D33.2.2 (Final)

Report on literature on mobile learning, science and collaborative acitivity

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Nature of the deliverable : Report

Dissemination level : Restricted

Planned delivery date : November 2005

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Prepared for the European Commission, DG INFSO, under contract N°. IST 507838
as a deliverable from WP33
Submitted on 22-12-2005

Summary

This report combines: a literature review of work on mobile learning in informal science settings, a report on empirical work on mobile learning in each of the partners, and guidelines on context-awareness

History

Filename	Status	Release	Changes	Uploaded
D33-02-02-F.pdf	Final	2	Completed	22/12/2005
D33-02-02-F.pdf	Final	1	Completed	16/12/2005

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Object of this document

This document reports on the activity of one of the Jointly Executed Integrated Research Projects (JEIRP) within the Kaleidoscope European Network of Excellence. The JEIRP set out to address mobile learning in informal science settings. This document covers two key actions within the project.

1. The project carried out a literature based study to examine work and views on the area formed at the intersection of mobile learning, informal learning and science learning. The findings of that desk research form the first part of this report (section 2).

2. The project also monitored and shared activity within the partners that could be related to mobile learning in informal science settings. These were shared through presentations, workshops and meetings. The second part of the report presents summaries of some of this work (section 3) and a discussion of the impact of context which formed a special area of work in the project (section 4).

1 General Introduction

Mobile technologies promise new and exciting opportunities for learners and teachers in a climate of distributed, ubiquitous, informal learning supported by mobile and ambient computer technologies. As Weiser (1991) has noted, “The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.” We consider the potential for computer technologies to be woven into visits to museums, exhibition centres, and other informal settings where learning about science might take place, and consider the ways in which this kind of embedded technology might be implemented, and how it might benefit learners. Embedded technologies are coming to rely on being able to detect information about their users, starting with physical location, but now moving towards more socially-enabled applications.

This review offers a survey of the literature and research examples relating to mobile learning in informal science settings, including the use of computer technologies to capture and exploit information about the learner’s context. Dewey’s pragmatism holds that we must strive to uncover the truth through experimentation and tangible interactions with the world, and contemporary perspectives on science teaching are returning to this view. There is a call for learning science in modern education to be more like doing science itself, supporting experimentation and experiencing up-to-date methods and techniques for gathering data, determining facts, and formulating and testing hypotheses. An important tool in making science learning more like science doing is the use of modern computer technologies to offer learners ways of interacting with artefacts, materials, experts and their peers that were previously unfeasible in educational settings. Moreover, there is an increasing move to expanding the notion of educational settings so that learning can take place in a wide variety of places, making the most of authentic environments containing objects relevant to learning topics and allowing learners to interact in new and engaging ways, both with learning materials and with each other. Mobile computing devices are at the forefront of this new wave of educational technologies, offering as they do the chance for learners and teachers to get out of the classroom and go beyond the traditional computer-as-content-provider model which has persisted in education for so long.

We review the use of mobile and ambient technologies for supporting informal science learning, considering contemporary perspectives on mobile and informal learning, learning in science domains. Examples from the research that represent the current state of the art in this field are presented along with more conceptual work which frames our discussion. Work from the project partners relevant to our topic is presented, along with a summary of common themes, perspectives, and directions for future research.

Executive Summary

The work presented in this overview helps us raise and address some of the key questions about working with concepts of mobility and informal learning. The answers we give are not the only ones that are possible but have emerged from a shared view of what makes this view of learning interesting and challenging to study.

What is mobile learning?

Mobile learning has often been described as learning that takes place through the use of mobile devices, such as PDAs, laptops, and mobile phones. However, there are more dimensions to mobility that should be explored when looking at mobile learning. In summary, these include:

1. The use of portable technologies.
2. The peripatetic learner who moves between different learning settings (spatial mobility).
3. The learner alternating between different tools and topics of learning (tool and thematic variance).
4. Learning's dispersion in time, which makes it hard to define precisely the start and end of a learning episode (learning is cumulative: current learning builds on previous learning and forms the basis for future learning).

What is informal learning?

Informal learning has often been defined in contrast to formal learning, as learning that happens away from classrooms, schools, educational institutions. Such definitions have been challenged on the premise that the setting is only one dimension of a learning experience and there is no evidence that it is sufficient to provide qualitatively different learning. Rather, it is suggested, attributes of (in)formality can be identified in any one learning experience. Such attributes may relate to the process, purpose, content, or location of the learning experience.

Studies of informal learning have tended to focus on informal learning that is deliberate on the part of the learner. However, research suggests that learning may not always be identified as such until much later than the experience itself, as might be the case with learning while browsing a newspaper, or during a chat with a friend, or while letting one's mind wander and making some realisation.

