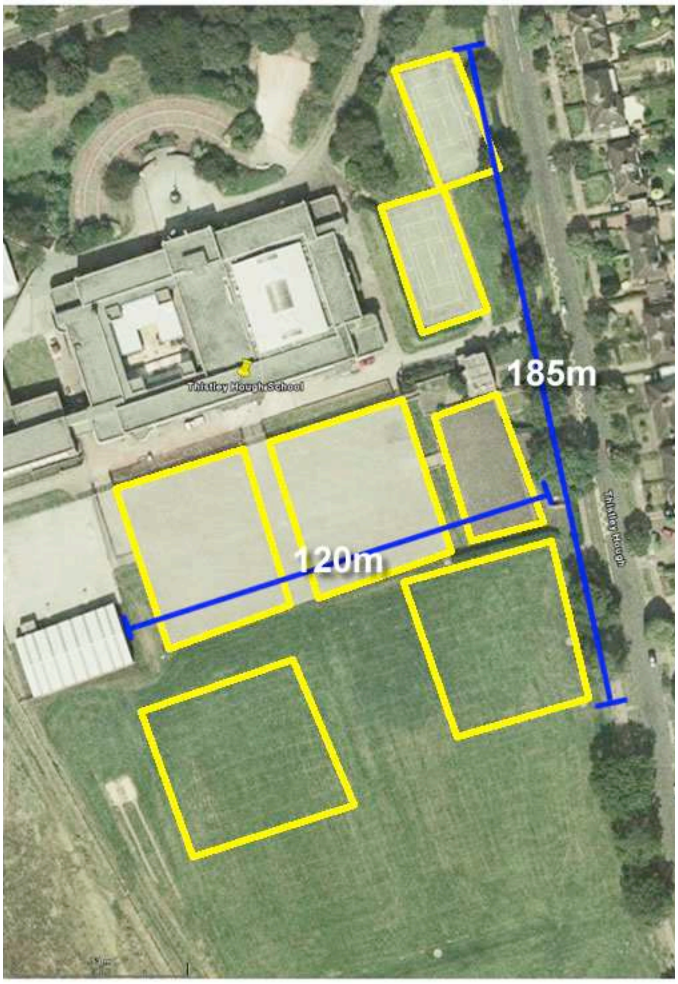

Figure 40: map showing school grounds used for Study 2

Figure 40 (above) shows an aerial view of the grounds where Study 2 was carried out. The areas used for the activity are the rectangular areas marked out in yellow. These areas are located in a space approximately 185 x 120 metres in size, but not all of that area was used (specifically, the school buildings and the front parking area were not used). This meant that all of the salient locations for the learning activity were within the area normally used by the students during recreational periods, or during Physical Education classes.

The school grounds comprise a number of tarmac areas that serve as parking areas, all weather pitches, and tennis courts. There is also a large grassy field used as a sports pitch. The north and east side of the grounds are adjacent to residential properties, whilst the south and west sides are elevated in relation to the surrounding area and are not as close to neighbouring properties. The main tarmac area adjacent to the school, and the field adjacent to it, have an observable incline descending to the west. These observable features of the physical environment were used as the basis for the design of the learning activity for Study 2.

7.2.4 Learning activity

7.2.4.1 PDA version

Students played the BuildIt game as described in Chapter 6. Learners worked in pairs using one PDA (a Mio Mitac P550 with built-in WLAN and GPS) between them. The PDA was running the PaSAT client software, connected to the PaSAT game server running on a laptop.

For convenience, a summary of the game (described in detail in Chapter 6) is provided below.

The object of the game is to find suitable sites on the school grounds for three new buildings. There are seven potential building sites occupying areas where there are currently tennis courts, tarmac, playgrounds, and fields.

Players have fixed budgets for cost and risk, and must successfully place all 3 buildings on 3 different sites without exceeding either of their budgets.

Buildings incur different costs and risks depending on where they are placed. For example, a tall building placed close to nearby houses on one of the tennis courts will be low cost because (in the game) building on existing concrete surfaces is cheaper than building on grass, but it will be high risk because of the risk of complaints from local residents. A building that is less tall will still incur higher costs for building on the court site, but will incur a lower risk of complaints.

Players play the game by moving around the grounds, taking Estimates and Building buildings. Estimates tell them what the costs and risks will be for a particular building at a particular site, whilst Building something provides the same information but at the same actually erects the building and adjusts the remaining budgets for cost and risk accordingly. Players can only take six estimates.

The game is won by successfully placing all three buildings on three different sites without exceeding the limits of either the cost or risk budgets. The game is lost if either budget is exceeded at any time.

7.2.4.2 Paper-based version

To serve as a comparison to the PDA version described above, an alternative version of the learning activity was devised that did not depend on any technological support. The intention of this was to provide a comparison that would allow us to investigate the impact of:

1. Forced movement between physical locations

2. The game task and associated constraints on the learning process

3. The impact of failure states on reflective processes

The paper-based version was thus designed to feature none of these elements, but to offer a plausible and feasible learning activity centred on the same topic, using the same underlying materials. The paper version included all of the same underlying information that was used in the PDA version, the crucial difference being how that information was made available to the learners. The platform for delivering the information was a paper booklet rather than the PDA, and the mechanism by which learners could obtain Estimates and Building Reports was a simple look-up operation using this booklet. There were no constraints on how many times learners could search for information.

The booklet was formatted to show the build and risk costs for a single building at a single site on each page. These costs were formatted in the same way as the reports shown on the PDA. The pages were in a random order, to ensure that learners had to look through the material to find what they were looking for.

Media Studio	**Court 1**
Basic Cost	150000
Extra For Foundations	0
Flood Risk	20
Planning Risk	30
Total Risk	50
Total Cost	150000

Figure 41: example page from paper booklet showing risks and costs for Media Studio on Court 1

The paper booklet also included a map of the area, which was exactly the same size and resolution as the overview map displayed on the screen of the PDA, and a page showing the details of each of the buildings to be built including height and base costs.

A worksheet (see Appendix L) was provided with three areas for learners to indicate the sites they had decided on for each of the three required buildings. They were encouraged to use this worksheet to take notes and it was stressed that they could change their minds, thus further weakening the game-based constraints present in the PDA version.

It was difficult to decide on the exact characteristics of the paper-based version, and numerous alternatives were considered. For example, the booklet could have contained a larger scale map providing more information about the sites, or the information could have been presented as a single table allowing learners to inspect the different costs and risks for sites and buildings. For the map we decided that this would provide additional information to learners that was not available (or was less accessible) in the PDA version. For the information presentation we decided that the process of sifting through information rather than being able to directly compare figures was important, since presenting the information as a table would change the nature of the task significantly.

As with the PDA version, this version of the task was designed in consultation with a teacher (Mr Ian Watts) at the school, and was tested for usability using a group of naïve users at the University of Nottingham. Neither the consultation nor the usability tests suggested any difficulties with using this particular version of the materials, and Mr Watts agreed that this paper booklet represented the kind of materials that could be used on a field trip that did not use PDAs to perform the task.

7.2.5 Data collection and analysis

We employed a mixed methods approach in the evaluation of this field trial, with an emphasis on qualitative analysis in the form of grounded theory.

7.2.5.1 Levels of analysis

The use of the PDA-based learning game and the paper-based comparison condition were analysed at a number of levels, as outlined below.

7.2.5.1.1 Usability and fitness for purpose

Notes were taken during the development, deployment, and use of the BuildIt game to allow a heuristic evaluation of the system in relation to building a mobile learning game that could scaffold learner activity.

7.2.5.2 Activity codes and quantitative analysis

For coding purposes, the video footage was divided into 30 second segments. This was preferable to coding every instance of activity, because of difficulties determining whether multiple instances counted as separate or the ongoing instances. (For example when planning was interrupted by another activity and the planning continued on the same line of thought is this the same instance or a new one?). Since the aim was to gather evidence, the actual proportion of time in each activity was important, so did not want to over-state the presence of codes by using multiple instances. Also, this would lead to greater chance of inter-rater disagreement. Operationally, it was very hard to distinguish individual events, so instead the protocol was to code for presence of at least one instance in a 30 second block. This meant that sometimes multiple instances that could have been coded separately got grouped together, but this conservative approach was deemed more appropriate and easier to manage.

7.2.5.2.1 Grounded theory analysis

We followed the grounded theory method to analyse the behaviour of learners in the PDA condition, coding the video footage of their activities in an iterative but non-linear way and developing categories that described clusters of behaviours. We were then able to group these categories together to determine how they were related to one another, and to derive a theory that explained learner activity observed during this trial that was *grounded* in the data collected during the study. The grounded theory approach is summarised in Chapter 3, and the details of how it was applied to this study as presented in section 7.4.2.

7.2.5.3 Data collection in the field

Video and audio recordings were made of learners in the field using handheld video cameras and wireless tie-clip microphones. All video tapes were later transferred to hard drive for use in analysis packages and for archiving.

Recording was carried out by the researcher and by a member of technical staff at the school.

7.2.5.4 Triangulation of results

The use of multiple methods means that we are able to *triangulate* our results and explore support (or lack thereof) for different interpretations and conclusions relating to learner activity. This technique is frequently used, especially in studies using qualitative approaches, to ensure that interpretations are valid and that alternatives are not unduly discounted. There are several types of triangulation available to qualitative researchers, as identified by (Denzin, 1978). In this case we are applying *methodological triangulation*: using a range of different methods to crosscheck and validate results.

7.2.6 Technical set-up

7.2.6.1 PDAs

The BuildIt game was played using handheld computers (PDAs) in the school grounds. The game activity was developed using the PaSAT framework (see Chapter 4), with some modifications (mainly on the client side) to implement functions specific to this activity (see Chapter 6). The PDAs used were the Mitac Mio P550s, with built-in GPS and WLAN connectivity, running Windows Mobile 5, .NET Compact Framework 3.5. We used 10 PDAs in total, which were kept fully charged. When the battery was discharged participants were given another PDA to continue the activity.

7.2.6.2 Wireless coverage

As described in Chapter 4 the PaSAT system uses a client-server architecture, with the game state and rule engine maintained on a server (a laptop in this case) and mobile client software running on PDAs that can connect, display a map of the current area with learner location highlighted, show current game status information, and allow the learner to invoke in-game actions.

Wireless network coverage was provided for the whole playing area using three commercial-grade access points that supported roaming. As players moved around the grounds, the access points automatically performed hand-overs of the connection, providing seamless wireless connectivity for the game. This was mostly transparent to the users, who experienced reasonably reliable wireless connections from their PDAs.

Due to the layout of the site, the access points could not be placed to provide a seamless network using only wireless connectivity, hence network cables were required to connect the access points in a radial configuration using a separate network hub to provide a closed network. Each of the access points was connected to the central network hub using standard ethernet cable. Power was provided to the access points using Power over Ethernet (PoE) adapters that delivered low voltage power through the same cables used for the network connections.

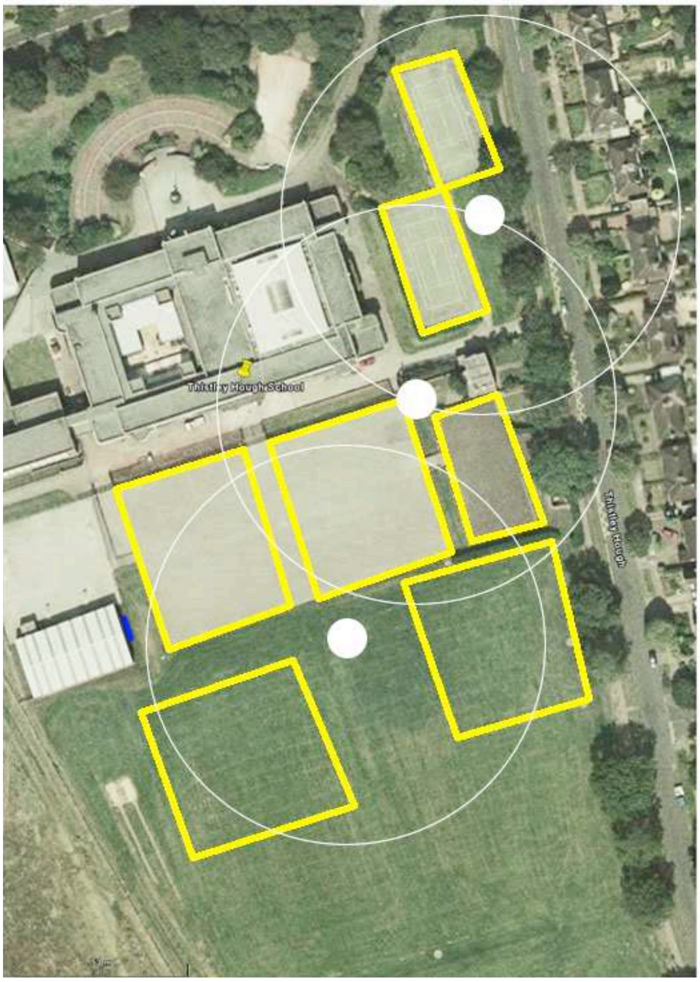

Figure 42: map showing school grounds with locations of wireless access points

Figure 42 shows the location of the wireless access points used in Study 2. This configuration was determined by initial testing of the wireless coverage and identifying areas not adequately covered by the access points. A modification was required in order to ensure coverage between the tennis courts (top left) and the main tarmac area adjacent to the school building (centre).

7.3 Quantitative results

7.3.1 Movement

Movement during the task was recorded in the system logs that included a log of which game square the PDA was in. These logs were then analysed to show specific locations over time, with time spent in each location also recorded. Movements between individual game squares were not analysed, only movements between locations, in the case of BuildIt this meant the building sites.

For the Paper version, movement was logged by reviewing the video footage and noting when the players moved from one location to another. Logs were then constructed for the paper version in the same format as those generated by in the PDA version.

A Man-Whitney U test showed that learners in the PDA condition visited significantly more sites (mean 5.1) than learners in the paper version (mean 2.75) ($U=6.5$, $n1=10$, $n2=8$, $p<.001$ one-tailed). However, there is a caveat to this result in that it must be re-iterated that learners in the PDA version were *required* to move to different locations in order to perform game actions, whereas learners in the Paper version were not required to move.

The actual movement of the learners needs to be considered along with the *activities* they were performing, what phase of the activity there were in, what prompted them to move, and how they reacted when they arrived at a new location. This level of analysis is provided by the grounded theory analysis in Section 7.3.4.

7.3.2 Video coding and Activity codes

7.3.2.1 Developing the coding scheme

The coding scheme for the video footage was developed by first identifying the specific types of phenomena that we wished to code, to allow us to perform a meaningful comparison between the two conditions. As well as giving us quantitative information about the presence of particular behaviours and events, this coding process was also intended to serve as the line-by-line coding required for the open-coding stage of a grounded theory analysis.

As the footage was viewed and analysed, it transpired that the codes from this scheme were more descriptive than required for grounded theory work, and so this coding eventually guided a second open-coding process on segments of footage that this coding scheme suggested were appropriate for further analysis. Line-by-line coding was performed in the second phase, described in Section 7.4.2.

We first of all identified possible aspects that would be appropriate to code:

- Learning behaviours
    - Planning
    - Reflection
- References to the environment
- Movement
    - Setting off
    - Arriving
- Directly observable game actions
    - Building
    - Estimating
- Responses to events and states
    - going bust
    - winning

After identifying these groups, we began by coding 10% of the available footage to determine the suitability of this scheme. Two samples were taken for each pair, the first sample at 1/3 of the way through, the second at 2/3 of the way through. We found that the groups identified were appropriate, but some additions were required to fit with the exact behaviour of the learners. The additions made to learning behaviours were:

- Learning behaviours:
    - Asking a question

- Agreement
- Discussion
- Suggesting a theory
- Testing a theory
- Response to failure (or perceived failure)
- Receiving a prompt
- Taking notes

We found that learners made references to things other than just the environment, so a new References category was created:

- References:
  - Environment
  - Task constraints
  - Buildings
  - People
  - Materials

We found that learners made physical gestures during the activity:

- Gestures:
  - Pointing to a location
  - Physical indicator (of size or relative position)

We also found that during the task learners made use of information that was drawn from several sources:

- Sources:
  - Knowledge (pre-existing)
  - Task knowledge (obtained during the task)
  - Notes
  - Partner
  - Teacher

- Researcher

Finally, the tools that learners made use of were coded:

- Tools:
  - PDA
  - Worksheet
  - Paper

For ease of coding, these codes were then grouped into Activities, Sources, References, and Tools.

During coding, dependencies between these codes were discovered (for example, a Question activity often required a Source and a Target), so the coding scheme was slightly modified for use with Nvivo to clarify some aspects of the observed behaviours.

The complete, finalised coding scheme is included in Appendix I.

After modifying the coding scheme, we coded another 10% of the footage, and found that no further modifications were required.

7.3.2.1.1 Segmentation

It became apparent that trying to code the exact timings of actions, behaviour, and phenomena was difficult, and actually not required for the analysis of this study. We decided instead to code the video footage as discrete 30 second segments, stating for each segment which codes were present. The exact timing of the codes was deemed unimportant. This meant that it was easier to perform a comparison of codes for inter-rater reliability (see below) and that the coding process was much easier to perform than if we had required the exact timings for each code.

It should be noted that although the coding scheme was developed primarily to code behaviours and activities present in the PDA condition, it was of course a necessity that the scheme also adequately described the behaviours and activities present in the paper version. No behaviours or activities were found to be present in the paper version that were not adequately represented by the coding scheme – this was also the opinion of the independent rater who had also viewed footage from both conditions.

This coding of the video was performed using the Digital Replay System (Crabtree, 2009). A screenshot of this system showing codes being added to the footage is included below in Figure 43 below.

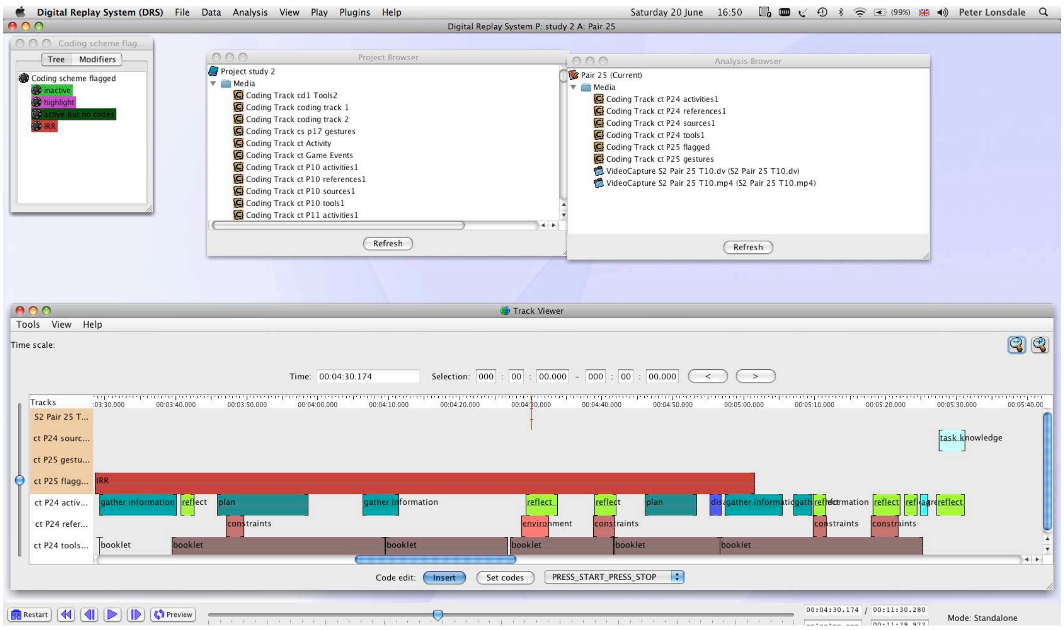

Figure 43: Digital Replay System being used to code video footage

7.3.2.1.2 Summary descriptions of salient codes

Appendix I contains a complete description of the codes used to note the behaviours and activities observed during the trials. To aid discussion of these codes in the following analysis, we include here (Figure 44, below) summary descriptions of the codes that are most salient for this discussion.

Planning/Reflecting	Planning: talking about actions to take, deciding on what they should do next, making suggestions about what to do without any reflection. Reflecting: talking about what they have seen, or what they know, what has happened, without any planning. Operationally it was very difficult to separate planning from reflection, so although they are coded separately in some instances, they are considered together for most of the analysis
Ask a question	asking a significant question that requires an answer before they can continue, not part of general discussion/planning/reflecting
Estimate	using the PDA to obtain an estimate (in paper version, calculating the cost or risk of putting a building in a particular location)
Build	using the PDA to build a building (in paper version, calculating the cost or risk of putting a building in a particular location, and writing it on the worksheet)
React to game event	a direct response (positive or negative) to a build or estimate action, immediately following the action, and not characterised by planning, reflecting, or discussing. eg. "Oh no that's really expensive"

Agree	a significant agreement on a course of action or assessment of information or situation, ie not a simple "yep" during discussion, but a substantial agreement following a disagreement
Disagree	a significant disagreement on a course of action or assessment of information or situation, where one partner shows firm disagreement with what their partner suggests
Suggest theory	a suggestion about the underlying mechanics of the task, ie why a building is expensive or risky in a particular location
Test theory	performing an action (estimate or build) intended to directly test a theory previously stated
Form a goal	deciding on a goal that needs to be achieved to progress in the task
Gather information	gathering information (costs, risks, environmental characteristics)
Arrive	arrival at a new location (for paper version, arrival at a new location was not as significant an event, so it was coded as they stopped moving to perform an activity, such as discussion etc)
Response to failure (or threat of failure)	a direct response to a game event they perceive as failure, such as an estimate or build showing more cost or risk than they expected

Prompted	being prompted or given information by a teacher or researcher that helps them to move forward or make a decision. May be in response to a question, or spontaneous prompt. Prompting does not include provision of basic info that is generally available for the task, ie reminding them what to do, how to do it etc
set off	setting off heading for another building site
Take notes	taking notes during the task (for the paper version, this is writing their answers on the worksheet – no pairs took other notes during the paper version)

Figure 44: selection of code used in the video coding process

7.3.2.2 Inter-rater reliability

The reliability of the coding scheme developed for use with the footage from Study 2 was explored by asking an independent rater to use the coding scheme and comparing their codes to those of the researcher. Approximately 10% of the total footage was used for assessing this inter-rater reliability, spread across all participants in both conditions.