- We therefore suggest that unintentional informal learning should not be neglected when looking at informal learning.

Assessing informal learning is problematic for two reasons. First, it is often difficult to identify that it has taken place at all. Second, lacking any pre-set learning objectives as they exist in formal learning, what the learner takes out of an informal learning experience is even more personal and bound to the individual learner's circumstances. Moreover, some types of informal learning experience aim to inspire the learner to follow on the learning (for example, learning in museums).

- Therefore any assessment of informal learning needs to look not only at the learning that took place during the experience, but also at learning that takes place following the experience.

What is informal science learning?

The setting of science learning has been the basis for distinguishing between formal and informal science learning: when science learning takes place outside schools or other educational institutions, then it is informal science learning. With regard to this dimension, informal science learning has been studied in interactive science centres and science museums, in hobby and interest clubs, and in the family.

Informal science learning in interactive science centres and science museums has been studied in the context of organised school visits, with pre-set activities carried out before, during and after the museum visit; and in the context of family visits. While the first type is perceived as more structured than the second, both types of visit can enable rich collaboration among the students and the exhibits.

Hobby and interest clubs are settings that can foster both formal and informal science learning, through the mixture of learning experiences they offer, ranging from hands-on experiential learning, curriculum-based teaching, assessment of practical and theoretical skills, support for the organisation of personal knowledge, etc.

Children's informal science learning in the family and the community is often driven by the child's desire to find out the why's and how's of their environment. It appears that family and friends offer a rich environment for interactions, joint investigations, testing and forming of theories and ideas about science and technology. Adults' informal science learning in the community is also more effective and meaningful the more personally relevant the learning experience is.

How can mobile technologies be used to support informal science learning?

Mobile technologies have been successfully used for science learning during field trips, where they enable the learners to gather scientific data for later analysis in the classroom. They have also been used with success to support classroom-based collaboration among students as they integrate naturally in face-to-face collaboration situations. Furthermore, mobile technologies have been used to support informal learning outside the classroom that supports classroom-based formal learning (e.g. BBC's Bytesize); in mobile learning games; to foster mobile learning communities through mblogs; and to serve as mobile guides delivering content on museums, botanical gardens, even cities.

With regard to informal science learning, research has mainly focused on using mobile devices to support informal science learning in science museums and interactive science centres. Applications include supporting collaboration between visitors by means of enabling them to inspect each other's experience, to communicate with SMS, or to collaborate on specific tasks; encouraging reflection-in-action by presenting the informal learner with appropriate questions and information that trigger reflection on what they are experiencing; and by enabling the learner to construct personal trails of their learning, leading to an increased sense of ownership.

What is contextual learning?

We identify contextual learning as learning that takes place in a more authentic context than a typical classroom setting, supported by appropriate mobile or ambient technologies. The learner benefits from acting within a realistic learning context, with the technology facilitating the interaction with learning materials and activities that would not otherwise be available from that context.

How can mobile technologies support contextual learning?

Many examples of mobile technologies supporting contextual learning demonstrate mobile devices acting as data logging tools that allow learners to collect data from realistic settings. These data logging activities can make use of built-in software on most PDAs, with learners collecting textual or numerical data. There are also various add-on sensors available that allow mobile devices to be used as probes to collect information from the environment.

Mobile technologies can also provide support for contextual learning by allowing the delivery of appropriate learning content on a just-in-time basis, for example medical students who can access video and audio materials as they go on ward rounds.

What is context-aware learning?

Context-aware learning applications can tailor the behaviour of a device to suit the learner's current situation. Context in this sense is an ill-defined concept, but can include any aspect of the environment and the user themselves that can be used to effectively drive a learning application. A distinction is made between context-aware applications that can actively react to context, and those which store contextual information for later use – for example to provide more meaningful logging of activities. Some applications may do both.

How can mobile technologies support context-aware learning?

We identify five major categories of context aware systems for learning applications:

1. Capturing and replaying context
2. Content selection and adaptation
3. Sharing experiences

4. Games and Interactive experiences
5. Streamlining interactions

What are the user interface guidelines for context-aware systems?

Context-aware applications are a new form of interactive technology, and as such there is a lack of guidelines for implementing usable interfaces for them. We consider key papers from the literature, the context-awareness work reviewed for this report, and our own experiences to propose a set of initial guidelines for representing the state of context-aware systems to users, and providing appropriate control over the system.

What research is underway at partner institutions relevant to these themes?

The partners in this project are involved in a variety of projects relating to mobile learning in informal science settings. Areas of research include

- investigations of how users appropriate mobile devices as tools for everyday activities;
- the development of mobile systems to support learning in museums, galleries and other heritage sites;
- support for learning in non-classroom environments through ambient and mobile technologies;
- the design and development of mobile applications that allow tools previously confined to labs or classrooms to be used in more meaningful contexts.

2 Mobile – Informal – Science Learning

2.1 Introduction

The focus of this part of the report is on the main concepts tackled within this project, namely science learning, informal learning and mobile learning, and on the intersections between them. Each of the remaining subsections deals with one of the areas shown in Figure 1 below.

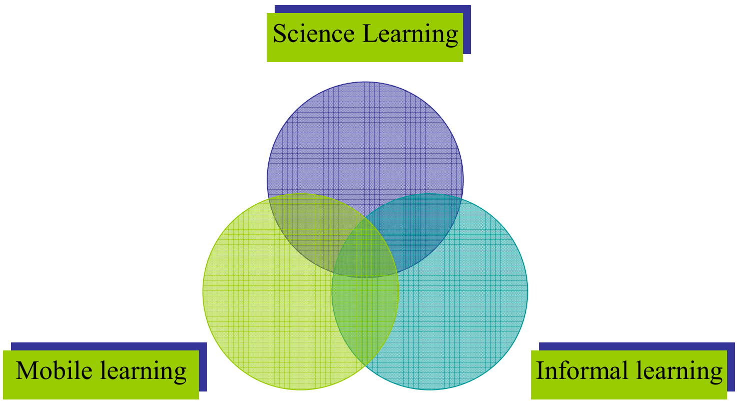

Figure 1: Intersections between mobile, informal, and science learning.

2.2 Informal learning

Defining informal learning has been the subject of much debate. Heimlich (2005) argues that this is because discussions focus on learning not from the perspective of the learner but through the lens of the provider: if learning happens in the context of an educational institution, then it is formal learning; otherwise it is informal learning. Falk (2005) argues that the physical and institutional setting alone are unlikely to qualitatively influence the type of learning that occurs, therefore using the terms ‘formal’ or ‘informal’ as modifiers for learning is misleading. What, then, is informal learning?

The term has been used in classifications of types of learning experience. Mocker & Spear (1982) provide a typology of learning based on where the locus of control lies for decisions regarding the goals of learning (what is to be learned is decided by the learner vs. the institution) and the means of learning (how it is to be learned is decided by the learner vs. the institution). Livingstone (2001) provides another typology based on the organisation of the knowledge to be learned (pre-established vs. situational) and the degree of directive control of learning (primary agency with the learner vs. with the teacher). In both these typologies learning that happens within, or alongside the mainstream systems of education, with the presence of a teacher, trainer or mentor to control the process, and with a pre-established body of knowledge to be learned in the form of a curriculum, is referred to as formal learning. Learning where the learner is in control of the process, and the knowledge to be learned is more situational than pre-established, is referred to as informal or self-directed learning.

Informal learning of this sort is at least as common as formal learning. Tough (1971) reported that adults perform an average of eight informal learning projects per year. Livingstone (2000) reported that the average adult spends 15 hours a week on intentional informal learning activities. Livingstone and Stowe (2001) reported that 44% of Canadian adults participate in formal courses or workshops; whereas 96% report intentional, informal learning activities.

Tough (1971) and Mocker & Spear (1982) identify informal learning as intentional, purposeful learning activity. Tough's (1971) definition of a learning episode requires that it is an episode in a person’s life in which “more than half of the person’s intention is to gain and retain certain definite knowledge and skill” (p. 7). In Mocker & Spear's (1982) definition both informal learning and self-directed learning are interpreted as including decisions over what and how to learn. The Commission of the European Communities (2000) in its Memorandum on Lifelong Learning defines lifelong learning as “all purposeful learning activity, undertaken on an ongoing basis with the aim of improving knowledge, skills and competence” (p. 3). Falk’s (2005) term ‘free-choice learning’ as an alternative to the term ‘informal’ implies that the learner chooses to learn.

In these interpretations of informal learning, it appears that purposefulness is a pre-requisite for considering an activity as learning. Tough (1971) argues that “only when (the adult) has the intent to learn will (he) seek new sorts of help and resources that might be developed for him” (p.32). However, people often learn unintentionally, because they happen to browse a newspaper, because they let their mind wander and make some realisations, or because they have a chat with a friend about a topic that proves interesting. These are perhaps of the most characteristic examples of informal learning, yet often neglected.