The coding scheme that was developed for the video footage included codes representing a range of different behaviours, including i) directly observable behaviour, ii) actions within the game, iii) behaviours consistent with learning activities, and iv) spoken references to aspects of the task and the environment.

With such a range of codes, we expected initial disagreement between the raters, since not only did the particular meaning of codes need to be established but also how to apply the coding scheme and to ensure that all appropriate codes were used at appropriate times. Below we review the process used to assess inter-rater reliability and the steps taken when disagreement was found.

7.3.2.2.1 Clustering over-lapping codes

After the initial session of coding by the independent rater, the two coding sets were analysed for concordance using Cohen's kappa (Cohen, 1960). Kappa provides a measure of agreement between two raters by taking into account the observed agreement and the agreement expected by chance. This analysis suggested that there were particular areas where agreement was low between the researcher and the independent rater. Steps were taken to investigate the cause of this disagreement, and to determine whether the disagreement could be resolved, or whether the coding scheme needed to be modified.

The first step was to ensure that codes that actually referred to overlapping phenomena were clustered together. This was true for codes referring to planning and reflection. Three separate codes were originally in use to represent these behaviours, even after it had been determined that planning and reflection were operationally impossible to separate in the footage. Kappa values for these three codes were very low. After clustering the codes together, the kappa value was higher, but still indicated significant disagreement between the raters.

Closer inspection of the type of disagreement indicated that, for the PDA condition, disagreement mostly arose when the independent rater stated that planning and reflection behaviour was present when the researcher had not. This appeared to indicate conservative coding on the part of the researcher, and after discussing the relevant video segments agreement was reached between the researcher and independent rater that yielded a kappa value of 0.6457 (for the original 10% of the video used for the inter-rater testing) for codes relating to planning and reflection in the PDA version. Since this is higher than the generally accepted value of 0.6 for kappa, the agreement between coding for these segments was deemed to be adequate, and we concluded that the coding scheme and coding by the researcher were appropriate for the study.

For the Paper version, disagreement was of the same nature: the independent rater stated the presence of planning and reflection activities where the researcher did not. In this case, conservative coding (that is *not coding* the presence of a behaviour) on the part of the researcher was *not* desirable, since for comparison purposes we do not wish to have any negative bias on the presence of planning and reflection in the Paper version. The video segments where the raters disagreed were reviewed and in most cases agreement was reached on the presence or absence of planning and reflecting behaviour. This led to a kappa value of 0.5714 (for the original 10% of the video used for the inter-rater testing). This below the desired minimum of 0.6, but was not felt to be a crucial factor since the comparison of codes between conditions forms only one part of the analysis of this study.

7.3.2.2.2 Coding game events

In other cases, we found that disagreement was present because of the occurrence of game events that were visible to the researcher (who was extremely familiar with the game activity) but which were not immediately visible to the independent rater. After clarifying the indicators of these activities with the independent rater, kappa values of 1 were achieved for all codes relating to in game activities. There were no cases where the researcher had stated that a game action had occurred when in fact it had not, but there were many cases where the independent rater had not been aware of the performance of a game action.

7.3.2.2.3 References to the environment, materials, and task constraints

References to the physical environment, the constraints of the task and the materials at hand (such as the PDA or paper booklet) were also important phenomena so agreement was closely inspected for these codes.

In many cases, when the video segments were reviewed, we found that the independent rater had simply not used the codes as they felt that what was being coded was adequately represented by the use of other codes. In other words, their application of the coding scheme was the issue, not fundamental disagreements over whether a phenomenon or behaviour was present. We reviewed all the segments where the raters disagreed and after discussions reached agreement on most segments, giving kappa values ranging from 0.639 to 0.4828. Again, since this coding of observed behaviour is only one aspect of the analysis for Study 2, we felt that these values were acceptable.

7.3.3 Comparing codes between PDA & Paper conditions

We performed a series of statistical tests to determine whether there were significant differences between the PDA and Paper versions of BuildIt. Since this was an exploratory, open-ended study, we do not present any specific hypotheses relating to the analysis of the activity codes. However, based on related work we expected that in most cases the PDA would lead to a richer learning experience and hence a greater incidence of the activity codes.

We compared all codes between the two conditions and we report here only results where significant differences were found, or where it is meaningful to report no difference. We do not report the majority of cases where no difference was found.

Appendix M contains a full listing of the frequencies of all observed codes across both conditions showing descriptive statistics including means and standard deviations.

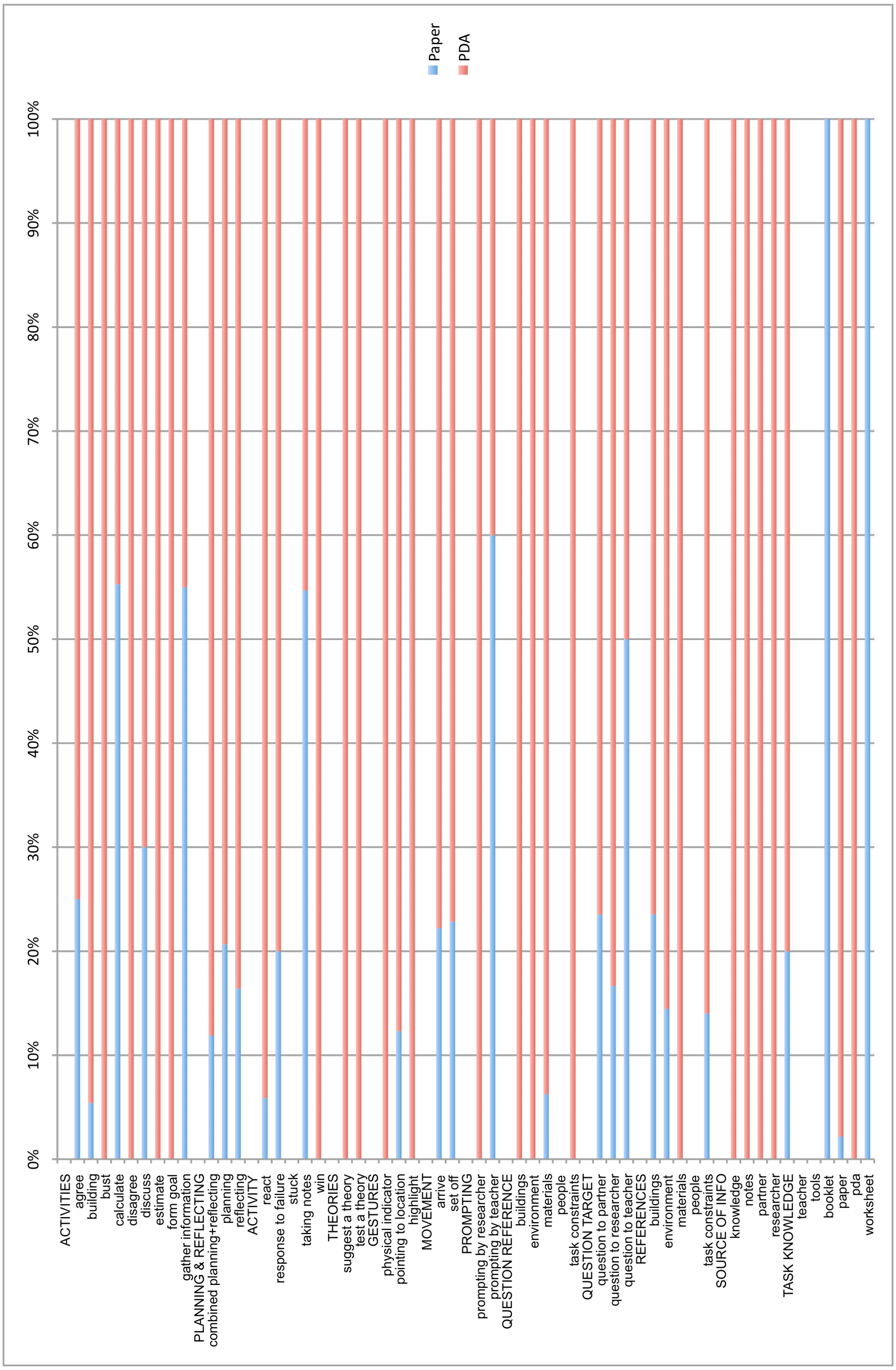

Figure 45: activity codes in PDA and Paper versions, shown as percentages of total observed codes

Figure 45 (above) shows a graphical representation of the incidence of the codes between the two conditions, PDA and Paper. As we can see from this chart, in most cases the observed codes appear to be more prevalent in the PDA condition. In this section we consider specific codes that are significant to our analysis, and present statistical evidence where appropriate. These statistical tests do not comprise the central focus of our evaluation of the BuildIt game, so we do not attempt to draw overly specific conclusions from these results. These results are mainly useful in highlighting the differences between the PDA and Paper versions and in focusing the grounded theory analysis later. Additionally, we draw on these findings in the Discussion later to triangulate our results and critically assess our grounded theory analysis.

In all reports of statistical tests below, p values are indicated as being less than 0.05 or 0.01. In many cases, specific comparisons between conditions using statistical tests are not useful because of low frequencies. We have not reported these tests. In all cases, the sample sizes are n_1=10 (PDA condition) and n_2=8 (Paper condition), and the significance levels are for two-tailed tests. The data used for these tests were the raw frequencies of the occurrence of the behavioural codes derived from the video footage. These frequencies were assumed to be ordinal data, and so non-parametric tests (Mann Whitney U) have been used.

7.3.3.1 Evidence of Planning and Reflecting

A Mann-Whitney U test comparing the incidence of all planning and reflecting codes between the two conditions, PDA and Paper, indicated there were significantly more incidences of planning and reflection in the PDA version ($U=8.5$, $p < .01$). The median number of incidences was 23.5 PDA version, 5.5 for the Paper version.

We also looked at the correlation between planning and reflecting activities and the incidence of references to the environment, task constraints, and materials. We found that there were significant, meaningful correlations in all cases except planning and reflection and references to the materials. There were too few references to the materials in the PDA condition to provide a good basis for performing a correlation.

It is important to note that whilst Planning and Reflection were originally coded as separate activities, we found during the course of the analysis that Planning and Reflecting were very difficult to operationalise distinctly, and so it made sense conceptually to combine these codes for the subsequent analysis. For this reason, Figure 45 (above) shows data for Planning, Reflection, as well as Combined Planning & Reflection.

7.3.3.2 Active engagement versus search

Comparisons indicated that there were significantly more incidences of gathering information in the Paper version ($U=10$, $p < .01$, medians 2.5, 5). The median number of incidences was 2.5 for the PDA version, 5 for the Paper version. This, considered along with the lower incidence of planning and reflection in the Paper version, suggests that learners were more involved in a data gathering, search-type task than in the PDA version. Further support for this is found in learners' significantly greater tendency to take notes in the Paper version ($U=16$, $p < .05$, medians 0, 3).

By contrast, learners with the PDA showed significantly more engagement with the environment, through pointing to the space around them ($U=9.5$, $p < .01$, medians 6.5, 0.5), and making references to the environment itself during their planning, reflection, and discussion ($U=10.5$, $p < .01$, medians 6.5, 0.5).

The PDA version also led to more incidences of suggesting theories about the underlying mechanics of the game – learners using the PDA demonstrated significantly more evidence of forming theories than in the Paper version ($U=12$, $p < .01$, medians 1, 0).

Learners in the PDA condition also demonstrated more ‘pointing to location’ ($U=9.5$, $p < 0.01$, medians 6.5, 0.5) but there was no corresponding difference in ‘physical indicators’.

7.3.3.3 Affective engagement

It seemed that the PDA version also led to more engagement in the affective sense – learners using the PDA were more likely to exhibit an emotive reaction to obtaining information during the course of the task ($U=3$, $p < 0.01$, medians 3, 0).

7.3.3.4 References during Planning and Reflection

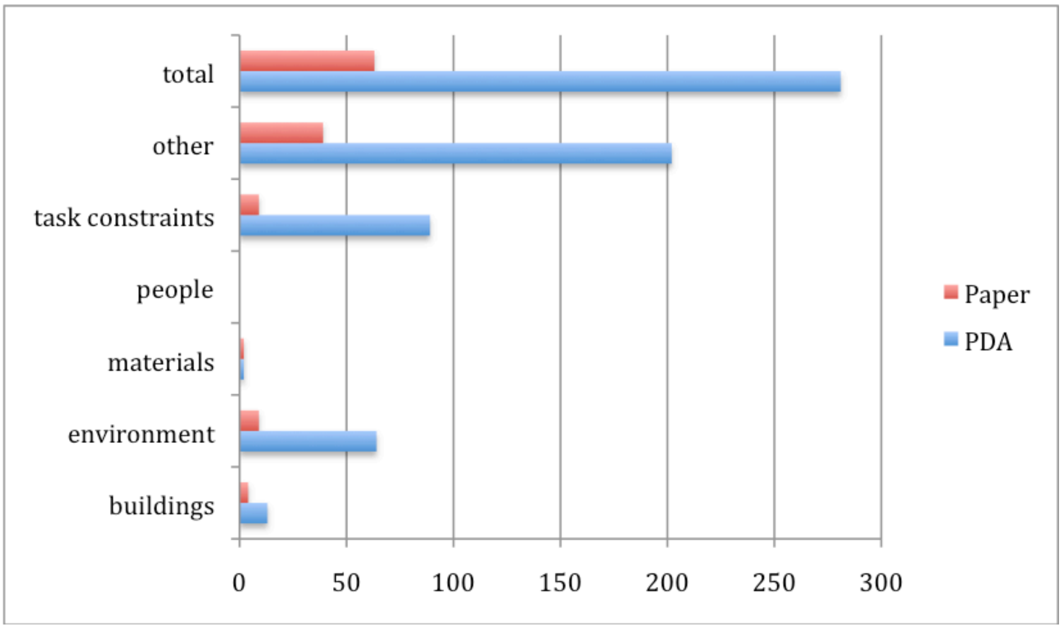

Figure 46: chart showing co-occurrence of Planning/Reflection with references to other factors

Figure 46 (above) shows the incidence of references to task constraints, people, materials, the environment, and in-game buildings made by learners whilst they were engaged in planning and reflection, for both PDA and Paper conditions. As can be seen, learners made more references to task constraints and the environment in the PDA condition than in the Paper condition.

The ‘Other’ category included in Figure 46 represents any instances of planning and reflection where there was no clear reference to task constraints, materials, people, or the environment. This type of planning and reflection was not explicitly coded – the totals for the ‘Other’ category shown above were calculated by subtracting the number of instances that contained salient references from the total of all of instances of planning and reflection. These were instances of generic planning activities, for example where learners suggested possible sequences of actions, but which did not refer to elements of the task itself as seen in other instances. For example, instances where learners made comments such as “Shall we go that way?” or “Let’s do this one now” followed by discussion were evidence of planning where there were no explicit references to the task constraints, the environment and so on. Most of these instances appear to be instances of planning. Since these instances were not coded explicitly we do not have exact figures, but a review of a number of these instances suggests that they were mostly instances of planning. Reflection appeared far less likely to occur without reference to task constraints, materials, people, or the environment.

Man-Whitney U tests indicated that environment ($U=9.5$, $p < .01$) and task constraints ($U=17.5$, $p < .05$) were significantly more likely to co-occur with planning and reflection in the PDA version than with the Paper version.

This suggests that, as well as the PDA version leading to more planning and reflection in general, the environment and task constraints may have played a role in prompting those discussions, although these results are merely suggestive since we do not have evidence of causality.

7.3.3.5 Learning Cycle

We found significantly more incidence of a Plan-Act-Reflect cycle in the PDA condition than in the Paper version ($U=4.5$, $p< .01$, medians 10, 0). This was tested by clustering codes in Nvivo into Plan, Act, and Reflect, and then running a query to determine instances where these codes occurred in sequence within a two-minute time period.

We used a two-minute interval because a review of episodes of activity within Nvivo indicated that the majority of groupings of activity codes occurred within periods lasting between one and two minutes. This interval thus seemed to be a suitable threshold to use in order to prevent the query returning false results based on sparsely distributed codes.

7.3.3.6 Coding items showing no differences

There were no significant differences between the PDA and Paper versions in terms of how much prompting they received, or the questions they asked and where those questions were directed.

Figure 45 (p241), which shows coding instances proportionally between the PDA and Paper conditions, suggests that there were differences observed for these coding items, however the observed frequencies and number of cases were too low for a sound statistical comparison to be made. The data (represented as percentages) are included in Figure 45 (p241) for completeness.

7.3.4 Post-task questionnaires

A post-task questionnaire was distributed to the students to gather feedback and to gain an indication of their recall of the task. However, the return rate was too low to justify any analysis of the results from this questionnaire. Despite our best efforts, only three students from the PDA condition responded, and only one from the Paper version.

7.4 *Qualitative results*

7.4.1 Analysis tool: Nvivo

When beginning the qualitative phase of analysis, we found that the Digital Replay System used to develop the coding scheme used above was inadequate and somewhat unwieldy for the analysis we wished to perform. In particular, the means by which codes could be inspected and modified were quite limited, and did not lend themselves to a more in depth qualitative analysis. For grounded theory work, it is important to have a way of easily querying the data and generating new codes and categories on the fly.

We decided to use Nvivo (QSR International, 2009) instead for the qualitative phase of the analysis, a CAQDAS (Computer Aided Qualitative Data Analysis Software) tool that has been used for many years by qualitative researchers and which now offers the means to work with multiple video sources and to develop rich sets of codes required for grounded theory work. Whilst Nvivo does not expressly support the development of grounded theory, it does allow working with codes and data at the required level, and as such is a popular tool for researchers wishing to develop grounded theory (for example Pace, 2003; Bringer *et al.*, 2006).

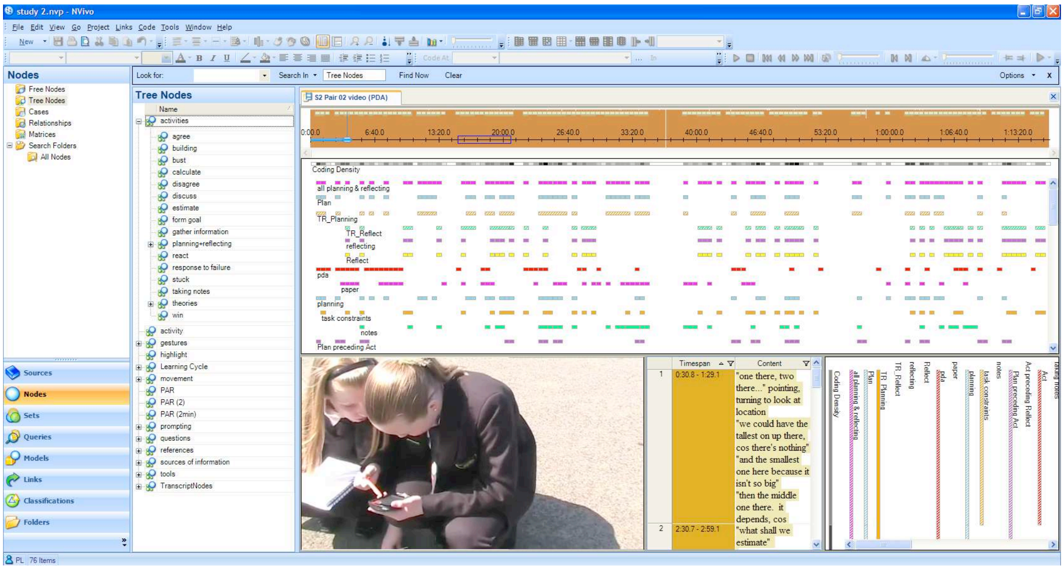

Figure 47: Nvivo being used to annotate video with codes

7.4.2 Grounded theory as applied to this study

We describe here the general process used to apply grounded theory to this study. Although this process is presented as a number of stages, each of which is dependent on the preceding stages, it should be remembered that grounded theory advocates moving between stages where appropriate to further explore, examine, and interpret the data. The sequence presented here is to give a guide to the overall shape of the process, and further details are provided below about some of the shifts between stages. However these were often too subtle to record and document. Grounded theory is very much intended to be a flexible approach, which can and should be tailored for the particular research study it is used for. Here we outline how we applied grounded theory to the analysis of learner behaviour in the BuildIt trials.

7.4.2.1 Process

We focused primarily on the PDA version for the grounded theory analysis, since this version of the activity is the one that employs new techniques for engaging the learner in field-based learning, with few existing accounts available in the literature and even fewer grounded theory accounts. Where appropriate, we make comparisons to the

Paper based version, using data from the Paper version to support our ideas or suggest alternatives.

We began by performing selecting segments of the video footage obtained from the field trials to use in the grounded theory analysis. These videos were not analysed in their entirety using grounded theory, instead specific segments of the footage were selected for analysis by using the coding scheme developed earlier as a guide. Since all video footage was already present when the grounded theory analysis was begun, the process of selecting segments from this corpus of footage comprises the *data collection* part of the grounded theory process presented here.