Vavoula (2004) presents a typology of learning based on the presence of, and control over, the goals and the process of learning. In intentional formal learning, either the goals or the process of learning, or both, are explicitly defined by a teacher or by an institution. In intentional, informal learning, the goals and the process are explicitly defined by the learner. In unintentional, informal learning, the goals of learning are not specified in advance, and there is no prescribed learning process, but they can develop 'on the fly' as a learning occasion arises.

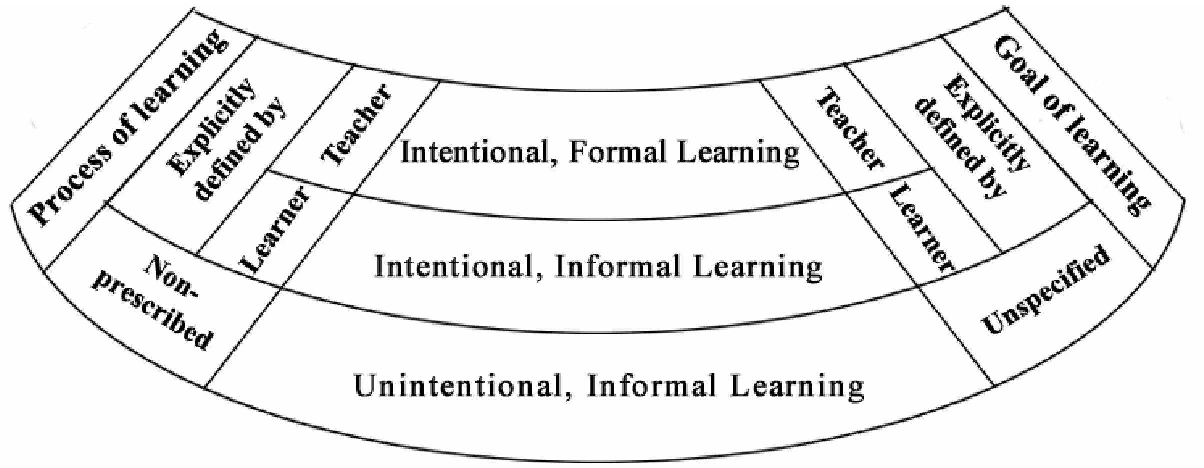

Figure 2: Typology of learning based on the presence of, and control over, the object and the process of learning (reproduced from Vavoula 2004)

The reason that some informal learning definitions require that learning happens intentionally might be that informal learning is often difficult to identify and measure: "informal learning is typically opportunistic, not carefully structured, driven by the learner and shaped by learning context. There are no singular times of 'before' and 'after' because informal learning is continuous" (Alsop and Watts 1997, p 641). Moreover, informal learning outcomes (in terms of knowledge gain) are not qualitatively the same for different individuals. As Rennie and Williams (2002) point out, "it is well established that people do not absorb scientific knowledge, unchanged, from any source" (see, for example, Jenkins, 1994; Layton, 1991;Wynne, 1992). Instead, they restructure the knowledge they receive to suit their own needs, translating and reworking it into a meaning that makes sense to them in their own personal circumstances. This makes it difficult to measure outcomes of visits (to science museums) in terms of specific content knowledge." (p. 707). The personal nature of meaning making is also true for formal learning, however, in formal learning there are pre-set learning goals that the learners are expected to achieve as part of the meaning-making process.

Evaluating informal learning becomes, then, problematic in the sense that traditional methods of evaluating learning outcomes by assessing change after a carefully structured learning intervention are not applicable – at least not without dramatically changing the nature of informal learning. In discussing learning from museums[1], Falk (2004) asserts that ‘narrowly focused investigations that ignore the complexities of the real world are problematic’ (p. 592), and suggests the metaphor of documentary filmmaking for research in informal learning (focusing on museum settings): “like good documentary filmmaking, quality learning research requires collecting a wealth of data and sifting through it and then reassembling the pieces into a multilayered, compelling, accurate, but still comprehensible story; a story of real people, living real lives” (p. 593).

In line with the above remarks, studies of informal learning are usually based on learners’ accounts and metacognitive analyses of their learning (by means of semi-structured interviews, surveys, and diary studies) (see for example Tough (1971), Livingstone (2001), Vavoula (2004, 2005), Alsop and Watts (1997), etc.). Such retrospective accounts of learning come with limitations themselves, as they suffer two problems: first, events might be forgotten and omitted from the account, or the amount of detail recalled in retrospect might be less than that sought; second, a degree of rationalisation or ‘tidying up’ of retrospective accounts might be introduced by respondents. Moreover, children as informal learners may not possess the metacognitive skills necessary for producing such reflective accounts of their experiences. Techniques such as the interpretive case studies described in Anderson et al. (2003) may be more appropriate with children. In any case, the selected research methods should allow studying not only the learning that occurs *during* informal learning experiences, but also the learning that develops *following* informal learning experiences. Dierking et al. (2003) assert that learning does not result from single, individual experiences, but is rather cumulative:

“emerging over time through myriad human experiences, including but not limited to experiences in museums and schools; while watching television, reading newspapers and books, conversing with

[1] Museum learning has largely been considered as a case of informal learning; the topic will be discussed in more detail in section 2.5.

friends and family; and increasingly frequently, through interactions with the Internet. The experiences children and adults have in these various situations, dynamically interact to influence the ways individuals construct scientific knowledge, attitudes, behaviours, and understanding" (op cit, p. 109).