Grounded theory holds that the researcher is most familiar with the data and hence their ideas about what is important form a crucial part of the analysis (Strauss and Corbin, 1998). Having been present during the actual field trials and being familiar with all of the video footage available, our interpretation was that episodes of planning and reflection were the most salient, at least for a first analysis, and hence these segments were chosen for the grounded theory analysis. Using Nvivo, we were able to easily pull out these segments for use in this analysis. All segments that had previously been coded as featuring some aspect of planning and/or reflection were used; none that met these criteria were excluded.

Once segments had been selected, they were transcribed and descriptive notes were taken (NB these were not codes, these were descriptive notes) to preserve the richness of what was taking place. This was done to minimise the need for the researcher to re-watch the footage during the analysis, but the footage was reviewed later when appropriate and necessary, for example in the selective coding stage (see below).

Grounded theory analyses typically start with a transcript as a data source. However, for this study, we wanted to maintain the source video footage as our data, for two reasons. Firstly, we did not wish to transcribe the video footage in its entirety – there was a lot of material that was effectively noise, and so it made more sense to selectively code the video footage rather than produce a transcript for the whole session. Secondly, the raw footage contains information that cannot be rendered effectively in a transcript, such as the non-verbal interactions between learners, the gestures they make to the environment, and their actual physical movements. We wanted to preserve these aspects of the footage and so all data analysis was done using the raw footage itself, with transcripts for specific segments serving only as a guide after the footage itself has been inspected.

Following the initial data collection phase, we performed open coding on the data to identify *categories*. In grounded theory, *category* is the term used to refer to an event, phenomenon, or other occurrence in the data that we wish to represent with a code.

The open coding was performed by reviewing the transcripts and notes from the video footage and analysing the discourse and events for meaningful categories. When a category was identified, this was coded by taking a note of the name of the category in the notes section of the transcript, and using Nvivo's "code in vivo" function to create a new node (or use an existing node with the same name) for that category.

At the end of this the open coding process, we had identified 157 different categories from the data. These categories are presented in list form in Appendix J. Some illustrative examples are given below in Figure 48:

decision making

definite stop

devolved choice

diffused responsibility

disappointment

disbelief

disproportionate thinking

elimination

embarrassed

Figure 48: examples of codes from open coding phase

It must be emphasised that, in line with the grounded theory approach, these codes were generated purely from the data and not according to any expectations or predictions related to the data. Undoubtedly the experience of the researcher in designing and running the trials that gave rise to the data leads to a colouring of the interpretations offered, but the actual generation of codes at this stage was done in a grounded fashion, noting what was taking place and the meaning behind it.

Open coding was followed by axial coding, whereby categories are examined to determine how they group around dimensions central to those categories, and in particular looking at whether similar categories referred to the same concept or were in fact distinct.

Where categories were similar, they were grouped together into clusters, sometimes using one of the existing categories as the group name or, if more appropriate, creating a new category to contain the grouped categories.

Where categories were distinct enough to suggest two or more groups should be used, the source material was revisited in order to determine the salience of the different groupings and the specificity and usefulness of the codes arising from the open coding. As a rule of thumb, categories that occurred fewer than three times in the entire dataset were set aside (but not deleted), and categories that occurred more than six times were highlighted for further examination. Note that these guidelines were not followed arbitrarily – in cases where a particular behaviour or activity appeared significant even if it occurred only once or twice it was reviewed in line with the non-linear approach to grounded theory analysis.

An example of how the process of developing a grounded theory is non-linear is found in our exploration of the results of game actions. Open-, axial-, and selective coding suggested that learners responding to the results of game actions was a significant category to explore. The original focus of the open-coding process was video segments that featured planning and reflection, and it transpired that many of these included responses to game actions. However, not all instances of game actions had been explored, so we returned to the video footage to selectively explore instances of game actions that were not included in the original open or axial coding process. This gave us a chance to explore the notions being developed relating to learners' responses to the results of in-game actions.

The process of selective coding, which typically 'follows' axial coding, is intended to allow the researcher to 'test' their theories and observations by returning to the dataset from which the model is being constructed and looking at how well the current model fits with specific cases and instances within that data. The intention is to actively look for cases and instances that do not fit, to help refine the model.

Saturation is the stage in grounded theory when no new codes arise from the data, and the codes generated so far are assumed to be adequate for describing phenomenon seen so far. During the grounded theory analysis of the BuildIt trials, we found that no new codes arose after we had analysed six of the 10 PDA trials. No further codes were discovered after this point for either PDA or Paper versions. This does not mean that there was not further refinement of the codes that had been developed, but no new categories were identified within the data that needed exploring *for this particular study*.

7.4.2.2 Structure: theory as narrative

When writing up grounded theory studies, the write-up typically follows one of two general styles (Wolcott, 2001). *Method-as-narrative* uses the actual process of performing the grounded theory analysis as a framework for the write-up, describing the development of categories and how they relate to one another. We have opted to use the *theory-as-narrative approach*, using the actual categories identified as a framework for our discussion and discussing their development only where necessary for elaboration.

7.4.3 Grounded theory analysis

7.4.3.1 PDA version

7.4.3.1.1 Process

After clustering and grouping the large number of categories identified in the open-coding, we found that categories fell into three main groups, with a fourth category that wove through all the data and related to all the other categories. This fourth category that linked the others is referred to in grounded theory as the *core category*.

Establishing a core or central category is a required part of the grounded theory process. The core category or process is expected to occur throughout the data analysed and to relate to most, if not all, of the other categories identified. The core category is essential not just for the development of the grounded theory itself, but also forms a central part of writing-up the findings from a grounded theory analysis and presenting them to others.

7.4.3.1.2 Core category for the PDA version: Choosing

To identify the core category, we took a step back from the low level analysis and re-visited the original footage, asking "what are they doing?" at a higher level. Ignoring the details of how they were performing the task yielded different concepts such "making decisions", "deciding" and "choosing". This latter category appeared to be a high level concept that could be a good candidate for a core category, and we tested this by reviewing the original data and coding for the category where appropriate. We found that this category was present in the vast majority of segments selected for analysis, and could easily be related to all other categories. These are the first two of Strauss & Corbin's criteria for identifying a core category. The category of choosing also fits with the other criteria identified in Strauss & Corbin (p147).

We therefore identified that the core category for the learners using the PDAs to complete the BuildIt game was *choosing*. This category was generated from the data indicating the activities relating to planning and reflecting that learners exhibited at many points during the task. We could have called this core category planning and reflecting, but this would not reflect the higher, more conceptual feel that a core category should have. More importantly, the core category should allow further generalisation through the inclusion of other categories and subcategories, and so should not be too specific in its nature. Having identified choosing as the core category, we are happy that this is the central concept running through the data gathered from the video footage of the students, and that this represents the fundamental basis of what they were trying to do: choose the right options that would allow them to complete the activity successfully. Planning, reflection, discussion, and other activities relating specifically to learning, which is obviously a primary focus of this study, all occurred in relation to *choosing*.

The core question that was maintained during the analysis was: *what is the impact of the PDA game on learning activity?*

7.4.3.1.3 An "ideal solution" benchmark

To provide a benchmark or touchstone for us in considering learners' activities in the field and their strategies in completing the BuildIt task, it is useful for us to outline an idealised pattern of activity that would lead to finding a solution (for the game). We do not specify a particular solution, since the aim of the game is exploration and not a specific outcome; instead we provide a set of steps that, if followed, would give rise to an effective engagement with the BuildIt task. It is useful to compare learners' activities in the field to this idealised pattern of the activity and ask "where do they deviate from this pattern, and why?" In particular, we are interested in exploring the role of the environment and the PDA-based game on their actual pattern of activity, and asking how the impact of these factors can cause learners to deviate from an ideal pattern of activity, with either positive or negative consequences.

The idealised pattern of activity (from the educator's perspective) would be:

- Develop an awareness of the task and the materials.
- Form some initial ideas (predictions) about what is likely to occur.
- Plan the use of the limited tools (estimates) available, in order to achieve optimal use of resources (cost & risk budgets).

- Recognise that each tool use needs to give maximum return on investment, so there is a need to plan use of these tools accordingly.

- Plan first use of tool, gather data, compare it to what was predicted, and modify plans accordingly.

- Assess the meaning of data obtained: would it be a good place to build? Need to think not about immediate factors, but look ahead and plan for what might happen with later estimates & building. Need to make some assumptions, but also need to recognise that assumptions make be wrong, and an element of risk is involved. Need to minimise risk. Use data to inform planning, and continue in this manner. At each point where a decision is required, need to think about the factors influencing that decision, and recognise that there are multiple factors involved.

In the sections below, we refer to this idealised pattern of activity as the *ideal solution*.

We now present descriptions and analysis of the categories identified during the grounded theory analysis, along with illustrative examples and discussion of their implications for understanding learner activity. As with all qualitative research, we have had to choose which aspects of the findings to present here, and which to omit for the purposes of clarity (Wolcott, 2001). In the sections below we provide more details of the groups of categories identified, how they relate to one another and to the core category.

7.4.3.1.4 Generalising

Learners were seen to construct knowledge, information, or beliefs from one location or situation and apply these to other situations or locations. They used the PDA to perform game actions that revealed information to them, and they were able to apply that information to related sites within the game, and to make predictions about information they might find elsewhere. They were also able to use their own ideas, which may have been formed independently of information gathered from the PDA, to generalise about other sites and buildings.

This act of generalising was central to the performance of the activity: learners were required to use their limited resources to gather specific information, and to use that information to make predictions and so avoid the need to gather further information about similar sites.

The act of generalising therefore involved both the gathering and storage of information, and recognising similarity in the characteristics of sites where that information could be applied.

> "if you think about it, it's going to be higher, flood risk, higher's better than low [pointing to low and high locations] even though it's only that much [indicates vertical distance with hands] it's still useful isn't it, so you've got to think of height" (Pair 4A)[4]

Here, Pair4A makes reference to other locations and their relative heights by pointing to two locations with different heights and asserting that “higher’s better than low”. Having just received information via an Estimate in their current location, he is able to apply this knowledge to other sites and is using the physical properties of the environment as part of the discussion.

> "cos I don't want to use another estimate on the other field one"
>
> "no cos we've got 3 estimates left"

---

[4] *When referring to quotations from specific learners, we use the notation ‘PairN[A|B]’ where N is the pair number and A or B is used optionally to refer to a specific member of the pair.*

"cos there's 2 tennis courts so we could do one up there, and then we'd have enough" (Pair 5A)

Here, Pair5A is recognising and asserting that the two tennis courts are similar enough for a single estimate to be sufficient to provide the information they need about those locations, and there is a reference to physical location “up there”.

7.4.3.1.5 Over-generalising / going beyond the brief

There was evidence that learners sometimes “went beyond the brief” in the sense that they considered factors of the environment and aspects of the task that were not indicated as being important or relevant. It was inevitable that their discussions and reflections on what was important sometimes deviated away from the central aspects of the task, and of course the task itself was designed to encourage free-thinking and an exploratory approach to solving the given problem. It is interesting to look at what prompted these deviations, in particular deviations that tended to interfere with their completion of the task.

What we find is that in some cases the environment itself was the cause of these deviations, and so in this case the environment could be seen as having a negative impact on the learners’ activities in direct relation to the task at hand. However, these instances are still examples of how the environment prompts their thinking, and gives rise to thinking about new aspects of the task that would not have been considered if the task had not been situated in the physical environment.

For example, when considering whether to place a building on the small area of tarmac (Tarmac 1), Pair23A remarks "yeah but if you think that won't be as big and it's going to be an awkward shape" (Pair 23). This comment relates to the small size of Tarmac1 compared to other tarmacced areas on the grounds, and also to shape of the tarmac itself, which is apparently judged to have an impact on whether the site is suitable for either the building in question, or buildings in general (this is unclear). The mechanics of the game require the learners to consider the characteristics of different sites and how these relate to costs and risks; the shape of the building sites is not mentioned as a possible factor. So, here we see a clear example of how the environment can give rise to consideration of non-obvious factors in the choosing process. In this case the factor being considered deviates from the ideal solution, but in a variant of this task the shape of the building sites could be important.

Significantly, this observation is made before they have obtained any estimates or placed any buildings so, despite having seen an example of the building reports in the task briefing, their ideas are less constrained by the game than later in the task.

> "should have 'em all close together shouldn't you, but we don't want them all on the tennis courts" (Pair 20)

Pair 20 discuss the merits of having buildings close together, but not necessarily all on directly adjacent sites. This is also an example of a *minimal exchange* (see below) where learners make remarks and comments to one another that require no clarification or justification, but are posited as fact and apparently accepted as such by their partner. This again is an example of considering factors beyond the scope of the game: there is no rule about having buildings close together, but they apply some common sense and stipulate this as a goal for themselves early in the task. Unlike Pair23 above, Pair20 have obtained estimates by this point so are familiar with the factors that are important for the game; this appears to be an example of them continuing to include factors in their planning for which they have seen no evidence of importance for the task.

> "I think we should put the [teaching block] over there, and the studio over there, no it'll be better cos it'll be close together" (Pair 20)

Pair20 persist with this reasoning until late in the task, with their logic apparently unchanged by the results of the Estimates and Build Reports they obtain. There is no mechanism in the game to vary the costs and risks of the buildings depending on other virtual buildings placed close by, so here we see learners persisting with an idea of something being “better” that is not part of the game.

> "it blocks off some people's..."
>
> "if people can park there, people have got nowhere else to park" (Pair 3)

> "where's the car park gonna be? we can't just have this cos this is where parents drop people off, and plus there's people just across the road so we've got to think of there"
>
> "yeah but there's people over there too"
>
> "yeah but there's something in the way there, there you can just see straight through it"
>
> "yeah but you could build something" (Pair 23)

The two examples above, from Pair3 and Pair23, show that aspects of how the environment is currently used can influence learners' planning, again prompting them to consider factors that go beyond the design of the task and distracting them from the ideal solution. These examples, which are discussed in more detail in Section 7.4.3.1.7.3 below, show that learners' knowledge and experience of how the environment is currently used can have an influence on their planning for future use of that environment, despite the task being purely hypothetical.

Another example of over-generalisation is the learners taking into account the impact of the actual building process, rather than just the impact of the finished building itself. For example, Pair23A remarks:

> [discussing building the media studio on the tennis courts]
>
> "yeah but you've still got the building risks"
>
> "yeah but there's building risks everywhere int there"
>
> "no I don't mean like that, I mean the people across the road are gonna hear more and complain"
>
> "yeah but you don't get much more thingy [low risk?] than media studio"
>
> "you've still got to build it, it's not just gonna magically appear!"(Pair23A)

Here, she is trying to convince her partner that a building is not a good choice for a site, and uses the impact of the building process as a factor in her reasoning.

Pair23 also discuss the impact of the surface type (grass), and include the changes that will result from their own proposed buildings in their reasoning:

> "do you think there might be a different flood here, for dining hall"
>
> "this is all grass!"
>
> "yeah but you'd take the grass away you don't get it"
>
> "yeah but it's all grass! so basically we'd still be around the grass so if you had a dining hall"
>
> "that what I'm on about if you have the dining hall here there won't be any like thingy will there, like risk of anything flooding" (Pair23)

This suggests that learners were able to consider temporal factors, as well as being focused on the present moment. It is possible that being present in the environment encouraged this mode of thinking, but we cannot determine this from the evidence we have from this study.

7.4.3.1.6 Comparison and evaluation

Evaluating information and making comparisons comprise the core activities that learners engage in to complete the BuildIt game. There are many specific examples of comparisons and evaluations, and these activities relate particularly strongly to the core category of *choosing*. Since these activities form the core part of what the learners are doing in the field, it is crucial to look at how the environment and game impact on these activities and the processes that drive them.

Learners carry out the task of finding sites for the three proposed new buildings by gathering information and making predictions about sites and the risks and costs of particular buildings on those sites. They are thus required to *evaluate* the information they receive and *compare* it to other information and to the ideas they have formed about the factors underlying the task. In the data analysed, we see that these activities occur frequently, and that both the environment and game play a significant role in prompting and shaping these activities.

> "can we go on to the others then, see which one's the best, see if we did one on there, and one on there like you said..." (Pair2)

This quote from Pair2 summarises the basic strategy employed by most learners: gather information and see which one is "best". The constraints of the BuildIt game mean that this strategy needs some careful planning, since not all information that is present within the game can be gathered.

Pair3 also demonstrate the same basic strategy at the beginning of the task:

> "think we should get an E off one and see which one's going to be better, at risk or cost" (Pair3)

We can see that multiple factors can impact on this evaluative process. Here, Pair2 are taking Estimates on the tennis courts and receiving results that are higher than they had expected.

> "so if that's 48 and we've only got 40 left, and that’s 68, arrrgh!"
> [expression of shock at figures of 48 and 68]
>
> "we couldn't guess the risk could we cos there isn't a total number"
>
> "we can have teaching block on the grass, makes us go bust by 2000"
>
> "shall we have that cos it's only 46"
>
> "so we've got 114 left, then we've got 68" (Pair2)

This second quote from Pair2 shows how comparisons between different items of information are influenced by the current state of the game and other information they have gathered. Here, they decide on a building “…cos it’s only 46”, when previously they have displayed shock at receiving 48 as a risk estimate. After gathering more information, they are able to re-evaluate their assessment of what constitutes high and low figures, and are also influenced by what stage they are at in the game. When they start out, information is cheaper, and they have more options, but as they get closer to having used up all their estimates they are more inclined to make choices that previously they may have excluded.

This is evidence that the game constraints help encourage learners to employ critical thinking that is relevant to their particular situation.

Pair3 also demonstrate evaluation of information in relation to game constraints:

> "try teaching block cos that was most expensive so we'll see how much that actually is"
>
> "110 the risk is, we've only got 160"

"not very good for that then is it" (Pair3)

They use the game constraint of maximum permitted risk to evaluate whether 110 is high or not.

Pair3 use this kind of comparative evaluation again, this time in relation to costs, when discussing the price of the media studio:

"we'll try... media studio. how many have [estimates] we got left?"

"4"

"yeah try it then"

"44 risk and 150 [000]. it isn't loads of money is it, cos we'd still have 650000 for 2 buildings and we'll stil have 116 risk left"

"shall we go with that, shall we build it"

"yeah"

Here they decide that 150,000 is not too high a price as it compares favourably with the total 650,000 they have remaining in their budget.

7.4.3.1.7 Impact of the environment on choosing

We also see evidence of the impact of the physical characteristics of the environment on this evaluation process – Pair3 discuss options and suggest the coach park as an alternative because it is higher:

"now the courts are on quite high ground as well so the flood risk would be quite low"

"but then there's the coach park which is even higher"

They have established that height is an important factor when considering flood risk, and the observable properties of the environment around them contribute to and influence their decision-making.

Pair22 also respond to the physical properties of the environment:

> "tennis courts what about the tennis courts cos they're on the high bank,
> the water will roll down the bank"
>
> "that could be a good place, let's go over there"

7.4.3.1.7.1 Proximity

The environment can impact on learners' decisions and thinking by simply being present in front of them. We observed numerous instances of learners being influenced by what they saw in front of them, or things they noticed or were aware of in the distance. In this way the environment can serve as a powerful enabler of enumerating choices or making predictions about physical properties that may be important, but there is also evidence to suggest that the environment can engender inappropriate trains of thought, or cause an unhelpful focus on factors that appear important simply because they are close at hand.

Pair3 demonstrate the power of proximity when they choose an option to investigate simply because it is the closest location to them:

> "5 estimates left, and we've checked..."
>
> "we've got 2 estimates per building"
>
> "try the coach park" [the coach park is right next to them] (Pair3)

This is also seen in:

> "didn't they say there was one up there?"
>
> "yeah do you wanna go up there then?" [pointing to the field] (Pair3)

This may be an efficient use of their efforts: since they do not wish to randomly move around the space, choosing nearby locations first seems sensible. But this means that they are biased towards sites that are nearby, and then biased towards sites near to those sites in turn. This kind of strategy is an obvious one, but shows how the environment can easily influence learners' planning.

This influence may at times be highly positive: because they can see options in front of them, they are highly aware of what is possible, and they are prompted to consider various sites by glancing around. In general, this is probably a major enabling factor that keeps learners working through the task. However, if they consider options that are visible in front of them at the exclusion of other (perhaps more suitable) options, then the environment has actually provided a negative influence on their activity.

Pair18 provide evidence of this when they remark:

> "let's put the canteen here, might as well" (Pair18)

They decide to put the dining hall at their current location, apparently seeing no reason not to do so, and more significantly, seeing no reason to place it elsewhere.

They do something similar when they decide on a location for the media studio:

> "somewhere over there, so it's near, shall we do that, shall we have a look" (Pair18)

Their remark "so it's near" is possibly a reference to placing buildings close together (an example of 'going beyond the brief') but must also be considered as evidence of them not wishing to travel far to find a good site. Although none of the students uttered a single word of complaint about having to move around a large open space, often retracing their steps, we must consider the impact that this physical effort could have had on their decisions. There is also an intriguing example of learners seeking to choose actions that fit their current location, rather than deciding on actions and then finding appropriate sites for those actions. Pair19 ask "what do we want here?" rather than “where do we want to go to achieve X?” Similarly, Pair22 comment "we're here now aren't we. shall we see what this one is?" suggesting they are choosing the current location simply because that is where they have found themselves. In the absence of any other prompts, this power of the environment to provide and afford alternatives is a good thing, but could possibly lead to choices that are less then optimal for the task at hand.

The things that learners observe in the environment prompt them to make suggestions and form beliefs about factors that may be important for the task. For example, Pair3A states "but head for that one with the flooding cos you've got the gates around it so not much water comes through". Here we see that the physical properties of the environment – the presence of gates – has prompted the formation of a belief which is then stated as a factor to be considered in the game, and which guides their current decision. We found that learners would often remark on aspects of the physical environment and that these comments would follow the pattern of *belief as fact*, that is ideas and suggestions were actually stated in a very concrete fashion with no consideration of alternatives.

We see this again from Pair3 when they state that "…the courts are on quite high ground as well so the flood risk would be quite low". Other examples include:

> "the field's gonna be better, cos it's bigger, that's the purpose, but we need a foundation" (Pair18)
>
> "if we put it here, and it's tipping it down with rain, the canteen will fall down there" (Pair18)
>
> "what about over there, on the [coach park]?"
>
> "that's a bit small innit" (Pair22)

7.4.3.1.7.2 Observations become beliefs become facts

All of these examples show how the environment itself can lead to beliefs about the underlying mechanisms of the task they are trying to complete. This prompts and encourages ideas, but at the same time these beliefs and ideas are stated as facts and are not questioned by either the learner who states them or by their partners.

There are also examples of 'belief as fact' statements that are not related to the environment, so this is not a phenomenon restricted to this context, but it does appear that this tendency, combined with the powerful prompts provided by the environment at hand, can lead to inappropriate and inaccurate beliefs that go on to be considered as facts. This is a major deviation from the ideal solution: learners do not question their own thoughts and ideas, and instead tend to focus on their initial thoughts and run with those. Given that these thoughts are grounded in the environment, there are persistent cues that could cause these beliefs to be maintained rather than questioned; seeing another environmental feature of the same type that prompted the original thought could again prompt that thought rather than prompting critical evaluation of it.

7.4.3.1.7.3 Previous knowledge

Learners' knowledge and experience of existing uses of particular areas of the environment could also bias their planning. There was evidence that the current use of the environment could intrude on learners planning for the future, i.e. they were not running with the task and how to get it done but rather getting stuck thinking about the current situation.

The primary example of this was the car park, which learners were reluctant to use because it then meant that there would be nowhere for people to park. Two pairs mentioned this in their discussions:

> "it blocks off some people's..."

"if people can park there, people have got nowhere else to park" (Pair3)

"where's the car park gonna be? we can't just have this cos this is where parents drop people off, and plus there's people just across the road so we've got to think of there"

This is evidence of over-generalisation of the needs of the task - they had not been told anything about considering losing existing facilities, but this was a significant factor in their discussion. This suggests that there was a tight integration between the physical environment and the learning task, but that this can actually hinder as well as help, because they get 'stuck' and cannot move beyond the current situation. Instead they prioritise the status quo. It was not just the loss of facilities that impacted on learners' planning: they also showed evidence of preferring to maintain current patterns of activity rather than introducing new ones. Pair22 discuss the placement of the dining hall, and prefer to place it close to the existing canteen:

"oh dining hall cos people will come down here and eat, cos the canteen's already down there already" (Pair22)

Previous knowledge and experience impacting on their current planning was an example of how readily learners *integrated* the actual physical environment with the virtual, imagined one that contained the new buildings. This integration was also seen at other times, and demonstrated how what learners saw in front of them could influence their activities. Pair23 argue about the impact of the presence of grass on a building site, showing how learners could have different perspectives on the importance of physical elements:

"I'd say media here"

"would you I'd say dining hall"

"do you think there might be a different flood here, for dining hall" "this is all grass!"

"yeah but you'd take the grass away you don't get it"

"yeah but it's all grass! so basically we'd still be around the grass so if you had a dining hall" (Pair23)

One factor that occurred several times was the proximity of the new buildings to one another, and to the existing buildings. Pair5 remarked "right, just look around and see where would be the best place to put things, like we've got a dining hall there, right in the front of the school".

The proximity of the buildings appeared to be a good thing for the learners in terms of enhancing access to the buildings. Other physical features were also mentioned in relation to access – Pair8 remark "... shall we have canteen and then teaching block, cos then we can just walk down some steps" noting that the pre-existing steps will provide good access to the new building.

Pair8 are not the only ones to note the stairs for access – Pair18 also comment on this feature:

We see this issue when Pair8 are discussing the location of the dining hall:

"do we want teaching block here, or canteen?"

"canteen"

"canteen? rather have the teaching block here, then you can just walk to the canteen"

"if you build the canteen here, you've got a good foundation, you've got stairs" (Pair18)

Despite the problems highlighted above, there was clear evidence that the physical characteristics of the environment, their meaning within the game, and the meanings that learners constructed for themselves, had a positive impact on the learning activity. Learners were prompted by the properties of the land they saw around them, and displayed clear awareness of how multiple factors could affect the task at hand.

Pair4 are looking for locations with lower flood risks than they have seen previously, and are prompted by the lay of the land:

> "let's go on to the field, cos if we go on to the field it's got like a bank hasn't it, so that's a hill, so if there was flooding it would be less cos it would go down"
>
> "tell you where else we could get one, by the Barn, down that way"
>
> (Pair4)

Not only are they able to reason about the difference between the sites they are discussing and consider the physical aspects of the environment, they are also able to generate more options based on what they are seeing. This demonstrates the enabling power of the environment to give learners the means to generate *choices* for themselves within the task.

There is also evidence that the environment serves to encourage critical thinking through the form of asking “why” and “what if” questions. Here, Pair8 have obtained an Estimate for the Teaching Block on the field, which gives them a large extra cost for foundations. They muse:

> "oh! foundations, how come it goes up so much when we're on the field?
>
> Wonder what would happen if we went to the tennis courts?"

This type of critical thinking is exactly the kind of activity we want to encourage in relation to learning about science and performing enquiries, and here we see it arising directly from a result of a game action. The impact of game actions and constraints is discussed in 7.4.3.1.8.

7.4.3.1.7.4 Generating hypotheses

Learners demonstrated their ability to form hypotheses about the underlying mechanics of the game on several occasions. They made clear statements about what they had observed, and translated these observations into predictions and/or explanations. Significantly, in all clear cases of hypothesis formation, it was the environment that gave rise to their statement of the hypothesis.

> "we're paying more for the land around it" (Pair 2)

> "now the courts are on quite high ground as well so the flood risk would be quite low" (Pair 3)

> "that one's got less of a slope on it hasn't it, so it would probably be less flood risk" (Pair 3)

> "the bigger it is the more it floods across" (Pair 4)

> "I know why this isn't high risk, cos it's on a bank isn't it" (Pair 4)

> "tennis courts what about the tennis courts cos they're on the high bank, the water will roll down the bank" (Pair 22)

> "well if we build on here you've got the concrete as a foundation but if you build on the grass... I think it's gonna be a lot easier to build on concrete cos it won't affect as many people and it'll be better, I'm thinking here" (Pair 23)

These examples demonstrate the effect the presence of the environment had on learners' ability to infer the rules of the game and generate appropriate hypotheses.

7.4.3.1.8 Impact of the game on choosing

In this section we consider how game constraints and player reactions to game events impacted on how learners made choices.

7.4.3.1.8.1 Constraints

The design of the game was based, by necessity, on specific constraints that meant that learners had limited resources with which to solve a problem. These constraints appeared to play a role in learners' activities in the field, with learners making frequent reference to these constraints and the impact of them being observable in learners' discussions, decisions, and actions.

Learners were able to use the constraints of the task to guide their planning. The simplest way they did this was to simply exclude options that were not possible due to their lack of resources. For example, Pair2 cross items off their list based on whether they are feasible or not:

> "if we've got 700000 left, we can't buy that one cos we'll go bust [crosses off on paper], and we can't buy that one [crosses off again] (Pair2)

The restriction on their resources also prompted some sensible planning about the use of those resources – Pair3 decide early in the task that finding a home for the most expensive building first will be easier than trying to find a place for it later:

> "try teaching block cos that was most expensive so we'll see how much that actually is" (Pair3)

Individual decisions could also be influenced by the sense of limited resources: Pair22 decide to Build without Estimating because of they only have four remaining estimates:

> "estimate"
>
> "no cos we've only got 4 left"
>
> "yeah but's worth it"
>
> "no cos we've got 3 [to build] I think we should just build it straight away"

Learners clearly attributed value to the in-game resources they were using to complete the task. The following are quotes relating to the use of resources showing how careful learners were with using them:

> "we've only got estimate left, so if we use that we don't know what we're doing on the field" (Pair2)
>
> "cos I don't want to use another estimate on the other field one" (Pair5)
>
> "we just wasted an estimate. I thought you wanted to build it over there, it's wide open, cos there's like nothing there" (Pair20)
>
> "estimate"
>
> "no cos we've only got 4 left"
>
> "yeah but's worth it" (Pair22)

We also saw that the results of game actions, both Building and Estimating, appeared to act as prompt for learner activity.

7.4.3.1.8.2 Reactions to game events

Performing game actions, Build and Estimate, was the method by which learners obtained information during the task. These actions, and their results, served a number of purposes:

1. They provided information about the environment.
2. They provided information about the buildings they wished to place.
3. They provided information about the interaction between the environment and the buildings.
4. They provided evidence to either support or discredit learners' predictions about the above.
5. They provided the means to progress within the game.

Learners' use of these actions and their responses to the results is therefore crucial to our understanding of how learners performed the task, and how the PDA-based game and environment impacted on that performance.

Learners grasped the utility and meaning of the game actions without any apparent difficulty, and showed no hesitation in using these actions to perform the task. We can explore how the game impacted on learner activity by examining learners' responses to the results of the actions they performed.

We found that the result of an action was a significant shared object that played a large role in the initiation and coordination of action. Once an action had been taken, learners received information that served as a focus for their attention, prompting reflective comments and observable non-verbal behaviours suggestive of shared reflection. For example, glances and looks were often exchanged between learners to indicate their opinion of the result of an action, without overt comments being made. The receipt of an event result like this was taken by both learners as a prompt to reflect and consider alternatives, and was a very natural mechanism to which they responded. The presence of these events in the PDA version was a significant factor in maintaining the flow of their activities, which was lacking in the Paper version. The central mechanism at work here is unknown information becoming known, a design pattern that is used frequently in games design and which was deliberately chosen as part of the design for this task because of its fit with the task and environment in which it was to be performed. The evidence suggests that these events do indeed significantly contribute to the flow of the activity, with learners implicitly understanding the mechanisms at work and knowing how to respond to them without any need for discussion.

We can compare this to the Paper version, where information was similarly unknown, to gain further insight into the importance of the interactive mechanism at work here. In the Paper version, learners were similarly discovering unknown information, but the process for doing this was qualitatively different: they did not have to perform any particular action to reveal the information, and did not have to wait for a response from the system. Instead, they simply looked for the information and found it. This process did not give rise to the same ebb and flow of action and reflection (combined with planning) that we saw in the PDA version, suggesting that the mechanism for revealing unknown information through learner actions was an effective one. In the Paper version, we might say that the information was not really unknown but rather *unseen*, and was easily obtainable. In the PDA version, specific actions were required, along with physical movement, which may have rendered the result of those actions more intrinsically rewarding, hence giving rise to a richer response to them.

Reactions to game events included a range of emotions, including joy, frustration, embarrassment, surprise, and disappointment. These reactions in turn gave rise to particular activities by the learners. For example, Pair2 are disappointed to discover that an Estimate returns the same results as a previous one, and are prompted to explore an alternative:

> "what if we change to dining hall, is that a different price, but we can't cos we've only got 2 estimates left"
>
> "try that, just go"
>
> "oh it's the same" [sad, disappointed]
>
> "that was the highest over there, so what if we go over there and choose a different one"

This is a typical example of the pattern of activity that was observed during the trials. Learners would choose an action (Build or Estimate, or move), perform the action, see the results, and the response to those results would then lead to further choosing. When the chosen action to move to another location, the response was less salient than when the action was a game action. The process of choosing, as discussed in Section 7.4.3, could incorporate a range of processes, ranging from discussion, making predictions, and generalisation.

Another example, from Pair3, clearly shows how the result of a game action leads to the formation of an idea of how the game works (which is quite correct in this case) and a firm decision on their next action:

> "70 risk"
>
> "hmmm I wasn't expecting that" [embarassed, hand to mouth]
>
> "750000!"
>
> "that's cos it's on grass int it"
>
> "I dunno"

"shall we go back to the tennis court?"

"let's go back on the tennis courts cos teaching block on the field's not going to be good is it"

The interesting thing to note here is the comment “I wasn’t expecting that” made by Pair3A. This indicates that Pair3A had made some form of prediction about what the result would be, but this prediction is not verbalised. When the results do not match this prediction, a hypothesis is formed, and stated to his partner, and their next action is decided on based on this unexpected result: they discount the two building sites on the field as possible locations for the teaching block because of predicted high costs, which is correct according to the game design.

Pair23 demonstrate similar behaviour, receiving unexpectedly high flood risk figures and using the environment to generate an explanation:

"flood risk 50! [exclaims, surprise, looks around] oh yeah, cos if it floods, and it's running this way"

"if we put it over there do you think there might be a bit less of thingy"

"no because it's gonna move down this way"

"yeah I know but if you have it over there there'll be a little bit less of a risk"

Here we see that Pair23A’s reasoning is not just a one-off thought: she uses it to argue with her partner about a suitable location, and her partner uses the same reasoning (the slope of the ground) to counter and maintain that her suggestion is suitable.

One of the key things we were interested in exploring was the role of failure, or perception of potential failure. We wanted to know if this could have a positive impact on learners’ activities. What we found was that few responses to game events could be categorised as a response to failure, and instead the most common response appeared to be to unexpected results, in other words they were *surprised*. The frequency with which learners appeared to be surprised suggested that, as well as just hoping for good results, they may have actually had expectations about the results they obtained. None of the learners chose their candidate building sites randomly, they all employed some kind of reasoning to arrive at their decisions, and they then displayed a range of reactions to the results they see arising from these decisions.

What is significant is that learners do not articulate specific predictions, but their responses suggest that they were hoping for or expecting something other than what they see. This is not just blind hope, they appear (in most cases) to have followed a line of reasoning that makes sense to them, and are disappointed.

In the absence of specific predictions being verbalised, it perhaps makes more sense to conceptualise this phenomenon as 'learner expectations', meaning that they appear to have hopes and expectations for particular sites and actions that often do not match with what they actually see when they perform the game actions. This mismatch between expected results and observed results then gives rise to reflection and initiates the process of choosing their next action.

In contrast to the 'negative' reactions to game events, we found few examples of positive reactions to game events, and when these did occur, they did not lead to idea generation. For example:

> [they take an Estimate]
>
> "we'll have enough! we're not going to go bust!"
>
> [joyful, exclamation]
>
> "oh we'll have enough, we're not going to go bust!" [joyful]
>
> "can we build it here now"

"yeah build it now" (Pair2)

Similarly, we did not observe any occasions when learners' expectations fit well with what they see. There are no instances of learners saying things like "That's what I expected" or "Yes that's what I thought". This is to be expected – the game is designed such that a complete understanding of the rules and factors at work is unlikely to be reached within a single session. So what we are seeing is a mechanism that drives learner action forward: they expect something, they see something different, they generate ideas about why that has happened, and they use these ideas to choose more actions.

In contrast, when we looked for related examples from the Paper version, we found no evidence of surprise, and no evidence of predictions being made, whether articulated or not. This comparison was performed by selectively examining sections of the footage from the Paper version that had been coded for 'gathering information'. These two activities are, for the Paper version, indicative of the learners obtaining information from the booklet – the analogue of obtaining estimates or build reports from the PDA. This suggests that they had some expectation of results (it indicates that they were making predictions, whether verbalised or not) and that they could effectively and quickly evaluate the results. So learners were making predictions in situ, and they knew what the results meant, and their reaction was to then gather more information and make more predictions. Conversely, the Paper version had no surprise, and learners did not react in the same way.

7.4.3.2 Paper version

In order to aid our comparison of the PDA and Paper conditions, we performed a grounded theory analysis of learner behaviour during the Paper version using the same method as for the PDA version. This section presents the results of that analysis, and draws direct comparisons with the PDA version.

7.4.3.2.1 Process

We performed line-by-line analysis of footage from the Paper version using the same criteria as for the PDA version: segments where Planning and/or Reflection had been identified were transcribed and these transcripts were coded following the same protocol.

This analysis was conducted after the analysis of the PDA version was complete. Our aim for this analysis was to provide a comparison of the PDA and Paper versions. This aim guided the grounded theory analysis for this condition. Once open coding had been completed we grouped codes together to identify a core category that could help us explain and understand the other codes we had identified.

7.4.3.2.2 Core category for the Paper version: Search

We reviewed the categories emerging from the data in the same manner as for the PDA condition, and found that the category of *search* was an appropriate core category around which the other categories could be clustered. This was based on observations that learners in the Paper version were frequently engaged in the activity of looking through the paper booklet to obtain data, and this activity was not performed subsequent to the suggestion of hypotheses or possible solutions but rather formed the focus of their actions during the task. Other activities, such as reasoning, were performed in relation to this data search rather than exploration of the environment.

7.4.3.2.3 Pattern of activity

The general pattern of activity for learners in the Paper condition was markedly different to that observed in the PDA condition. Whilst learners did move between building sites, they did so much less than their peers in the PDA condition and their activities were not punctuated in the same way by these movements.

Learners were typically seen to visit several sites and consider some possibilities for placing buildings, and would then dwell in one location for a longer period of time whilst reviewing a number of options. This was in contrast to the PDA version, where the students typically considered only one or two options in each location, moving between locations more frequently.

7.4.3.2.4 Using data

Learners' discussions centred on the identification and confirmation of data from the paper handout pertaining to options they were discussing. They were often seen to use the booklet to obtain a number of costings for different options and to consider these in light of their own priorities relating to where to erect the buildings.

For example, the following exchange by Pair 24 demonstrates a focus on finding suitable values in the data without any reference to the reasons behind those values:

> "where are we walking anyway are we doing the media studio or the teaching block or the dining hall"
>
> "basic cost court 1..."
>
> "what building?"
>
> "any. we can have the dining hall, MS, or TB. Flood 2, that's 100000, 200000, altogether 300k"
>
> "yeah but look at the risks on that, 10, is it 10 out of 10?"
>
> "no"
>
> "what's it out of"
>
> "so total risk is 12. planning risk... is 2, so that'd be alright"
>
> "yeah but we haven't looked at any other for dining hall"
>
> "yeah so find dining hall... what was that that was flood 2"

"media... TB... ah"

"look at all the risks"

"yeah but extra foundations so that'd be a bad place, field 2 we've got... teaching block... tarmac..."

"that's only 100k"

[flicks through booklet]

"yeah but then there's too many risks"

"dining hall tarmac 2"

"that's not that bad"

"it's not as bad as the others and it's a bit cheaper isn't it so we could consider that" (Pair 24)

Other pairs demonstrated similar tendencies to focus on searching the data looking for what looked like acceptable results. Pair 25 make a reference to one location being likely to be similar to another, but only in the context of a search of the data:

"I think we should go further on the field, cos we'll block out this, do you get me"

"yeah"

"cos if you come out there you're going into one so"

"the field, which field?"

[leafs through sheets]

"so field 1 or field2"

"field 2 I think, that's that way"

"field 1 for the teaching..."

"field 2 for the teaching block, hold on we need to go on to field 2"

"teaching block tarmac2" [looks through booklet]

"teaching block field 2 wasn't it, field 2 field 2"

"well our budget is 800k, if it was here, so then we'd have 50"

"how much is the risks"

"flood risk is 10"

"40 risk altogether"

"not 40 risk, that's the total risk 20"

"so it's not much"

"but the cost is a lot, and we've got to think cheap, to get the other ones"

"so what's field 1 then" (Pair 25)

7.4.3.2.5 Reasoning

Learners did not demonstrate much evidence of reasoning about the task using the environment as a reference. What reasoning they displayed appeared to focus on the relative sizes of the available building sites, with no mention of other characteristics of the environment.

The following examples illustrate this focus on the size of the sites:

"they're not that big though the tennis courts" (Pair 25)

"which one's the biggest one cos we need lots of space for a big one" (Pair 25)

"we've took tarmac 2 as an idea cos it's spacious" (Pair 24) "see, if you use both the courts together you'd be alright, spacious, but if you use one of em"

"see that looks a bit wider don't it, from here" (Pair 24)

Where we did see evidence of reasoning based on environmental references, these were based on prior knowledge and not on the data presented during the task itself. Pair 13 demonstrate this with their exchange:

"we can't have it on the court"

"why"

"cos I've seen it flood there, when its been raining" (Pair 13)

7.4.3.2.6 Predictions

A key difference between the PDA and Paper version was that we saw no evidence in the Paper version of learners making predictions about what the costings would be before they looked them up in the booklet. There was evidence that learners reasoned about the data they had obtained so far and used these data to make predictions (such as "tarmac 2 will be the same as tarmac 1" [Pair 25]), but they did not make predictions before beginning the process of obtaining a costing.

In the PDA condition, we found that even though learners did not articulate their predictions, there was evidence that they had in fact formed an expectation, as evidenced by their reactions to the results of the Estimate action (see Section 7.4.3.1.8.2).

However, in the Paper version, we saw neither articulated predictions nor reactions to costings obtained from the booklet – learners in the Paper condition were never surprised by what they found, only dismayed. For example, this exchange from Pair

17 shows a negative response that is not followed by any reflection on the data, only a comment on its implications:

"court 2"

[looks up data in booklet]

"oh dear"

"what?"

"I'm just saying, it's really high"

"is there anywhere else we could put it?"