The cumulative nature of learning makes it difficult to isolate a distinct learning experience for inspection. As discussed earlier, this is less so with formal learning, since it happens at a specified time-place as detailed by the timetable and with specified learning goals as detailed by the curriculum. Whereas informal learning, lacking in uniform structure and organisation, may not even be identified as a learning event at the time.

A final issue that is worth considering is the extent to which formal and informal learning are mutually exclusive. According to Colley et al. (2003):

"it is not possible to separate out informal (...) learning from formal learning in ways that have broad applicability or agreement. Seeing informal and formal learning as fundamentally separate results in stereotyping and a tendency for the advocates of one to see only the weaknesses of the other. It is more sensible to see attributes of informality and formality *as present in all learning situations. These attributes are characteristics of learning to which writers commonly attach labels such as formal and informal. The challenge is to identify such attributes, and understand the implications of the interrelationships between them. For analytical purposes, it may be useful to group these attributes into four aspects of learning. They are: location/setting, process, purposes, and content." (executive summary, original emphasis).*

The following table summarises Colley et al.'s (op. cit.) analysis of these four aspects:

Aspect	Formal	Informal
Process	• Tasks structured by a teacher • Didactic, teacher-controlled pedagogic approach • Pedagogic support provided by teacher • There is (formative or summative) assessment	• Incidental to everyday activity • Democratic, negotiated or student-led pedagogic approach • Pedagogic support provided by friends or work colleagues • No assessment
Location/ Setting	• Location in educational institution • Time restrictions, specified curriculum, predetermined objectives, certified	• Location in workplace, local community or family • Open-ended, no or few time restrictions, no specified curriculum, no predetermined objectives, no external certification
Purposes	• Learning is the prime and deliberate focus of activity • Learning is designed to meet the externally determined needs of others with more power (dominant teacher, examination board, employer, government)	• The activity has another prime purpose and learning is a largely unintended outcome (e.g. in the workplace or local community) • Purpose is learner-determined and initiated
Content	• Focus on acquisition of established expert knowledge / understanding / practices • Emphasis on propositional knowledge • Focus on 'high status' knowledge • Outcomes are rigidly specified	• Focus on the development or uncovering of knowledge derived from experience • Emphasis on everyday practice or workplace competence • No focus on high status knowledge • Outcomes are flexible, negotiable or serendipitous

Table 1: Attributes of formality / informality grouped under four aspects of learning (derived based on Colley et al. 2003)

It may not be possible, thus, to identify purely formal or purely informal learning situations. Rather, as Colley et al. (op.cit.) suggest, *"we need sophisticated ways of identifying and describing the complexities of formality and informality in learning, the interrelationships between different* *attributes in a particular setting, and the significance of all this for the learning that takes place and for its potential improvement"* (p. 31).

For the remainder of this report, the term 'informal learning' will be used to signify ***a process of learning that occurs autonomously and casually without being tied to highly directive curricula or instruction.***

2.3 Science learning

In this section we will consider some contemporary perspectives on science learning. We include work on learning basic and complex science concepts along with work on learning about the process of science. In preparation for this discussion it is important to remember that these theories of science learning are grounded in contemporary views about the purposes of science education. Osborne and Hennessy (2003) and others have provided an account of the history of science education, which draws attention to the traditional view of science education as 'essentially a pre-professional preparation for those who were interested in pursing scientific or technical careers'. However contemporary perspectives view science also as 'part of the cultural education of the rounded individual.'

2.3.1 Contemporary perspectives on science learning

In this section we consider some theories of learning which have been applied to the consideration of science learning. A very useful grouping of theories is offered by Sfard (1998). She considers learning as best considered as a 'patchwork of metaphors.' The patchwork of metaphors she describes includes two main ones: the Acquisition metaphor (associated with traditional views of learning) and the Participation metaphor (associated with more radical social theorising about the learner.)