"there's the dining hall" (Pair 17)

7.4.3.2.7 Reactions to data

In line with the lack of evidence of predictions and subsequent surprise as noted above, although reactions to costings obtained from the booklet did show some emotive content (suggesting that learners were involved in the task), unlike the PDA version there was no evidence of surprise. Significantly, we also saw no evidence in the Paper condition of obtaining a costing from the Paper booklet prompting reflection in the way that we saw unexpected results from the game prompt reflection in the PDA version.

7.4.3.2.8 Over-generalising / going beyond the brief

As in the PDA condition learners were seen to over-generalise and go beyond the brief, postulating reasons for not considering certain options or preferring others based on spurious reasoning that went beyond the information presented to them during the task.

For example, Pair 25 express a preference for a site more distant from a chosen building:

"I think we should go further on the field, cos we'll block out this, do you get me"

"yeah"

"cos if you come out there you're going into one so" (Pair 25)

Learners did not appear to consider the physical characteristics of the potential building sites other than size and location. A number of learners made observations relating to the size of the building sites and the assumed footprint of the buildings however this information was not provided to them and was not indicated to form part of the task.

7.4.3.2.9 Data collection as the focus

It seemed that the collection of data (in the form of costings from the booklet) was the focus and driver of many of the students' discussions.

For example, this exchange from Pair 25 shows a focus on data and no discussion of its implications (other than whether it represents a suitable option or not):

"they're not that big though the tennis courts"

"but they don't need any foundations, the flooding risk is 70 though, which is more than any of the others"

"I don't think we should do the courts"

"no but what else is there. tarmac 2, which is there, so that's one of the low risks and it is cheap, no extra foundations which is good, flood risk 20 though"

"total risk 40"

"cos of planning risk"

"put it there" (Pair 25)

7.5 Conclusions

In this section we draw together the findings from both quantitative and qualitative analysis, and consider them in terms of i) the game and associated constraints, and ii) the environment and associated physical activities, and iii) potential support for enquiry-based learning.

This section presents an overview of the salient results from the quantitative and qualitative analyses above. These results, their relation to learning theory and previous related work, discussions of how BuildIt supported enquiry learning, and implications for pedagogy and future research are then discussed in more detail in Chapter 8.

7.5.1 Impact of the situated learning game

In general terms, the game was very successful in engaging the learners in the task and maintaining their interest, and encouraging problem solving. Almost all of the participants in the study stated that they enjoyed playing the game, and appeared to have no issues with the learning activity embedded in the gameplay. Learners were typically able to conduct their activities within the game without help after only a few minutes of supervised play.

It seemed that the PDA game condition offered a qualitatively different activity for the learners, with their pattern of behaviour being typified by many episodes of planning and reflection punctuated by movement, game actions, and interpretation of the results of those actions. By contrast, we found that in the Paper version learners exhibited much more activity related to simply gathering information – the activity for them was more about searching the data (the paper booklet) rather than active exploration.

We saw evidence indicating that the game and its associated constraints coincided with incidences of planning and reflection. We have no direct evidence of causation, but both the quantitative and qualitative results from this study indicate that the game constraints featured heavily during planning and reflecting activities. We interpret this as an indication that the game was successful in prompting planning and reflecting, and that learners responded to their observations of the constraints the game placed upon them by choosing options and interpreting the results of their actions within the game. This is certainly what was indicated by the qualitative results: we found that unexpected results from in-game actions led to episodes of reflection. This is also supported by observations of learners in the Paper condition: we saw no episodes of reflection that were triggered by events during the task (in this case the results of searching for and finding specific costs and risks in the paper booklet). What little reflection we did see in the Paper version appeared to be focused on aspects of the task that had not been indicated to the learners as being pertinent, such as the relative locations and sizes of the available building sites.

Alternative explanations include i) these planning and reflection episodes simply coincided with references to the game constraints with no causation, or ii) the planning and reflecting gave rise to the references to the game rather than vice versa. However, due to the results from the grounded theory analysis (which suggest that planning and reflection was in many cases prompted by observations of game constraints), and the apparent lack of similar planning and reflection in the Paper version, we do not favour either of these alternative explanations.

A salient point to note about the results of actions leading to reflection is that in several cases learners expressed surprise and made comments indicating that they had specific expectations for the result that had not been met. However, learners tended not to articulate their predictions.

The presence of constraints within the game was also seen to be a successful mechanism for enabling effective discussion and decision-making: learners were able to use the constraints of the game to guide their planning. They did this in several ways, including eliminating options that were simply unavailable because of a lack of in-game resources. Learners also demonstrated that they had a sense of the value of the resources within the game, and their intrinsic motivation to play the game led to them managing of those resources, which helped them to complete the task.

One aspect of the engagement provided by the game that could potentially be considered problematic is the learners' over-generalisation of issues within the task due possibly to the fantasy elements of the game causing them to look beyond the here-and-now of the task. We saw this most clearly when learners were sidetracked into thinking about the processes involved in constructing the buildings, or disregarding sites because of concerns about long-term impacts of building at those locations. In these cases, we could view some aspects of the game as having interfered with the core enquiry processes desired for the learning activity by promoting a fantasy context in which the learners were too deeply involved. We saw some evidence of this also in the Paper version, suggesting that such over-generalisation is not unique to the game context presented in the PDA version, but it is possible that the game exacerbated this issue.

Responses to results from in-game actions were a significant feature of the behaviours demonstrated by the learners. The most salient response was surprise, when learners received a result that they were not expecting (as indicated by their comments or behaviour). This surprise then tended to lead to discussions about what had caused the unexpected results, and what their next actions should be.

7.5.2 Impact of the environment

As was intended, the environment played a powerful role in the BuildIt learning activity. In many respects this was in expected ways, and the effects were in general positive and fit with existing theories and related projects. However we also found some potentially negative effects on the learning process that arose from interactions with and influences from the environment.

The environment served as a prompt for learners' discussions. They commented on what they saw in their immediate environment and engaged on another in discussion that was pertinent for the game. They commented on physical characteristics that they observed in their immediate environment, and also referred to characteristics of other sites that they had visited. Significantly, they also made comments about locations that they had not visited, and made predictions about how the characteristics of those sites might affect the game. The environment was also used as a shared artefact for discussion, with learners pointing to features, and even mirroring environmental characteristics with gestures, during discussions. References to the environment were strongly associated with planning and reflecting activities. All of these behaviours pointed to a successful integration of the environment into the game and the learning activity itself.

However there were ways in which the environment appeared to distract the learners away from the core learning activity, which was centred on gathering data and finding suitable solutions to the task. The simplest way in which this occurred was *proximity*: learners responded to what they saw in front of them, favouring options related to what they could see rather than exploring other, more suitable alternatives (which were not so proximal). Also, learners could be sidetracked by their *existing knowledge* of the environment, and would focus on factors that had no bearing on the game or on the data they were collecting.

7.5.3 Concluding remarks

This chapter has described Study 2, which evaluated the use of a situated mobile learning game, BuildIt, to support reflection and related processes in an active, outdoor enquiry-based learning activity. We believe that we obtained useful data and insights into how a situated mobile learning game may impact on a field-based, enquiry-led learning activity. Results from the study presented here indicate positive effects arising from the use of a mobile game to support learners with their activities, and unexpected results from game actions were particularly successful in prompting reflection. There is also some evidence to suggest that the structure of the game and the environment were related to planning and reflection activities. There were clear indicators that the environment played a significant role in mediating the activity, and the physical characteristics of the environment were easily noted by the learners and used during their discussions. We also saw some unexpected effects arising from learners' previous experience of the learning environment, and the presence of environmental cues could sometimes waylay the learners in their reasoning.

In summary, the PDA-based game BuildIt appeared to offer support to learners engaged in the outdoor enquiry activity, with game events successfully prompting reflection and the constraints of the game helping to coordinate activities. However the results indicate that activities such as BuildIt need to be carefully designed to take account of interactions with the environment, and that learners require more support to articulate their reasoning and to avoid being distracted by irrelevant factors. The implications of these results along with suggestions for future work are discussed in Chapter 8.

Chapter 8

Discussion, conclusions and reflections

This chapter provides a summary of the research presented in this thesis, and discusses the implications of the findings in relation to existing learning theories, pedagogical practice, and technological trends. The limitations of the studies presented here are discussed, and outline possibilities for future work are presented.

8.1 Summary of research

This thesis has focused on the question of whether we can use situated mobile games to support active and reflective enquiry learning in a physical environment such as the grounds of a school. We surveyed the relevant literature, reviewed exemplary projects that demonstrated previous successes and problems, and identified three learning approaches – situated, experiential, and enquiry learning – that were relevant to this work. Our review suggested that previous work using 'games' as learning activities had not fully explored the use of core game mechanisms such as failure states, despite failure being a core component of successful learning according to the constructivist model underpinning situated and experiential learning theory.

In order to explore the use of mobile games in physical environments, we developed a software toolkit (PaSAT) to allow the creation and deployment of such games using handheld computers (PDAs) in the field (see Chapter 4). We used this toolkit to deploy a situated exploratory learning activity at a secondary school, and compared students' activities using this activity to similar activity conducted indoors, using the same technology (see Chapter 5). From this study we identified a number of potential benefits to using PDAs to support learning, but found that learners struggle to coordinate their activities away from the classroom, and teachers cannot provide the necessary support outdoors. Learners were highly motivated by the physical environment, and responded well to the challenge of completing location-based tasks, but tended to focus on surface level goals rather than the underlying learning activity.

Using the results of this study, and those of related projects, as a guide, we further developed the PaSAT software and then designed a mobile learning game – BuildIt – intended to support learners in the field by incorporating elements of the environment directly into the game and using failure states to prompt reflection in situ. We evaluated this game at another school, using both quantitative (activity coding) and qualitative methods (grounded theory) to provide insights into the impact of the game and environment on the students' learning activity. A paper-based activity was also used to provide a comparison condition.

8.1.1 Summary of the impact of the BuildIt game

Results of the video coding and grounded theory analysis indicated that the BuildIt game was successful in engaging learners and providing a framework that helped them to coordinate their activities in the field. We found that learners using the PDA exhibited significantly more planning and reflection behaviour than learners using the paper-based materials, and both the environment and game itself were strongly associated with planning and reflection activities. Game constraints appeared to be associated with learners reasoning about what options to choose within the game, and because of the coupling of the game to the environment this meant that the game promoted reasoning about the learning task. We also found that the environment was effective in providing a prompt for relevant discussion, and learners were able to make reference to the environment as a shared artefact in their discussions, and even made gestures that mimicked the characteristics of the environment. None of this was present when learners used the Paper version.

We did observe some problems arising from the impact of the environment. Learners were influenced by the proximity of features and sites so that they tended to focus sometimes on what was visible in their immediate environment, rather than considering more physically distant options. Learners were also influenced by their existing knowledge of the environment, and showed some reluctance to change the use of existing sites, citing problems with providing existing functions (such as car parking) elsewhere. This was also an indication that the fantasy aspect of the game setting worked well to engage learners, but suggested that they could become over-engaged in these aspects.

8.1.2 Comparisons to the Paper version

The Paper-based version appeared to be successful in providing learners with an alternative version of the task presented in the BuildIt game, but we saw far less evidence of the kinds of self-directed activity and reflection that was observed in the game version. The nature of the activity appeared to be centred on searching the available data for an appropriate option rather than engaging in active reasoning about the data they collected. Movement around the site was also different, with learners tending to visit several sites and then dwell in one site sifting through the data looking for a solution. Discussions appeared to focus on the physical characteristics of the buildings for which they were asked to find sites: there was far less discussion of the physical characteristics of the sites themselves than in the PDA condition. Significantly, we saw no evidence at all that learners were making any predictions about what data would reveal for a particular combination of building and site.

8.2 Critique of BuildIt

In this section, we offer a critique of the BuildIt activity and consider i) how interference with the physical world impacted on the activity; ii) the role of movement within BuildIt; and iii) to what extent BuildIt constitutes a ‘good’ game (or even whether it is a game at all).

8.2.1 Representation of a real-world task and interference from previous experience

BuildIt was intended to simulate the real-world scientific task of forming a plan to collect data, performing that data collection, using those data to make predictions about the environment being studied, and to collect more data to either support or disprove those predictions, and so on in a cyclical fashion.

This activity was encapsulated within a role-playing design game that required learners to take on the role of surveyors collecting data about building sites in order to locate suitable locations for new school buildings. The supporting technology allowed learners to interact with the game using movement, and provided the means by which feedback during the task was provided to learners. The aim of BuildIt was to explore the feasibility of using augmented reality game to support and encourage in-situ reflection in the area of scientific enquiry; the aim was not to simulate the actual activity of performing a site survey or of collecting data in the field, but to present learners with an authentic context that would ground their activities during the task.

We found that learners’ previous knowledge and experience of the physical setting of the BuildIt game influenced their reasoning and hence decision-making during the activity (see 7.4.3.2.8). This influence was also observed in the corresponding Paper-based version, but to a lesser extent.

Learners made assumptions and decisions during the activity that were apparently based on their prior experience of the physical sites they were considering for the task. They considered historical uses of sites in their planning, and in several cases opted to attempt to preserve the existing sites so that they could continue to be used for their current purpose. In all cases, such reasoning went "beyond the brief" in that they were not instructed to consider previous or current uses of the sites in their decision-making; learners were seen to spontaneously invoke justifications for decisions based on their previous experience.

These influences of previous experience give us an insight into the *magic circle* of the BuildIt game. This term was first introduced by Huizinga (1949), and has more recently been applied to video games. For example, Salen & Zimmerman (2003) describe the magic circle as encompassing both real and virtual spaces and assert that it serves to define both the *location* (in time and space) and *nature* (how it is played, by whom, and why) of a game.

Games engender and require some form of agreement or social contract between players so that everyone involved knows the rules of the game, what is expected of the participants, and what is to be expected when the game is over. For classical games, such contracts are fixed: rules, goals, and end states are agreed before the game begins, and all players know what is involved. The game then takes place in whatever location is chosen, using the required physical artefacts for playing the game. All of these things – the rules, the environment, and the expected end state – form what is known as the magic circle. Players enter the magic circle when they play a game; it is what defines where and how the game takes place. But the magic circle is not just about time and space, or hardware and software – it is something that is in the mind of the player, the *liminal interface* between the game and not-game (Nieuwdorp, 2005, p8).

A crucial aspect of the magic circle is that it can be (and often is) dynamic – this is especially true of pervasive or augmented reality games (Westera *et al.*, 2000; Montola, 2005; Nieuwdorp, 2005; Westera *et al.*, 2008; Montola, 2009). This means that the magic circle can extend to include additional elements whilst game-play is taking place. Montola (2005) identifies three ways in which the magic circle of a pervasive or augmented reality game can extend:

1. Spatially: the physical space in which the game is played may expand as players move to new locations, or play is taken up by players at more distant locations.

2. Socially: play may extend to encompass participants who had only peripheral involvement with the game, or even no involvement at all; the boundaries of playership become blurred and defining 'player' becomes more difficult.

3. Temporally: players may begin engaging with the game at times other than explicitly identified play sessions, and the game may become interleaved with everyday life.

Spatial and social expansions were not possible for BuildIt: the physical area in which the game was played was pre-defined, and only the two current players could have any impact on the game. However, the observed tendency for learners playing BuildIt to consider aspects of their previous experience of the environment can be seen as a form of *temporal expansion* of the BuildIt game. Although learners only played the game at a fixed time, elements from their previous experiences impinged on the game, and hence the magic circle could be seen to be expanding to include not just the current time frame but also previous time frames as well.

We also saw evidence that learners were considering future time frames as well as previous ones. Learners were observed considering the impact of the actual building processes that would be required if the actions they selected in the game were translated into actual building work. For example, some learners remarked on the impact of the building work on nearby residents. One pair also commented on the possible state of the ground surface following the building work in the context of a discussion about flood risks, demonstrating a clear possibility for learners to consider factors outside the assumed 'here and now' of the game.

These temporal influences were not considered during the design of the BuildIt game, or the paper-based version of the task. In hindsight it is easy to see how these influences arose as a side-effect of our aim of using the actual physical environment as part of the game itself, whilst simultaneously expecting learners to ignore previous temporal contexts. Ideally this should have been considered during the design phase: what we know about the associate nature of human reasoning indicates that it is highly likely that learners will use previous knowledge and experience when attempting to solve new problems. What this issue highlights is the inherent difficulty in attempting to using elements from the physical environment as part of a virtual game: it is impossible to know entirely what previous experience players will bring to bear on the activity (although some sensible predictions might be able to be made). Previous projects such as Savannah and Environmental Detectives did not appear to be affected by similar temporal expansion issues, most likely because they were either not attempting to use features of the physical environment (as in Savannah), or the task did not require any consideration of the existing uses of that environment (as in Environmental Detectives). The degree to which the physical play area is familiar to learners is likely to be an important factor – for BuildIt we used a small space with which learners were very familiar, but a space with which learners were less familiar could have led to reduced influence from previous experience.

It is important to note that the discussions that arose from learners' considerations of their previous experiences need not be viewed in a negative light. Although the discussions they had were off-topic in relation to the underlying model of the game, the intention was to encourage discussion and reflection in the field, and the BuildIt game appeared to be successful in doing this, albeit in unexpected directions. All of this illustrates the complexities of designing and deploying augmented reality games for education when the exact factors that may impact on the activity may be largely unknown. The design challenge is how to define and maintain a learning context, when it appears that magic circle of the game could fluctuate due to a number of factors. However this fluid nature of the magic circle could be exploited to engender rich discussions prompted by environments of which learners have detailed prior knowledge. This could be the real strength of these games: the capacity to prompt learners through exposure to rich, familiar contexts. However a dynamic magic circle could also impact negatively on a learning activity by giving rise to unpredictable observations and truly unexpected and unanticipated results, leading learners to become disillusioned with the scientific method we are trying to encourage. A dynamic magic circle is difficult to design for, but is a crucial consideration.

8.2.2 The role of movement

Movement was a central feature of the BuildIt activity undertaken by learners using the PDA: learners could only perform game actions on site where they were currently located, and so they were required to move to different sites in order to complete the game.

In the Paper version, learners did not have to move: they could perform the task without visiting any sites. However, they were told (as were the learners using the PDA game) that the physical characteristics of the sites were important in understanding the possible solutions for the task.

Movement was therefore a central feature of the BuildIt game, but not the Paper version. It is important to consider to what extent movement was a genuine requirement of the task as opposed to being an artificial constraint imposed by the game.

The requirement to move to each site was introduced in an attempt to ensure that learners were exposed to the physical environment of each available building site, since we wanted to explore the relationship between learners' discussions, their activity in the game, and the physical environment in which the activity took place. This was an important part of the aims of the activity: we wanted to promote reflection in-situ and so we needed to provide as rich a context for this reflection as possible. This was a design decision and visiting each site was not actually required in order to complete the task; the game could have just as easily been run without this constraint in place, for example by allowing learners to select the target location for each action from a menu or by moving around the map by clicking on the screen.

A similar constraint (albeit a soft one) was considered for the Paper version. Learners could have been instructed to visit all of the available sites and to only commit to placing a building if they were located at the chosen site. However, this conflicted with our aim of having the Paper version be as close as possible to a plausible activity that the school might ordinarily conduct, and this view was shared by the teachers we involved in the design of both game and paper activities.

An important aspect to consider is the reaction of players themselves to the requirement to move between locations in order to progress the game. There were no observed instances of players expressing any frustration or annoyance at this method of interacting with the game: they appeared to accept it as a natural and necessary part of the task, and appeared to put the time spent walking to a new location to good use by discussing their findings along the way. As well as promoting reflection directly in situ, it is possible that BuildIt, in affording a certain amount of physical distance between learners and the object of reflection, provided them with 'space' for such reflections – learners' movements meant that whilst they were close to one site, they were distant from all of the other sites. It would be interesting to compare the patterns of activity exhibited in this study with learners who are not afforded this kind of 'punctuation' of their activity.

To implement an augmented reality game and provide the link between the physical environment and the information space, it was necessary to provide a mechanism by which learner activity – *physical activity* – could be used to drive the game forward, by *coupling* learner movements with responses from the game. Game actions in isolation without movement may have sufficed, but not with the same level of coupling between the virtual and physical spaces. Our aim was to exploit previous findings that associating familiar actions with unfamiliar or unexpected responses can lead to productive reflection (Rogers *et al.*, 2002; Rogers *et al.*, 2002).

So movement was a requirement of the game rather than the task. But it was not a spurious, artificial one: rather it was one that served to enhance the *coupling* (Roschelle and Patton, 2002) between the information space of the design task and the environment in which that task was conducted. These two aspects were intended to combine to form an augmented reality learning activity.

In summary, movement provided the means by which learners could explore both the physical space and the virtual simultaneously, allowing us to implement BuildIt as an augmented reality game along the same lines as previous work such as Savannah and Environmental Detectives.

8.2.3 Is BuildIt a good game?

As part of our critique of BuildIt, we must conduct the same critical assessment that we have directed towards related projects, and consider to what extent the BuildIt activity constituted a good game, and whether it can be considered a game at all.

We set out to design a learning activity that could use game features to engage learners and enable reflection in situ. In Chapter 2, we discussed characteristics that have been identified by a number of sources as being essential for computer and video games, and we used these as our touchstone when designing BuildIt, as described in Chapter 6. These characteristics (adapted from Prensky, 2001) were:

1. rules
2. goals and objectives
3. outcomes and feedback
4. conflict or opposition
5. interaction
6. representation or story

Other prominent researchers in the field mostly concur with Prensky's six elements. For example, the widely cited Salen & Zimmerman (2003) describe a game as a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome. There is no definitive description of what makes a game a game in the literature, but there does appear to be agreement on the common elements that are necessary, and various games exhibit these elements to a greater or lesser extent depending on the nature of the game itself. It is thus not always immediately possible to determine whether an activity constitutes a game or not; it is necessary to consider the involvement and actions of the players, the context in which the activity takes place, and what kinds of interactions arise from players taking part in the game. In doing this, the question appears to become one not of whether an activity is a game or not, but whether it is a good game.

In reviewing the six elements described above in relation to the design and final implementation of BuildIt, we see that the activity that learners took part in included clear *rules*, *goals*, *outcomes*, and *feedback*. Players were aware of the aims of the task, how they were to set about attempting to achieve those, and they had interactive means to carry out their actions. When they performed actions, they received feedback about the effects of those actions within the game.

However, the BuildIt activity did appear to exhibit a lack of *story*, *interaction* and, perhaps crucially, *opposition*. The first two of these could easily be enhanced, for example by giving players more complex backstory or a more interactive narrative that could unfold during the task. However, the lack of opposition in BuildIt, from either the system or from other players, is a factor that merits further consideration due to its prominence in related studies of game design

Dynamic opposition in games has been cited by numerous sources as being a central feature of computer and video games (examples include Salen and Zimmerman, 2003; Squire, 2004; Habgood, 2005; Habgood and Overmars, 2006; Squire and Jan, 2007). and without such opposition a game is more likely a form of puzzle where a player is simply searching for a solution (Crawford, 1982). Opposition can come from other players, be they direct opponents or simply other people playing the same game whose actions impact on the current player. Alternatively, the system itself may provide opposition, through either random events or state changes, or dynamic artificially intelligent opposition that counters the player's own actions (Bjork, 2004). However we choose to define opposition, it is clear that BuildIt does not include this feature: players were required to find a solution to a problem, and despite them not having access to important information (the partial disclosure pattern – see (Bjork, 2004) and having to discover data along the way, they faced nothing that impeded their progress other than this lack of information. In short, there was no dynamic opposition, and so in effect they were solving a puzzle where the information they required to find a solution was accessible only by performing the actions required of them by the game (movement and performing Estimate and Build actions).

On these grounds it is possible to argue that BuildIt was not a true game, or at least was not a good one, since it failed to make the most of a central feature of successful games and did not provide dynamic opposition for the players.

It was clear when we first designed the BuildIt activity that it lacked this dynamic opposition, and so did not fulfil the original intention of making the most of game features to engage learners in the task. However, it was felt that including opposition of this nature would require the introduction of an artificial layer of 'gameness' that could actually detract from the desired 'clean' design that would allow us to assess impact on learner behaviour. For example, dynamic opposition could have been included by having random events that would affect the players' budgets, or by having an AI opponent who was also searching for suitable building sites and thus blocking player options on a turn-by-turn basis.

However, when we play-tested the first version of BuildIt, we found that players were engaged and *responded to the task as though it were a game*. This continued throughout the study. Learners appeared to be genuinely engaged by the task, asking questions about their performance and the underlying nature of the activity, demonstrating a willingness to persevere when they encountered failure. Above all, they looked like they were enjoying it.

Reflection on the original design goals for this research and on related projects suggested that including dynamic opposition might actually detract from our goal of assessing the impact of a location-based game on in situ reflection. Teachers at the school were happy with the design, and it appeared to meet our goals for conducting an evaluation of a location-based learning game, and we could not determine a way of introducing dynamic opposition that did not appear to negatively impact on the flow of the activity, i.e. it was possible that players might think that in fact it was too game-like and that important factors were due to virtual, in-game features rather than features of the physical environment. This highlights the inevitable tension that arises when attempting to follow design patterns and guidelines whilst simultaneously wishing to build an effective learning activity that can also enable effective observation and elaboration of learner behaviour. It seemed it was impossible to satisfy all of the identified requirements and still have something that could be implemented and deployed effectively and in a timely fashion.

However, we believe that dynamic opposition may not be the essential element that it has previously been hailed to be, at least not for augmented reality games such as BuildIt. The 'gameness' of the activity might not require any dynamic opposition at all, but could arise from a combination of the facets of the task. This view is also shared by some in the field, with Juul (2003; 2008) in particular proposing an alternative conceptualisation of games as having player *effort* rather than opposition as one of the central features (also noted by Montola, 2009).

If this is true, then it may be possible to create more game-like activities that give rise to motivation and engagement of the sort desired for learning, without recourse to the kind of conflict or opposition that is seen as the defining characteristic of contemporary video games – mobile games for learning might not need to incorporate the kind of opposing elements that are found in popular video games, but could exploit the tendency for learners to respond to these interactive experiences as engaging, motivating and structured activities.

The context for which BuildIt was designed and in which it was eventually deployed inevitably had an impact on its design. The activity had to fit into a one-hour slot and be easy enough for students to pick up and engage with in a short time. These constraints meant that BuildIt had to 'fit' into the 'space' that we had in which to run it. This is the challenge of implementing and deploying a mobile learning game within a real-world context, which gives rise to a new set of constraints not considered with the initial theoretical foundations discussed in Chapter 2. This challenge is discussed below in 8.2.4.

8.2.4 Theory versus practice: the problem of implementation and deployment

We sought to implement an augmented reality game that could support outdoor learning and which included elements of the physical environment in the learning activity. The original goals for this learning game were based on the theoretical foundations of enquiry learning, experiential learning, and situated learning, as described in Chapter 2. However, we found that the design of the game, as well as its eventual deployment, was ultimately shaped by the context in which it was deployed, and the constraints present within that context, as well as the theoretical foundations we started from.

Perhaps the most significant effect of this context was the realisation that a game that involved dynamic conflict and also required interaction with the physical environment would be difficult to implement for the one-hour slot available at the school where the trials for Study 2 took place. This time constraint also impacted on other elements of the activity that could have been expanded to provide a much more in-depth activity. The backstory, task goals, and available tools and game actions all could have been expanded to provide a more game-like experience. It was also difficult to embrace the ideas of experiential, situated, and enquiry learning approaches because of the constraints on time and hence complexity. We found that only those elements that were deemed most essential could be included.

We started with the principles that we had identified and we attempted to work forwards from them, whilst simultaneously looking at the resources and context(s) available to us. Big learning theories like “learning by doing” have to fit within the time frame offered by a school setting. For a fully-funded educational innovation programme this will most likely have protected time on a weekly maybe even daily basis, but for research (especially doctoral research) we must be content with what schools and individual teachers can offer. This means that we are testing big theories in small spaces, so we are trying to make our ideas and the theoretical principles we want to explore fit into the space that we have.

In terms of BuildIt, this meant we found that we could not offer a rich *backstory*, we could not allow leaners to fully take on the *role* of site surveyors with a range of *tools* and support reflection across contexts because we simply did not have the time.

These aspects of backstory, roles and tools have all been highlighted as important elements for successful education games (for example see Gee, 2005; Gee, 2005). Instead, the focus became "how can we make the most of the hour the children will be outside?" This brought a whole set of constraints to bear on the possible complexity of the BuildIt activity itself: students had to be able to play it in an hour, without much of that hour being taken up with them learning how to do it.

So BuildIt could possibly have been a much more complex activity, but it would have taken more time to play. Expanding the time allowed for playing the game, or allowing multiple play sessions, would have led to increased demands on teacher time in terms of coordinating the activity and the learning around it. Augmented reality learning is expensive in terms of both the equipment involved in deploying it and the time required to orchestrate it successfully.

8.3 Support for enquiry learning by BuildIt

In this section we critically consider the use of BuildIt for supporting field-based enquiry learning. Where appropriate, we draw comparisons with the Paper condition used in Study 2, but this section focuses primarily on the efficacy of the BuildIt game running on the PDAs.

We discuss the results in relation to the model of science learning presented in Chapter 2, adapted from McFarlane (2000), shown below in Figure 49:

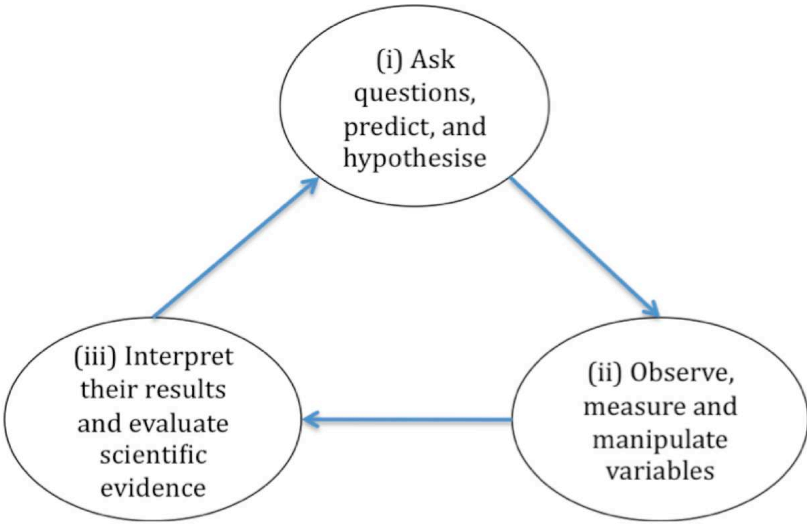

Figure 49: a model of science learning (adapted from McFarlane, 2000)

Since the aim of BuildIt was to explore whether a situated game could support enquiry learning, this model provides us with a framework to discuss the results of the evaluation of the BuildIt game presented in this chapter.

8.3.1 General processes

We saw evidence that learners in the PDA version were engaged in a range of activities related to and required for enquiry-based learning. They were seen to form hypotheses, generalise findings, discuss alternatives, and perform comparisons and evaluations. All of these fit well with existing models and requirements identified for enquiry learning, such as McFarlane (2000). In general, we found that planning and reflecting activities were more evident for the PDA version than for the Paper version, and results from our video coding suggest that learners using the PDA exhibited cycles of Plan-Act-Reflect more than learners using the paper materials. We cannot compare PDA and Paper versions directly for activities related to the Act category, since in the Paper version there were no equivalent 'Act' behaviours. However, the results do suggest that a more reflective approach was engendered by the PDA activity.

The nature of the learner activity in the PDA and Paper version appeared to be qualitatively different. Learners who used the BuildIt game on the PDA demonstrated active, reflective activity punctuated by episodes of decision-making. By contrast, learners who used the Paper materials appeared to be engaged in a search-like activity, poring over the available data looking for a solution without reflecting on the data they found. The role of the BuildIt activity on the PDA in prompting reflection appeared to be key: learners responded positively to results that surprised them by engaging in discussion and reflection. Although even learners using the PDA did not articulate any predictions, their reactions to unexpected data indicated that they had at least some unvoiced notions of what they were expecting. However learners using the Paper materials did not receive any such prompts, and were not seen to engage in the same kind of reflective discussions. It is possible that they too had notions of what to expect from particular combinations of buildings and sites, but they exhibited no surprise when looking at the printed data and so we would argue that the data presented via the game had a greater capacity to surprise, perhaps because the BuildIt game also had a greater capacity to engender implicit predictions.

We also found that, in line with contemporary views on the nature of the enquiry learning process (Reiff *et al.*, 2002), learners did not follow a strictly linear or cyclical path – as might be suggested by Kolb's cyclical model (Kolb, 1984) – but instead were engaged in bursts of clustered activity related to one of either data collection, interpretation, or hypothesis formation. The Plan-Act-Reflect cycles found by analysing the video coding data (in the PDA condition) suggests cycles, but the presence of this particular pattern does not preclude the presence of other patterns, either similar or dissimilar. When we looked at the actual behaviour of the learners we found that these cycles were punctuated by other (related) activities such as references to the environment, argumentation and discussion.

8.3.2 Asking questions and hypothesising

We saw clear evidence that the BuildIt game on the PDA prompted more asking of questions and suggesting hypotheses than the Paper-based version, and the grounded theory analysis indicated that these activities were closely associated with the environment and with the game constraints.

However, learners asking questions and generating hypotheses does not automatically lead to effective learning if they are not asking *appropriate* questions and generating *appropriate* hypotheses. Similarly, these activities must take place at appropriate times and be appropriately applied.

We did not see any evidence of students asking questions or generating hypotheses that were overtly inappropriate. However, we did see some evidence that learners failed to ask questions when they would have been helpful, in particular asking questions of their own reasoning (or that of their partner). As discussed in 2.4.4 learners have problems linking theory to experimentation, and our observations of student activity during the BuildIt trials accords with this. Learners were able to form predictions but were not apt to conduct investigations (no matter how simple) to confirm or dismiss those predictions, so this aspect of the task is one where further extensions to games like BuildIt could provide much needed scaffolding for students (see 8.5).

Also, in line with the problems identified in 2.4.4, we saw that students' misconceptions could be 'sticky', and that once they had conceived of a particular explanation or were considering particular aspects they tended to stick with those views and were unlikely to change them. The clearest example of this was learners' tendency to consider current uses of the environment as an important factor in the task: once they had decided on this as a reason for choosing a particular option they did not revisit their options. This was also true for other factors: students were not inclined to step back and reflect on their own decisions once they were made. This again is an area where activities like BuildIt could be used to introduce more prompts to help students follow more successful enquiry processes, and to reflect not just on information received but also on their own learning processes.

8.3.3 Interpreting results

Learners demonstrated clear evidence of engaging in 'interpretation' behaviours, through comparison, evaluation, and reflection. Learners were often seen to be searching for the 'best' option, and having to manage the resources available to them meant that the game structured their planning in this regard. Evaluation was seen to be a dynamic process, influenced by the current state of the game, demonstrating that the game itself had an impact on their reasoning.

We found that learners in the PDA condition expressed their surprise when responding to the results of game actions, indicating that they were making some predictions, and then being prompted by unexpected results. In the Paper condition, they showed little evidence of this reaction to surprise and subsequent discussion. There are two possibilities: i) they made predictions, but did not verbalise them at all and got no opportunity to respond to surprising results; or ii) they did not make predictions at all. In either case, the Paper version appeared to be much less successful at prompting discussion and reflection than the PDA version.

As identified in Chapter 2, *reflection* is a key component of an effective experiential learning activity (see Ackermann, 1996; Rogers and Price, 2004). We saw that reflective activity was clearly exhibited by learners using the PDA to play the BuildIt game, and moreover their discussions during the task were often reflective in nature, drawing on aspects of the environment, the game, and their previous knowledge to arrive at conclusions and ideas for their next actions in the game. We mentioned above the apparent link between reflective episodes and obtaining unexpected results from the game – the BuildIt on the PDA activity appeared to be particularly successful in this respect. We have no recorded instances of learners stating that the results they obtained matched their expectations. This suggests that unexpected results were common, but since we also observed no instances of learners becoming 'stuck' because of such results we believe that this mechanism was an effective one for driving the game forwards. This fits well with learning theory under the constructivist paradigm: recognition that one's current conceptualisation of the world leads to *accommodation*, a change in the learner's understanding to fit with the new knowledge, and this process is one important basis of learning. In the case of BuildIt, we saw that the PDA game gave rise to these instances of accommodation through presenting learners with information that did not meet with their expectations, and they responded favourably to this. The Paper materials contained the same data, but we did not see evidence of learners being surprised by it. This suggests two possibilities:

i) learners did not form any predictions at all in the Paper version, and so were not surprised by any data they came across

ii) learners did form predictions in the Paper version, but the mechanism of discovering the 'unexpected data' was not as effective in producing an emotive response as in the PDA condition.

In either case, it appears that this mechanism of surprising learners with data that do not match their predictions, whether voiced or not, is an effective means for prompting discussions.

8.3.4 Observing, measuring, and manipulating variables

The BuildIt game did not support the manipulation or observation of 'variables' in a scientific sense. The idea of manipulating variables was represented in the game as the selection of particular buildings for particular sites, with the result of these 'variations' being visualised a report showing costs and risks for that combination of site and building.

What we hoped to see during the game was learners using this mechanism to test their hypotheses by selecting specific sites to confirm or disprove their ideas. For example, if a student reasoned that a site on concrete would cost less, they could have obtained an estimate from a site with a concrete surface and then looked for site which was as similar as possible to the first site except for the surface type, in order to test their ideas about the impact of surfaces on build costs.

We did not see any evidence of this kind of activity during the game. Learners did form hypotheses, but did not appear to make any plans to test their hypotheses in any way. When they obtained data that supported or disproved a hypothesis they commented on this, but did not make any plans to specifically obtain such feedback. It seemed that learners were content to be passive recipients of data revealed by their actions within the game, but were not active explorers of that data and did not take any steps to attempt to test any predictions they had. As noted above in 8.3.2, students do tend to struggle with making this connection between theory and experimentation, and this is what we saw during the trials.

8.3.5 Learner Strategies

Whilst conducting the grounded theory analysis we also made notes on the strategies learners employed during the task, both in terms of game-playing and learning processes. Our analysis is less detailed in this area due to our focus on developing a grounded theory of learner behaviour rather than identifying strategies, but our analysis did reveal a number of issues relevant to future work in this area.

We observed a number of strategies that learners employed whilst playing the game, many of which were counter-productive and which future versions of BuildIt or related activities may be able to help avoid, whilst at the same time encouraging more effective strategies.

Learners tended to make definitive statements (for example "That'll be cheaper because it's concrete"), sometimes related to observations of the environment and sometimes based on speculation, and these statements quickly became accepted as fact within their discussions with their partner. This is discussed above (see Section 7.4.3.1.7.2) in terms of *minimal exchange* (where learners made unchallenged comments or appeared to have a shared understanding) and also in the *belief as fact* behaviour that many learners exhibited.

Belief as fact is a particularly salient issue because in many cases their beliefs were based on what they observed from the environment, suggesting that the physical features around them, as well as having a positive impact on the learning process, may also inadvertently give rise to undesirable foci on aspects without appropriate critical thinking. For example some learners discussed placement of buildings in relation to how easy it would be to access one building from another, which was not a factor in the game and did not relate to any of the information they were given.

Another major tendency was for learners to focus their attention on a single factor at any one time, ignoring other factors or at least paying less attention to them. This meant that learners would look for sites that were good to build on because of cost, but would fail to check that the risk factors were similarly attractive. There was some evidence that they failed to integrate their reasoning across the two core factors of cost and risk involved in the game, and focused on finding good sites rather than reasoning about what it was that gave rise to the characteristics of a particular site. So, despite us seeing evidence of critical thinking skills required for enquiry learning, we also saw evidence that learners could get stuck with concrete thinking and often failed to conceptualise the task as having to ask questions about what they observed.

8.4 Problems solved

In this section we review the problems addressed (at least partially) by the use of the BuildIt game to support students' enquiry learning in the field.

8.4.1 Surface level engagement – the 'treasure hunt problem'

The tendency of learners to focus on the surface level of a task and on performing simple actions within an interactive environment was observed in Study 1, and reported in Environmental Detectives (Squire and Klopfer, 2007). BuildIt appears to have effectively addressed the problem of learners engaging only with the surface level of a task. Learners were motivated to play the game and to understand the events and information presented to them. They were not overly focused on the gathering of data, or on the simple performance of in game actions. We believe that the constraints within the game (the limited number of Estimates) were an effective way of achieving this. We did not see any evidence of learners reacting negatively to these constraints; there were no comments about the game being too hard or frustrating, so we believe that learners were genuinely motivated to play and responded favourably to the constraints.

8.4.2 Coordination of activities

Learners appeared to be able to coordinate their activities and we observed a lot of activity that was related to planning. A caveat to this is that learners with the paper-based materials also exhibited few problems coordinating their activities. However, the task for them was much simpler and could be performed without moving between locations. They also did not have to make any decisions about options to follow-up. The BuildIt game appeared to be at least as successful in encouraging the coordination of self-initiated activity as the Paper version, for a more complex task.

8.4.3 Reflection in situ

Both the quantitative and qualitative results indicate the success of BuildIt in promoting reflection in situ. We saw an abundance of examples of learners reflecting in the field, discussing the environment immediately before them, more distant sites, and the game events and constraints they experienced during the task.

8.4.4 Problems inherent in experiential learning environments

In Chapter 2 we identified a number of problems that have been cited for experiential learning environments, namely the challenge of encouraging learners to be self-motivated (McCullan and Cahoon, 1979; Miettinen, 2000) and of encouraging them to reflect on their activities (Vince, 1998). From the results of Study 2 we believe that the BuildIt game was successful in engendering self-motivated activity from the learners and, as outlined above, in encouraging reflection in the field, thus addressing these particular problems. However, creating and deploying experiential learning activities may involve other challenges, and we do not claim to have developed a general solution to these challenges, only that the BuildIt game appeared to be successful in this case for these particular issues.

8.4.5 Enquiry learning problems

As discussed in Chapter 2, there are number of challenges involved in creating successful enquiry learning activities. Students can i) fail to recognise multiple causalities, or tend to focus on just one, and ii) fail to recognise cumulative effects, or even think that causes may vary between multiple investigations (Keselman, 2003). Also, children at the start of Key Stage 3 of the UK National Curriculum (the students who participated in Study 2 were at this stage) have little idea about the nature of experiments and that scientists predict the results and then test these predictions. We observed these problems, and others, in the evaluation of BuildIt, indicating that the strategies we used to motivate learners and to encourage reflection were not sufficient to address these problems. We did not expect this to be the case, and our primary aims were to encourage reflection in situ and to support the general enquiry process. These outstanding problems are discussed in the Section 8.5 below.

8.5 Possible extensions to BuildIt

We believe there are a number of ways in which the BuildIt game specifically could be enhanced to address some of the above issues. Some possibilities are outlined below.