This view is in contrast to a unified homogeneous theory of learning (a goal of the cognitivist school whose best example is SOAR, Anderson and Lebiere, 1995). This exemplifies the differences in the intellectual traditions between cognitive scientists and educational researchers. While the former have the aim of developing a single implementable model of fundamental cognitive processes of learning, educational research tends to start from learning as it happens and attempts to build accounts of its social and cultural complexity. In what follows we review some of this work.

For the last thirty years, constructivism has been the dominant perspective on understanding learning in science as a way of thinking about knowledge and coming to know. Work on science learning has been influenced by a focus on the need to help learners develop conceptions of basic science concepts. The dominant perspective has been constructivism. Driver et al (1999) summarise well the recent development in theories of learning applied to science as follows:

"The core commitment of a constructivist position, that knowledge is not transmitted directly from one knower to another, but is actively built up by the learner, is shared by a wide range of different research traditions relating to science education. One tradition focuses on personal construction of meanings and the many informal theories that individuals develop about natural phenomena …as resulting from learners' personal interactions with physical events in their daily lives (Piaget 1970)…. A different tradition portrays the knowledge construction process as coming about through learners being encultured into scientific discourses …Yet others see it as involving apprenticeship into scientific practices (see e.g. Rogoff and Lave 1984). …Clearly there is a range of accounts of the processes by which knowledge construction takes place." (Driver et al, 1999, p.5)

Prior knowledge in science turns out to be of great importance to subsequent learning. Driver at al. studied the ways that informal knowledge is drawn upon by students at school and how this knowledge interacts with the knowledge developed during activities.

The tradition is often linked with the influence of practical experience and inquiry on learning (see e.g. Millar, 2001 and Linn 2004).

A further impact of constructivism is the fundamental shift it has made in understanding the nature of science as an activity. This is a shift from the view that science is simply about the study of natural phenomena to Driver et al.'s view that it is about the *'constructs that are advanced by the scientific community to interpret nature'* (p. 59) As Bruner comments:

"The focus of attention shifts away from an exclusive concern with 'nature as out there' to a concern with – search for nature – how we construct our model of nature." (Bruner, 1996, p. 126)

Vygotsky's (1978) theorizing has been incorporated into a social constructivist view of learning that involves both social and individual processes. The social processes involve working together and students being introduced to the practices of the scientific community. Going further, the socio-cultural view of learning also draws on the work of Vygotsky. Socio-cultural theorists argue that both the social context of learning and the effect of the learner's socio-cultural background are of importance in the learning of science.

Brown adopted this socio-cultural approach in developing learning environments over a period of time 'fostering a community of learners' (Brown, 1997, p. 399). Brown is interested both in the nature of the learners' progression in scientific understanding, and in the processes necessary to engage learners and support their development of understanding. She also argues that knowledge must be meaningful to learners.

This notion of community of learners is strongly connected to the ideas of Lave and Wenger (1991) who used the term communities of practice as a metaphor for how people learn. These are *'relatively tight-knit groups of people who know each other and work together directly or indirectly.'* (p. 1)

Other socio-cultural theorists have struggled with the concept of communities of practice recognizing both its strength as a metaphor for group learning and recognising the distinction between learning about things and learning to be something.

"Of course, whatever the strength of communities of practice, people learn on their own picking up information from numerous sources about numerous topics without ever becoming a 'member'. We can learn something about Tibetan medicine or racing without needing to work with Tibetan doctors or becoming a Formula 1 driver. The critical words here however are about and become." (Brown and Duguid, 2000, p. 128)

Recent perspectives on learning stress how learning needs to be understood in relation to the development of human identity the idea of learning as identity creation. Wenger's 1998 book develops his social theory of learning involving community and identity focussing on the construction of human identity as the key underlying purpose of learning.

"In learning to be, becoming a member of a community of practice an individual is developing a social identity. In turn, the identity under development shapes what that person comes to know, how he or she assimilates knowledge and information." (Brown and Duguid, 2000, p. 138)

So developments in our understanding of theories of learning has resulted in taking a broader look at what constitutes the components of good science understanding. The focus from constructivism was on the development of difficult concepts. Their scope now is to include the processes of science, and science for citizenship.

The view of science understanding as an integral part of the life of students is also important. There has been some discussion about the importance of science becoming fully incorporated in the student's world view rather than the student adopting scientific ideas alongside deeply held but conflicting cultural perspectives (see e.g. Hodson, 1998; Cobern and Loving, 2004; Jegede and Aitkenhead,, 2004;Tobin, 2004)

One of the consequences of these contemporary perspectives on science learning is that science educators are looking for ways to demonstrate that work in classrooms is meaningful and useful for science learners outside the classroom and have the goal of transforming the experience of learning science to be more like doing science. While past experiences of curriculum development could be characterized as alternating between a focus on developing process or concepts, there is currently a recognised need to synthesise such approaches.