8.5.1 Incorporate dynamic opposition

As discussed above in 8.2, dynamic opposition was a game characteristic that was absent from BuildIt (see above for a discussion). Future versions could include dynamic opposition as a way of engendering a more game-like activity and to enable investigation of whether such opposition can support reasoning and decision-making.

8.5.2 Prompts to ask questions at key points

The BuildIt game has a predictable pattern of activity:

- Move to location
- Take Estimate or Build something
- Interpret results of action

- Consider other actions
- Move to new location

This pattern maps relatively well on the sequence suggested by models of science enquiry as presented in the literature of ask questions, interpret results, and manipulate variables (for example McFarlane, 2000; McFarlane and Sakellariou, 2002). Given this predictable sequence we could include prompts at key points to encourage learners to ask questions and to critically assess their own reasoning before committing themselves to action. It would be desirable to build these prompts into the game to maintain intrinsic motivation (Malone, 1980); this could for example be achieved by having the player receive messages from their 'boss' prompting them to carry out certain checks on their progress.

8.5.3 Build in articulation of predictions

Students not articulating their predictions is a challenge for situated learning in general (Herrington and Oliver, 1995). We saw that learners made predictions but did not express them. As a result, they could have failed to make the most of those predictions in performing the task.

We believe that BuildIt could be modified to include generation of predictions as an intrinsic part of the game. For example, learners could be required to make a prediction whenever they request an Estimate at a site. We could make this action rewarding by providing extra in-game resources if their prediction matched the actual report from the Estimate action (within certain tolerances). This would motivate learners to i) make predictions, and ii) articulate and discuss them.

8.6 More general implications for designing situated mobile learning games

This section presents a number of recommendations for the design of situated mobile games based on the results of the studies presented in this thesis.

8.6.1 Encourage articulation

We found that learners appeared to make predictions, but they did not express them – support for expressing their hypotheses is important in situated learning activities (as noted by Herrington and Oliver, 1995). Our evidence suggested that the students were forming ideas and predicting what would happen, but they were not articulating their thoughts and hence were not making the most of their reasoning. This is a key requirement that needs to be addressed. We suggest one possibility for extending the BuildIt game in Section 8.5.3.

8.6.2 Exploit surprise and unexpected results

Learners appeared to be clearly aware of the ways in which they could fail in the game, and they were highly motivated to complete the game without failing. However, failure (or impending failure) appeared to be less of a prompt to reflect than surprise and unexpected results. As discussed above, this maps well on to constructivist learning approaches (Section 2.4.6.3.2), and the results of the BuildIt evaluation suggest that appropriate use of surprise could be an important design strategy to promote reflection in the field. This also fits with observations from projects such as Ambient Wood (Rogers *et al.*, 2004), where unfamiliar results arising from familiar actions have engaged learners' attention.

8.6.3 Scaffold strategies and address problems in enquiry learning

Whilst we were successful in promoting reflection and in providing an effective framework that helped learners to coordinate their activities, we still saw problems that have previously been reported for students engaged in enquiry learning activities. Learners playing the BuildIt game did not appear to test out the hypotheses they generated using the game actions, and as a result were not fully engaged in an enquiry learning task. The implication here is that learners require much more explicit support not just for generating ideas but also for testing them against new data. The tendency for learners to derive concrete facts from single observations (observation becomes belief becomes fact – see Section 7.4.3.1.7.2) also indicates that learners require more support in these aspects of the activity.

Furthermore, we observed that learners responded to the problem-based nature of the task by forming a general notion of what they were required to do, but did not show any evidence of forming an over-arching strategy or plan whose scope encompassed the entire task. This may well be a type of game-playing style that we need to either *design around* (by structuring the activity differently) or *design for* (by accepting that activities of this type will be played as games and hence players will not form plans but instead engage in responsive behaviours).

Potential solutions for these specific problems include designing the game to include more structured activities. Using *scripts* to help scaffold enquiry learning is an approach that has been employed in previous mobile learning projects (for example Collins *et al.*, 2008). It would be advantageous if such scripting could be intrinsic to the game so that we do not lose the motivation and coordination that arose from the BuildIt activity. This would require any prompts or instructions to have direct relevance to the game, and be intrinsic to it, rather than appearing to be unrelated and therefore extrinsic.

8.6.4 Designing around the environment

We found that the environment played a powerful role in the situated learning activity facilitated by the BuildIt game. Learners were prompted by what they saw and used the environment as a shared object in their discussions. However, they could be distracted by their existing knowledge of the environment and experience of how it was currently used, leading to them ignoring potential avenues in the activity because of erroneous beliefs arising from this previous knowledge. We believe the implication here is that whilst the environment can form a significant component of a situated learning activity, such activities need to be carefully designed to try to avoid negative influences from previous knowledge and experience. Care also needs to be taken that learners are not overly influenced by just what they see in front of them. In BuildIt this was at least partially addressed by requiring learners to move to other locations, in other activities similar mechanisms may be necessary.

As discussed above, the capacity for the environment to prompt reflection discussion and to provide a motivating environment for learners could be seen as significantly positive enough to overcome any difficulties that may arise through distraction due to prior knowledge or experience. However this will depend on the focus of the learning activity. If a learning activity is narrowly focused on specific elements and aspects of the environment that transpire to be susceptible to interference from previous knowledge, it could well be that such interferences will have an grossly negative impact on the activity. But a learning activity that has general exploration and reflective discussion as its aim could see great benefits from learners' tendencies to bring their existing knowledge to bear on new situations and problems.

8.7 Limitations of these studies

In this section we describe a number of limitations of the studies presented in this thesis. We refer mainly to Study 2, but these limitations are equally relevant to Study 1, since both were conducted at secondary schools and used the same basic design.

Due to time and resource constraints, the learning activities presented in this thesis were designed as one-off, standalone activities that involved the learners for little more than an hour. We had little opportunity for preparatory or follow-up work with the students who took part in the field trials, and as such we had to evaluate the activities in relative isolation. It would have been much more desirable to integrate the research with the work the students were doing in the classroom, and to look at taking that work outdoors, rather than providing an activity that was not related to anything they were currently doing in school.

Our studies used a relatively small number of participants at two schools, and as such the findings presented here may not generalise to other groups of participants or settings. In adopting a grounded theory approach we are deliberately setting out to explain and understand the activities we observed during this study and not seeking apply these findings elsewhere, other than to consider their implications for future work. We feel that we gained valuable insights into how mobile technology may be used to support field-based enquiry learning, but being able to run more trials under different conditions and with a wider range of students is desirable.

We also had no opportunity to assess long- or even medium-term impact on students' learning. After Study 1 we had the opportunity to visit the school again and meet with the students who had taken part, but unfortunately this was not possible after Study 2. Questionnaires distributed to the students were not completed. This highlights the difficulties of working with schools where staff and students already have commitments and little time to take part in research. A larger scale project with more resources of its own may well be better placed to address these problems, whereas an individual PhD cannot do so.

The challenges of running trials in schools were also highlighted by the tendency for some school staff to offer students sometimes too much support in carrying out the task, possibly interfering with the aims of the study. The problem is that to work with schools a researcher must by necessity work with other professionals who are not familiar with the aims of a controlled evaluation, and short briefings beforehand cannot change this. We were able to flag any excessive support offered to the students and factor this in to our analysis, but the potential for data to be influenced by non-researcher intervention is a real issue for performing evaluations in the 'real world'.

8.8 Future research

Follow-up research should begin with a more in-depth continuation of the grounded theory study presented here, and expand PaSAT (or use an alternative platform) to examine how other game mechanisms, in particular failure, and specific *game patterns* (for a review see Bjork, 2004), can be used to support enquiry learning outdoors. This review should also take account of contemporary trends in game design. For example, children today play online games that encourage social interaction – these aspects need to be included in order to meet the expectations of learners/players.

We deliberately focused on the gaming aspects of the task to explore the impact of specific game elements, but future research would need to be more aligned with curricular goals and content. The first step would be identify specific sections of the curriculum that would be appropriate for extended support with mobile games, and to run early trials using mock-ups to assess their suitability. This would enable the research to be integrated into the work being done by the children in the classroom.

A primary aim should be to assess short-, medium- and long-term impacts of the use of such games for learning. Some studies have assessed the longer term impact of experiential learning activities (Bernhard, 2001), but this remains a relatively unexplored area, and it is clear that transforming science learning into something more like science doing will require more systemic change than can offered or assessed by one-off, standalone trials of learning technology.

Future research should also aim to directly address the outstanding problems associated with creating situated enquiry learning activities. A systematic programme of research could explore the use of specific game elements and mechanisms to address these issues. We advocate the continued use of qualitative methods to describe and explain the processes that learners are involved in during situated enquiry activities. Data logging techniques exploiting the mobile technologies being used by the students would be beneficial, for example gathering contextual data from each participant and storing that along with video and audio footage to provide a comprehensive means of exploring learner activity.

8.9 Final comments

The research presented in this thesis has explored the use of games situated in a physical environment to better support students' enquiry learning processes. We found clear indications that games can prompt reflection in the field, and can provide a suitable framework for helping learners coordinate their actions and decide on what to do next. The studies we have reported show the continuing potential of games to be developed in this field to provide new and effective forms of learning experiences in physical environments, using mobile technologies such as handheld computers as facilitators for those experiences.

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Appendices

Appendix A

Student Consent form, Study 1

Mobile Learning Games Research Project

Dear Student,

I am a PhD student at the University of Nottingham, and I would like to run trials of some software I am developing at Djanogly Academy. The software allows children and teachers to design learning games that can be played using handheld computers (PDAs). The games involve moving around in spaces such as a classroom or playing field, interacting with other players using the PDAs.

The headteacher Mr Butler and the class teacher Mr Frearson have agreed to let me to run these trials at Djanogly Academy. The trials will be run at the school during normal lessons, and should take up no more than two afternoon sessions over the course of a two week period.

If you are happy to take part, please could you complete the form below. If you have any questions please feel free to contact me – my contact details are below.

To help with the evaluation of the software, I would like to make video recordings during the trials. The video recordings will be used only for research analysis and will not be made available to anyone else at any time.

Please could you complete and return the form below to indicate whether you are happy to take part in these trials. If you do not return the form, I will assume that you do not wish to take part. If you change your mind after giving consent, you can withdraw from the study at any point without having to give a reason. For anyone who does not take part, alternative activities will be available whilst the trials are taking place.

Thank you

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Supervisors:

Professor Mike Sharples
School of Education

Professor Claire O'Malley
School of Psychology

Please complete this form and return it to the school

Child's name:

I confirm that I am happy to take part in the Mobile Learning trials Yes / No

I confirm that I am happy for video recordings to be made during the trials for research purposes Yes / No

Signature:

Appendix B

Parent Consent form, Study 1

Mobile Learning Games Research Project

Dear Parent or Guardian,

I am a PhD student at the University of Nottingham, and I would like to run trials of some software I am developing at Djanogly Academy. The software allows children and teachers to design learning games that can be played using handheld computers (PDAs). The games involve moving around in spaces such as a classroom or playing field, interacting with other players using the PDAs.

I am investigating how these types of games can be used in schools to provide new learning experiences for children. I am particularly interested in the types of games the children will create, and how the software can be used for different parts of the curriculum.

The headteacher Mr Butler and the class teacher Mr Frearson have agreed to let me to run these trials at Djanogly Academy. The trials will be run at the school during normal lessons, and should take up no more than two afternoon sessions over the course of a two week period.

If you are happy for your child to take part, please could you complete the form below and return it to school. If you have any questions please feel free to contact me – my contact details are below.

To help with the evaluation of the software, I would like to make video recordings of the children during the trials. The video recordings will be used only for research analysis and will not be made available to anyone else at any time.

Please could you complete and return the form below to indicate whether you are happy for your child to take part in these trials. If you do not return the form, I will assume that you do not wish your child to take part. If you change your mind after giving consent, you can withdraw your child from the study at any point without having to give a reason. Your child may also choose not to take part at any point, without having to give a reason. For any children who do not take part, alternative activities will be available whilst the trials are taking place.

Thank you

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Please complete this form and return it to the school

Child's name:

I confirm that I am happy for my child to take part in the Mobile Learning trials	Yes / No
I confirm that I am happy for video recordings to be made during the trials for research purposes	Yes / No

Print name:

Signature:

Appendix C Pre- and Post-Task Quiz, Study 1

Name:

Name 2 types of ground surface that can have an effect on flooding, and say what effect each can have:

Name 2 types of flood defences, and say what are the advantages and disadvantages of each:

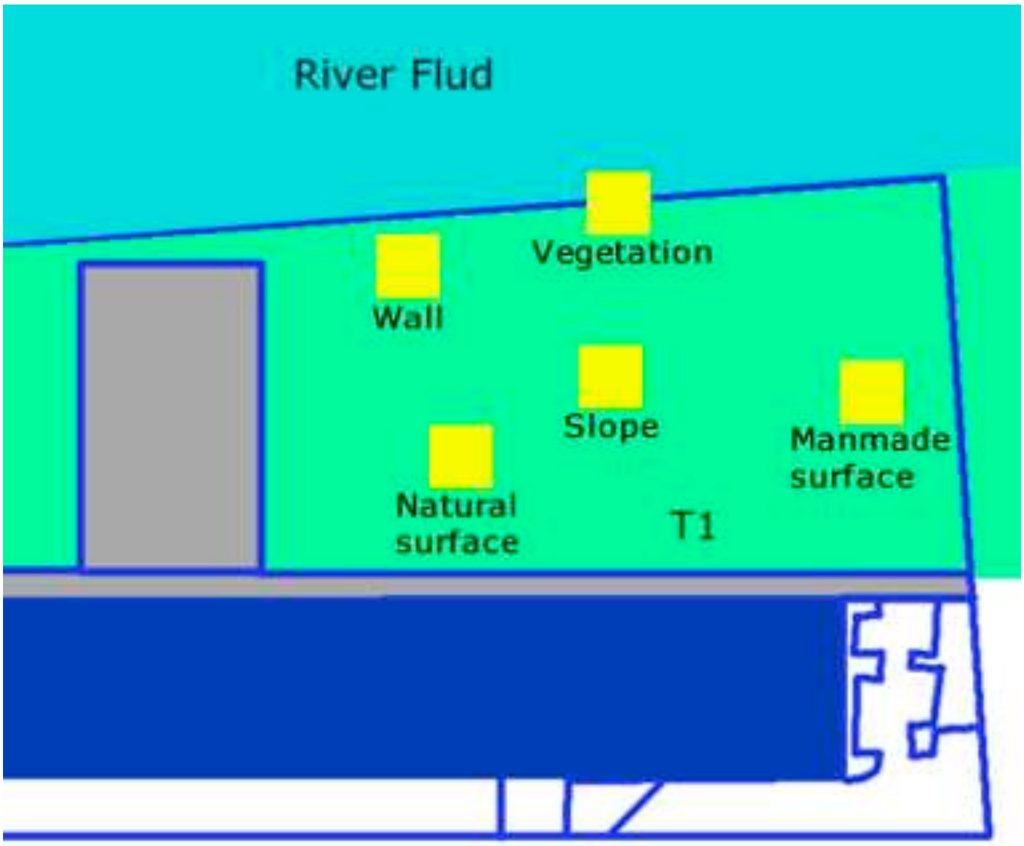
Flood defence	
Advantage	
Disadvantage	

	349

Flood defence	
Advantage	
Disadvantage	

Think of a reason why you might decide to deliberately flood a piece of land:

Appendix D Hotspot content from Study 1



Welcome to PASAT

Task 1: Explore the area

On your map there are several hotspots marked with a yellow square.

Go to these hotspots to learn about different factors that can affect flooding and the different types of defences we can build.

If you go to the top of the field you will find out why it is important to be thinking about flood defences around the school.

Take notes at each hotspot to help you remember what you have seen.

To learn about taking notes, see the instructions.

Hills and Slopes

Steep slopes can cause problems because water will tend to run down them quickly without having time to be absorbed into the ground. If the water ends up running on to a problem area like one with impermeable surfaces, there is likely to be a flood.

Where there are steep slopes that run on to flat areas, flood defences could help to slow the water down so it has time to be absorbed, or divert the water so that it goes somewhere else.

Q: Take a look around. What could we do to this slope to help slow the water down?

Natural Surfaces

Natural surfaces have no tarmac or other manmade surface on them. This means that when water flows over them, it can be absorbed into the ground. This is what normally happens when it rains. When there is a flood, there is more water to soak into the ground. If the water moves over the ground too quickly, or there are lots of impermeable surfaces, then there can be a flood.

Q: Look at the natural surface of the field, and then look at the surface of the car park. What will happen to water that flows each surface?

Impermeable Surfaces

Impermeable surfaces are surfaces that don't let water pass through them into the ground underneath.

Roads, pavements, car parks and playgrounds are all impermeable surfaces. Water cannot soak through them so it stays on the surface. When there is too much water, there is more likely to be a flood in areas where there are lots of impermeable surfaces.

New housing developments tend to have a lot of impermeable surfaces, so are more likely to flood than land that has not been developed.

Walls as Flood Defences

To stop high levels of water reaching areas we want to keep safe, we can build walls to hold back the water. For example we might built walls along the coast, or along a stretch of river prone to flooding.

Q: Look at the wall here and think of some reasons why building walls might not always be the best thing to do.

Clue: is the wall in good condition?

Trees and Vegetation as Flood Defences

Trees and other types of vegetation can help prevent flooding because

- they absorb a lot of water
- they stop water flowing too quickly over the land, giving it time to soak into the soil.

This is good if there are already trees and other plants in areas we want to keep safe, but what is the problem with using natural defences like this?

Q: make notes on the good and bad points of using trees and vegetation as flood defences

Clue: take a look at the tree - how old do you think it is?

Appendix E Student consent form, PDA version, Study 2

Mobile Learning Research Project

Dear Student,

I am a PhD student at the University of Nottingham, and I would like to run trials of some software I am developing at Thistley Hough High School. The software lets you take part in location-based outdoor learning activities using handheld computers (PDAs) with GPS. As you move around the school grounds the PDAs use GPS to track your movement so that you see information on the screen about the environment you are in. I am interested in finding out what the benefits are of learning about the environment by actively exploring it, and also in how gameplay can help to coordinate outdoor learning activities.

The headteacher Mr Haines and ICT teacher Mr Watts have agreed to let me to run these trials at Thistley Hough. The trials will be run at the school during normal lessons, and should take up no more than three one hour sessions over the course of a two week period. The trials will take place during May-July of this year.

To help with the evaluation of the software, I would like to make audio and video recordings of during the trials. The video recordings will be used for research purposes (including short clips being shown at meetings and conferences) but will not be made publicly available at any time. There is a separate section on the consent form to confirm that you are happy for recordings to be made and used in this way.

If you are happy to take part, please could you complete the form on the next page and return it to the school. If you have any questions or concerns please feel free to contact me or my supervisors – my contact details are below.

If you do not return the form, I will assume that you do not to take part. If you change your mind after giving consent, you can withdraw from the study at any point without having to give a reason. For anyone who does not wish to take part, alternative activities will be available whilst the trials are taking place.

Thank you

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Appendix F Parent consent form, PDA version, Study 2

Mobile Learning Research Project

Dear Parent or Guardian,

I am a PhD student at the University of Nottingham, and I would like to run trials of some software I am developing at Thistley Hough High School. The software lets students take part in location-based outdoor learning activities using handheld computers (PDAs) with GPS. As the students move around the school grounds the PDAs use GPS to track their movement so that they see information on the screen about the environment they are in. I am interested in finding out what the benefits are of learning about the environment by actively exploring it, and also in how the students' activities might be better organised by making it into a game that is coordinated by the PDAs.

The trials will be run at the school during normal lessons, and should take up no more than three one hour sessions over the course of a two week period. The trials will take place during May-July of this year.

To help with the evaluation of the software, I would like to make audio and video recordings of the students during the trials. The video recordings will be used only for research purposes (including short clips being shown at meetings and conferences) but will not be made publicly available at any time. There is a separate section on the consent form to confirm that you are happy for recordings to be made and used in this way.

If you are happy for your child to take part, please could you complete the form on the next page and return it to school. If you have any questions or concerns please feel free to contact me or my supervisors – my contact details are below.

If you do not return the form, I will assume that you do not wish your child to take part. If you change your mind after giving consent, you can withdraw your child from the study at any point without having to give a reason. Your child may also choose not to take part at any point, without having to give a reason. For any children who do not take part, alternative activities will be available whilst the trials are taking place. There is a separate form for students to provide their own consent to take part.

Thank you

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Appendix G Student consent form, Paper version, Study 2

Mobile Learning Research Project

Dear Student,

I am a PhD student at the University of Nottingham, and I would like to run trials of an outdoor learning activity at Thistley Hough School. The learning activity involves exploring the environment looking at factors that impact on building projects.

The headteacher Mr Haines and ICT teacher Mr Watts have agreed to let me to run these trials at Thistley Hough. The trials will be run at the school during normal lessons, and should take up no more than two 1 hour sessions over the course of a two week period. The trials will take place during May-July of this year.

To help with the evaluation of the software, I would like to make audio and video recordings of during the trials. The video recordings will be used for research purposes (including short clips being shown at meetings and conferences) but will not be made publicly available at any time. There is a separate section on the consent form to confirm that you are happy for recordings to be made and used in this way.

If you are happy to take part, please could you complete the form on the next page and return it to the school. If you have any questions or concerns please feel free to contact me or my supervisors – my contact details are below.

If you do not return the form, I will assume that you do not to take part. If you change your mind after giving consent, you can withdraw from the study at any point without having to give a reason. For anyone who does not wish to take part, alternative activities will be available whilst the trials are taking place.

Thank you

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Appendix H Parent consent form, Paper version, Study 2

Mobile Learning Research Project

Dear Parent or Guardian,

I am a PhD student at the University of Nottingham, and I would like to run trials of an outdoor learning activity at Thistley Hough School. The learning activity involves exploring the environment looking at factors that impact on building projects.

The trials will be run at the school during normal lessons, and should take up no more than two 1 hour sessions over the course of a two week period. The trials will take place during May-July of this year.

To help with the evaluation of the software, I would like to make audio and video recordings of the students during the trials. The video recordings will be used only for research purposes (including short clips being shown at meetings and conferences) but will not be made publicly available at any time. There is a separate section on the consent form to confirm that you are happy for recordings to be made and used in this way.

If you are happy for your child to take part, please could you complete the form on the next page and return it to school. If you have any questions or concerns please feel free to contact me or my supervisors – my contact details are below.

If you do not return the form, I will assume that you do not wish your child to take part. If you change your mind after giving consent, you can withdraw your child from the study at any point without having to give a reason. Your child may also choose not to take part at any point, without having to give a reason. For any children who do not take part, alternative activities will be available whilst the trials are taking place. There is a separate form for students to provide their own consent to take part.

Thank you

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Appendix I Video coding scheme for Study 2

Coding Scheme for Study 2

Activities:

What activity are the pair engaged in?

There may be some overlaps between these activities, so 2 coding tracks will be used

a01	Planning	talking about actions to take, deciding on what they should do next, making suggestions about what to do without any reflection
a02	Reflecting	talking about what they have seen, or what they know, what has happened, without any planning
a03	Combined planning & reflecting	Operationally is it very hard t separate planning and reflecting, so this category includes instances that fit both planning and reflecting simultaneously
a04	Discussion	(may include planning & reflection combined, cannot separate)
a05	Ask a question	asking a significant question that requires an answer before they can continue, not part of general discussion/planning/reflecting
a06	Estimate	using the PDA to obtain an estimate (in paper version, calculating the cost or risk of putting a building in a

		particular location)
a07	Build	using the PDA to build a building (in paper version, calculating the cost or risk of putting a building in a particular location, and writing it on the worksheet)
a08	React to game event	a direct response (positive or negative) to a build or estimate action, immediately following the action, and not characterised by planning, reflecting, or discussing eg. "Oh no that's really expensive"
a09	Agree	a significant agreement on a course of action or assessment of information or situation, ie not a simple "yep" during discussion, but a substantial agreement following a disagreement
a10	Disagree	a significant disagreement on a course of action or assessment of information or situation, where one partner shows firm disagreement with what their partner suggests
a11	Suggest theory	a suggestion about the underlying mechanics of the task, ie why a building is expensive or risky in a particular location
a12	Test theory	performing an action (estimate or build) intended to directly test a theory previously stated
a13	Form a goal	deciding on a goal that needs to be achieved to progress in the task

a14	Gather information	gathering information (costs, risks, environmental characteristics)
a15	Arrive	arrival at a new location (for paper version, arrival at a new location was not as significant an event, so it was coded as they stopped moving to perform an activity, such as discussion etc)
a16	Response to failure (or threat of failure)	a direct response to a game event they perceive as failure, such as an estimate or build showing more cost or risk than they expected
a17	Prompted	They are prompted or given information by a teacher or researcher that helps them to move forward or make a decision. May be in response to a question, or spontaneous prompt Prompting does not include provision of basic info that is generally available for the task, ie reminding them what to do, how to do it etc
a18	set off	they set off heading for another building site
a19	Off task	any activity not related to the learning activity
A20	Take notes	Taking notes during the task (for the paper version, this is writing their answers on the worksheet – no pairs took other notes during the paper version)
A21	Stuck	They get stuck with the task, saying they “don’t get it”, don’t know what to do

Tools:

Learners will use the following tools to carry out the above activities.

t01	PDA	the PDA they are carrying
t02	Paper	paper notes for taking notes during the task
t03	Speech	talking to their partner, a teacher, or the researcher

Sources of information (Tool 2)

When learners are gathering information, referring to knowledge, or asking questions there will be a clear source for that information, coded as follows.

s01	Knowledge	previous knowledge, reference to anything they knew before starting the task
s02	Notes	referring to notes they have taken during the task
s03	Task knowledge	referring to any information they have collected during the task, but which is not in written form (or not referred to in written form)
s04	Partner	their partner for the task
s05	Teacher	any member of school staff present during the task
s06	researcher	the researcher running the trial

References:

Learners are expected to make explicit references to a number of items during the task, with the following being salient for the analysis.

r01	Environment	any references to **the features of** actual physical environment in which the learners are carrying out the task, expected to be in relation to the placement of buildings, eg "It's expensive there because it's on grass" Must include a reference to actual or supposed features of the environment eg "let's put it here cos it's high up", not simply locative references such as "that one is over there" But locative references could be significant, if relative locations are being discussed as better or worse, eg discussing how long it would take to walk to a building from the existing buildings
r02	Task constraints	any reference to the constraints of the task (and current state of constrained variables) that impact on decision making, such as the limited budget and risk allowance, limited number of estimates and so on. eg. "We've only got 3 estimates left so let's do one here, and there, and then on the grass" "Shall we have this one cos it's only 10 there"

r03	Buildings	reference to the buildings they are required to build, ie their characteristics, costs, heights, and any other inferred characteristics
r04	People	references to experimenter, teachers
r05	Materials	reference to the materials used to perform the task, including the paper booklet, the worksheet, the UI and the content of the PDA

Gestures

g01	Pointing to location	Pointing to another location when referring to it
g02	Physical indicator	Using gestures to indicate size or relative position

Coding Protocol

30 seconds watched and then coded so that codes represent correct sequence of events. Actual timings not crucial, sequence is important. Code blocks set so as not to overlap 30 second boundaries.

Appendix J Open coding categories from Study 2

Open Coding Categories after Axial Coding/Clustering

action
action for info, not winning
assumed sharing
belief as fact
blame
caution
Checking
checking actions match agreed plan
checking on consistency
comparison
conclusion reached
conditional planning
constraints
Contemplating failure
current location as focus
decision making
definite stop
devolved choice
diffused responsibility
disappointment
disbelief
disproportionate thinking
elimination
embarassed
env as artefact in discussion
env as mediator
environment as prompt
environment influences planning
environment influences thinking
Environmental Properties in Discussion
estimate of effort
evaluation of performance
exclamation
exploration, not reasoning
factor interaction
faux discussion
fitting actions to location
focus on data not causes (was immediacy)
forgetting
form a plan
frustrated
game as shared artefact

gathering info
generalisation
getting a feel
go with what is known
Goal setting
going beyond the brief
guess
historical actions as resource
historical influences
hope not logic
hypothesis
id need~ memory
indecision
integration
joyful
limited by physical constraints
literalness
location as focus
looking for comparison
minimal exchange
modify each other's perceptions
motivated
motivation, intrinsic
moving off
negative reaction to result
no firm commitment
overgeneralising
pacers
partner
perceived difficulty
permission
physical char ref
plan sequence
planning actions
planning distinct from action
planning question
post-hoc realisation
process as well as outcome
proximity
qualifiers
question
question to partner
questioning
realisation
reasoning
reasoning about game
recognition of optimal data
reflection
reflection on building process, not just outcome
relative evaluation

reliance on actual facts
removal of PDA prompts reflection
replanning
required thinking
resource managment
resultAsPrompt
retrace
review state after action
reviewing
rhetorical
sad
satisficing
search, not plan
Self-initiated
sequence
sequential plan
shock
should be
single factor
single factor single time focus
single factor strategy
Statement of belief
strategy - most expensive first
strategy - opposite
strategy info then action
strategy~ 1 factor then another
strategy~ best chance estimate
subvert
suggesting plans
suggestion
suggests
surprised
taking time to decide
uncertainty
unknown info
unspoken reasoning
urgency
using constraints of task to filter possible actions
virtual resources have value
wait for info

Appendix K Raw data from Study 1 Quizzes

Outdoor																					
	Pre										Post (scored for comparison to Pre)										
	1	2	3a	3b	3c	4a	4b	4c	5		1	2	3a	3b	3c	4a	4b	4c	5	score	improvement
abba	2	2	2	2	2	2	2	2	2	18	3	3	2	2	2	2	2	1	2	19	1
billy	0	0	0	0	0	0	0	0	0	0	3	3	2	2	2	2	2	2	0	18	18
saad	0	0	0	0	0	0	0	0	0	0	2	0	2	2	1	2	2	1	1	13	13
dominic	0	0	0	0	0	0	0	0	0	0	2	2	2	1	0	2	1	0	2	12	12
sabah	2	2	2	2	0	2	2	1	1	14	2	2	2	2	1	2	1	1	1	14	0
faiza	2	2	2	2	0	2	2	0	1	13	2	2	2	2	1	2	2	1	1	15	2
callum	0	0	0	0	0	0	0	0	0	0	3	3	2	1	1	0	0	0	2	12	12
charlotte	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	1	17	17
																			average	15	9.375
																			st dev	2.72554	7.288689869
Indoor																					
	Pre										Post (scored for comparison to Pre)										
	1	2	3a	3b	3c	4a	4b	4c	5		1	2	3a	3b	3c	4a	4b	4c	5	score	improvement
Rhiannon	3	2	2	1	2	2	2	2	2	18	2	2	2	2	2	2	2	2	3	19	1
George	3	0	2	2	2	2	2	0	0	13	3	3	2	2	2	2	2	2	0	18	5
zara	2	0	0	0	0	0	0	0	0	2	2	0	1	1	0	0	0	0	0	4	2
peter	2	3	0	0	0	0	0	0	1	6	2	0	2	2	3	0	0	0	0	9	3
neelam	2	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	0	16	14
thomas	3	2	0	0	0	0	0	0	1	6	2	2	2	2	2	0	0	0	2	12	6
rachael	2	1	1	0	0	0	0	0	1	5	2	2	2	2	0	0	0	0	0	8	3
vedat	2	2	0	0	0	0	0	0	0	4	2	2	2	1	2	0	0	0	0	9	5
nicole	2	2	2	0	0	0	0	0	0	6	3	2	2	2	2	0	0	0	0	11	5
hari	2	1	2	2	1	1	1	1	0	11										0	-11
										6.888889									average	11.7778	4.888888889
										5.278363									st dev	4.99444	3.789605667
Grey indicates data excluded because participant not present at pre or post test.																					

Appendix L Worksheet provided for Study 2 Paper condition

Use this worksheet to write down where you think the buildings should go. For each building, write down the location you choose, how much it will cost there, and what the risk will be.

When you have done all 3 buildings, write your total cost and risk at the bottom of the page.

Your total cost must not be more than £800,000.

Your total risk must not be more than 160.

Dining Hall	
Location	
Cost	
Risk	

Media Studio	
Location	
Cost	
Risk	

Teaching Block	
Location	
Cost	
Risk	

Total Risk	
Total Cost	

Appendix M Raw data from Study 2 video coding

(starts next page)

	A : activities	B : agree	C : building	D : bust	E : calculate	F : disagree	G : discuss	H : estimate	I : form goal	J : gather information	K : planning+reflecting	L : all planning & reflecting
1 : S2 Pair 02 video (PDA)	0	0	5	0	11	0	0	7	2	24	0	81
2 : S2 Pair 03 video (PDA)	0	0	3	0	0	0	0	4	0	2	0	34
3 : S2 Pair 04 video (PDA)	0	1	7	0	4	0	0	7	1	4	0	28
4 : S2 Pair 05 video (PDA)	0	0	1	0	0	0	0	4	2	4	0	28
5 : S2 Pair 08 video (PDA)	0	0	2	0	1	0	0	5	0	3	0	20
12 : S2 Pair 18 video (PDA)	0	1	2	2	0	0	1	3	0	1	0	17
13 : S2 Pair 19 video (PDA)	0	1	4	1	0	1	4	3	0	2	0	6
14 : S2 Pair 20 video (PDA)	0	0	3	1	0	0	2	3	1	3	0	22
15 : S2 Pair 22 video (PDA)	0	0	5	0	0	0	6	1	0	0	0	25
16 : S2 Pair 23 video (PDA)	0	0	3	0	1	0	1	2	0	2	0	20
mean	0	0.3	3.5	0.4	1.7	0.1	1.4	3.9	0.6	4.5	0	28.1
stdev	0	0.48	1.78	0.7	3.5	0.32	2.07	1.97	0.84	6.96	0	20.1

	A : activities	B : agree	C : building	D : bust	E : calculate	F : disagree	G : discuss	H : estimate	I : form goal	J : gather information	K : planning+reflecting	L : all planning & reflecting
6 : S2 Pair 10 video (Paper)	0	0	0	0	4	0	2	0	0	4	0	3
7 : S2 Pair 11 video (Paper)	0	0	1	0	1	0	0	0	0	10	0	0
8 : S2 Pair 12 video (Paper)	0	0	0	0	0	0	1	0	0	5	0	2
9 : S2 Pair 13 video (Paper)	0	0	0	0	3	0	2	0	0	5	0	8
10 : S2 Pair 16 video (Paper)	0	0	1	0	4	0	0	0	0	4	0	4
11 : S2 Pair 17 video (Paper)	0	0	0	0	4	0	0	0	0	9	0	7
17 : S2 pair 24 video (Paper)	0	0	0	0	1	0	0	0	0	13	0	25
18 : S2 Pair 25 video (Paper)	0	1	0	0	4	0	1	0	0	5	0	14
mean	0	0.13	0.25	0	2.63	0	0.75	0	0	6.88	0	7.88
stdev	0	0.35	0.46	0	1.69	0	0.89	0	0	3.36	0	8.17

M : combined planning+reflecting	N : planning	O : reflecting	P : react	Q : response to failure	R : stuck	S : taking notes	T : theories	U : suggest a theory	V : test a theory	W : win	X : activity	Y : gestures	Z : physical indicator	AA : pointing to location	AB : highlight	AC : Learning Cycle	AD : Act
17	40	45	16	2	0	26	0	1	0	0	0	0	0	5	0	0	26
8	17	15	3	0	0	0	0	5	0	0	0	0	0	10	5	0	13
2	2	25	10	2	0	3	0	2	0	0	0	0	1	15	2	0	21
3	14	13	1	0	0	0	0	0	0	0	0	0	0	9	0	0	10
1	12	14	4	0	0	0	0	1	0	0	0	0	0	2	0	0	11
0	16	5	5	0	0	0	0	2	0	0	0	0	0	8	0	0	6
0	3	5	3	0	0	0	0	0	0	0	0	0	0	1	0	0	11
3	13	11	2	0	0	0	0	1	0	0	0	0	0	1	0	0	12
0	14	15	3	0	0	0	0	0	0	1	0	0	0	8	0	0	13
3	15	10	1	0	0	0	0	1	1	1	0	0	5	5	0	0	9
3.7	14.6	15.8	4.8	0.4	0	2.9	0	1.3	0.1	0.2	0	0	0.6	6.4	0.7	0	13.2
5.25	10.3	11.7	4.71	0.84	0	8.17	0	1.49	0.32	0.42	0	0	1.58	4.48	1.64	0	5.92

0	3	0	0	0	0	8	0	0	0	0	0	0	0	2	0	0	2
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3
0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3
0	7	1	1	0	0	2	0	0	0	0	0	0	0	1	0	0	3
1	2	1	1	0	0	4	0	0	0	0	0	0	0	0	0	0	2
1	6	4	1	0	0	7	0	0	0	0	0	0	0	0	0	0	4
3	7	20	0	1	0	10	0	0	0	0	0	0	0	3	0	0	4
0	11	5	0	0	0	0	0	0	0	0	0	0	0	3	0	0	2
0.63	4.75	3.88	0.38	0.13	0	4.38	0	0	0	0	0	0	0	1.13	0	0	2.88
1.06	3.62	6.79	0.52	0.35	0	3.54	0	0	0	0	0	0	0	1.36	0	0	0.83

AE : Act preceding Reflect	AF : Plan	AG : Plan preceding Act	AH : Reflect	AI : Reflect preceding Plan	AJ : movement	AK : arrive	AL : set off	AM : PAR	AN : PAR (2)	AO : PAR (2min)	AP : prompting	AQ : prompting by researcher	AR : prompting by teacher	AS : questions	AT : question reference	AU : buildings	AV : environment
27	51	29	45	24	0	9	15	5	20	20	0	7	0	0	0	3	3
10	25	17	15	16	0	3	6	2	10	10	0	0	1	0	0	0	0
21	4	3	25	6	0	9	10	1	4	4	0	0	0	0	0	0	0
6	17	8	13	13	0	5	6	1	2	2	0	0	0	0	0	0	0
10	12	15	14	10	0	5	5	3	11	11	0	0	0	0	0	0	0
5	16	8	5	4	0	2	3	3	7	7	0	0	0	0	0	0	0
4	3	4	5	2	0	4	6	1	1	1	0	1	0	0	0	0	0
11	16	17	11	10	0	2	8	2	12	12	0	0	0	0	0	0	0
11	14	11	15	12	0	6	7	1	10	10	0	0	3	0	0	1	0
8	17	14	10	13	0	4	5	4	12	12	0	0	0	0	0	0	0
11.3	17.5	12.6	15.8	11	0	4.9	7.1	2.3	8.9	8.9	0	0.8	0.4	0	0	0.4	0.3
7.27	13.4	7.65	11.7	6.32	0	2.51	3.35	1.42	5.65	5.65	0	2.2	0.97	0	0	0.97	0.95

0	3	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0
0	2	2	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0
0	7	1	1	0	0	3	3	0	0	0	0	0	3	0	0	0	0
0	3	3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
2	6	3	4	4	0	2	4	1	3	3	0	0	0	0	0	0	0
6	9	3	20	8	0	4	4	0	4	4	0	0	3	0	0	0	0
0	11	3	5	4	0	0	2	0	0	0	0	0	0	0	0	0	0
1	5.13	1.88	3.88	2	0	1.75	2.63	0.13	0.88	0.88	0	0	0.75	0	0	0	0
2.14	3.76	1.36	6.79	3.02	0	1.49	1.06	0.35	1.64	1.64	0	0	1.39	0	0	0	0

AW : materials	AX : people	AY : task constraints	AZ : question target	BA : question to partner	BB : question to researcher	BC : question to teacher	BD : references	BE : buildings	BF : environment	BG : materials	BH : people	BI : task constraints	BJ : sources of information	BK : knowledge	BL : notes	BM : partner	BN : researcher
10	0	11	0	12	21	0	0	5	5	1	0	37	0	0	36	1	3
0	0	0	0	5	1	0	0	3	9	1	0	14	0	0	0	0	0
1	0	0	0	1	1	1	0	3	8	0	0	13	0	0	2	0	0
0	0	0	0	3	0	0	0	0	4	1	0	9	0	0	0	0	0
2	0	0	0	1	3	0	0	0	5	0	0	4	0	0	0	0	0
0	0	0	0	0	0	0	0	0	9	0	0	1	0	0	0	0	0
0	0	1	0	1	3	0	0	0	0	0	0	2	0	0	0	0	0
2	0	0	0	2	4	0	0	0	5	0	0	3	0	0	0	0	0
0	0	0	0	0	0	1	0	0	15	0	0	4	0	0	0	0	0
0	0	2	0	1	2	0	0	2	11	0	0	6	0	2	0	0	0
1.5	0	1.4	0	2.6	3.5	0.2	0	1.3	7.1	0.3	0	9.3	0	0.2	3.8	0.1	0.3
3.1	0	3.44	0	3.63	6.31	0.42	0	1.83	4.2	0.48	0	10.7	0	0.63	11.3	0.32	0.95

0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	3	0	1	0	0	1	0	0	1	0	0	0	0	0
0	0	0	0	0	2	0	0	0	1	0	0	2	0	0	0	0	0
1	0	0	0	2	3	0	0	0	0	0	0	4	0	0	0	0	0
0	0	0	0	1	0	1	0	4	8	0	0	5	0	0	0	0	0
0	0	0	0	0	0	0	0	0	2	0	0	3	0	0	0	0	0
0.13	0	0	0	1	0.88	0.25	0	0.5	1.5	0	0	1.88	0	0	0	0	0
0.35	0	0	0	1.2	1.25	0.46	0	1.41	2.73	0	0	1.96	0	0	0	0	0

BO : task knowledge	BP : teacher	BQ : tools	BR : booklet	BS : paper	BT : pda	BU : worksheet	BV : TranscriptNodes	BW : TR_Planning	BX : TR_Reflect
9	0	0	0	40	42	0	0	26	39
0	0	0	0	0	17	0	0	0	0
0	0	0	0	5	38	0	0	0	0
1	0	0	0	0	21	0	0	0	0
1	0	0	0	0	21	0	0	0	0
0	0	0	0	0	14	0	0	0	0
1	0	0	0	0	7	0	0	0	0
0	0	0	0	0	19	0	0	0	0
0	0	0	0	0	16	0	0	0	0
0	0	0	0	0	6	0	0	0	0
1.2	0	0	0	4.5	20.1	0	0	2.6	3.9
2.78	0	0	0	12.6	11.7	0	0	8.22	12.3

0	0	0	11	1	0	10	0	0	0
0	0	0	13	0	0	4	0	0	0
0	0	0	9	0	0	2	0	0	0
0	0	0	12	0	0	4	0	0	0
0	0	0	9	0	0	5	0	0	0
1	0	0	16	0	0	10	0	0	0
1	0	0	19	0	0	10	0	0	0
1	0	0	14	0	0	5	0	0	0
0.38	0	0	12.9	0.13	0	6.25	0	0	0
0.52	0	0	3.44	0.35	0	3.24	0	0	0