Subsequent sections will discuss mobile learning as a means to not only make science learning meaningful outside the classroom, but also to take the whole process of science learning outside the classroom and into the world.

2.4 Mobile learning

There are several comprehensive reviews of mobile learning research. The interested reader is encouraged to see for example Rogers (2002); Trifonova (2003); Attewell (2005); Georgieva et a. (2005); Naismith et al. (2005); Roschelle (2003) and Savill-Smith (2005). Based on these reviews, this section will take for granted that (a) mobile learning is a reality, (b) technological advances, innovations and applications enable mobile learning in more places, at more times, on more topics and (c) mobile technologies can effectively support a wide range of learning activity and processes.

With this as a starting point, we will set to unpack the 'mobile' in mobile learning, what it refers to and what are the dimensions that define mobility.

Mobile learning has often been defined in terms of the use of mobile technology:

"It's elearning through mobile computational devices: Palms, Windows CE machines, even your digital cell phone." (Quinn, 2000)

"The term mobile learning (m-learning) refers to the use of mobile and handheld IT devices, such as PDAs, mobile phones, laptops and tablet PCs, in teaching and learning." (Wood, 2003)

"According to software vendors, it's 'the point at which mobile computing and e-learning intersect to produce an anytime, anywhere learning experience.' Translation: It's the ability to enjoy an educational moment from a cell phone or personal digital assistant (PDA)" (Harris, 2001)

The obvious aspect of mobility in such definitions, then, is that of the technology involved: if the technology is mobile, then the learning is mobile. This, however, fails to acknowledge that mobile technology needs a mobile learner to carry it around, which brings about another aspect of mobility: that of a peripatetic learner who moves from place to place. If we define that a learner is mobile whenever they learn outside their usual learning environment (educational institution, home, work location), then we can analyse mobile learning in terms of portable technology and the peripatetic learner as shown in table 2. If the learner is at their usual learning environment (e.g. at their study at home) and they make use of fixed technology only, then the learning is non-mobile. If the learner is away from their usual learning environment (i.e. on the move), and they make use of portable technology, then the learning should definitely be characterised as mobile. If the learner is at their usual learning environment (e.g. classroom) but they make use of mobile technologies, then learning has largely been characterised as mobile (for example classroom applications of PDAs, such as in classroom response systems (Dufresne et al, 1996; Qwizdom, 2003). Cases where the learner is away from their usual learning environment (for example at a friend's house, or at an airport), but they make use of fixed technology (such as their friend's PC, or an information kiosk), we argue should also be classified as mobile learning.

	Learner mobility		
Technology portability		**Learner at usual learning environment**	**Learner away from usual learning environment**
	Fixed technology	Non-mobile learning	Mobile learning
	Portable technology	Mobile learning	Mobile learning

Table 2: Learner Mobility and Technology Portability

Looked from a broader perspective, we can explore mobility not only at a macro-level, with the learner moving about in space, but also at a micro-level, with the learner moving between tasks, activities, conversations and resources while seated at a desk in a fixed location. This brings forth a third element of mobility, that of *thematic and tool variance*: through the course of everyday life, a person carries out activities and tasks that often overlap in time or interrupt each other, and that may refer to .different (but perhaps related) areas.

A final dimension of mobility relates to learning's *dispersion in time*. As discussed in section 2.2, learning is a cumulative experience and it is not always possible to identify time- or location-bound instances of learning. There is a temporal dependence between learning episodes: what I learn now is based on what I already know and has the potential to shape the learning experiences that I will have in the future.

In summary, we can identify the following dimensions of mobility in learning in Table 3.

Dimension	**Non-mobile**	**Mobile**
Portability of tools/resources	Fixed tools/resources	Portable tools/resources
Peripatetic learner (spatial mobility)	Learner at usual learning location	Learner away from usual learning location, or on the move
Learner alternates between tools/resources (tool variance)	Learner uses single tool/resource	Learner uses a variety of tools/resources
Learner alternates between topics/areas (thematic variance)	Learner activity relates to single topic/area	Learner activity relates to a variety of topics/areas
Learning is dispersed in time (not always clear-cut start/finish)	Learning in one-off experience	Cumulative learning

Table 3: Dimensions of Mobility in Learning

2.5 *Informal science learning*

This section will explore informal learning in science. Wellington (1990) makes the following distinctions of the features of formal and informal learning in science:

Informal science learning	**Formal science learning**
Voluntary	Compulsory
Haphazard, unstructured, unsequenced	Structured and sequenced
Non-assessed, non-certified	Assessed, certified
Open-ended, learner-led, learner-centred	More closed, teacher-led, teacher-centred
Outside of formal settings	Classroom and institution-based
Unplanned	Planned
Many unintended outcomes (outcomes more difficult to measure)	Fewer unintended outcomes
Social aspect central, e.g. social interactions between visitors	Social aspect less central
Low ‘currency’	High ‘currency’
Undirected, not legislated for	Legislated and directed (controlled)

Figure 3: Features of formal and informal learning in science Wellington (1990)

As is evident in the above table, informal science learning is viewed as that kind of science learning that occurs outside traditional, formal educational institutions. We have already discussed in previous sections the caveats that have been expressed about such a dichotomy of learning experiences. However, the location/setting of learning remains a main determinant of the degree of (in)formality of a learning experience. In this section we will discuss contexts for informal science learning

2.5.1 Interactive science centres and science museums

Wellington (1990) argued that interactive science centres can contribute to (public) science learning in many ways. First, they can make cognitive contributions by providing new knowledge *that* certain things happen in certain circumstances, and, indirectly, by sowing seeds and leaving memories that may ultimately lead to understanding. Second, they can make affective contributions by generating enthusiasm, excitement and interest about deeper understandings of scientific phenomena. Third, they can make contributions in the development of the psychomotor domain by allowing learners to practice and develop psychomotor skills through interacting with science installations (manual dexterity, hand-eye coordination, etc.).

Learning in (science) museums has been studied extensively in the last 15 years in the context of school or family visits. Although usually classified as informal learning, school museum visits are generally more organised than family visits, with pre-set learning objectives (usually dictated by the National Curriculum), and often involving pre-visit – on-visit – post-visit activities. Aspects of pre-visit preparation that influence learning include the student's prior knowledge, specific classroom preparation for cognitive learning at the venue, and orientation to the site to be visited (Griffin, 2004). Such preparatory activities "improve the chances of learning especially if it involves integration of the school and museum learning and provides opportunities for student involvement" (op cit: p.S60). Anderson et al. (2000) identify added value from post-visit activities in that they support the student to assimilate newly learnt concepts and resolve possible misconceptions, and they build on the student's increased interest and motivation that resulted from the visit for follow-on learning. On-visit activities usually involve the use of spread-sheets for (guided) data collection by students individually or in groups. A lot of the responsibility to successfully integrate school museum visits with classroom learning resides with the teacher, and frameworks such as SMILES (Griffin 1998, cited in Griffin 2004) have been proposed to support teachers in providing students with integrated, meaningful experiences that are enjoyable and learning-rich.

Griffin (2004) presents a review of the research in relation to school group visits to museums (where a 'museum' is defined as "any out of school learning setting"). The review reveals that the cognitive outcomes of a visit are equivocal and context specific, as some studies have shown clear cognitive gains while others showed no specific gains[2]; that the social interactions around the exhibits increase student motivation and induce positive attitudes; that good integration with

[2] The problems in assessing cognitive gains from museum visits are unsurprising based on our discussion in section 2.2 of similar difficulties in assessing informal learning in general.

classroom learning yields improved chances for learning; and that students value the choice and control over what, why, and how they will learn in the museum (op cit).

Teachers and students view school visits to museums as structured and purposeful learning activities; in fact, they view the learning as a consequence of the structure and purposefulness. Families on the other hand perceive their visits to museums as opportunities for fun, enjoyable learning activities (Griffin 2004). Despite the more relaxed, informal character of family visits, rich parent-child interactions take place around appropriate exhibits and assist children to collect evidence and construct scientific theories.

Crowley et al. (2001) report a study of parent-child interactions in a science museum, focusing on interactions around a zoetrope. They found that, compared to children engaging exhibits on their own, children in parent-child groups spent significantly more time on the exhibit. Parents help children in the process of scientific evidence collection and comparison, as well as to encode information correctly to form theories by, for example, providing explanations, encouraging different interactions with the exhibits, etc. Such parent-child interactions are apparent in spontaneous, rather than obligatory, collaboration, and in more active settings (such as active experimentation with museum exhibits) rather than in reading or pretend-play. Crowley et al. (2001) coin the term 'explanatoids' to describe the short, 'just-in-time' explanatory nuggets that are offered to children by parents when relevant evidence is the focus of their attention while interacting with an exhibit. These are not deemed sufficient to teach complete concepts or strategies, but rather they serve the function of providing children an on-line structure for parsing, storing and making inferences about evidence as it is encountered.

The affordances of the museum exhibits themselves are important in enabling rich interactions, in that they need to support collaboration by allowing multiple access points, a multi-user capability, multiple possible outcomes, and content that is directly relevant to visitors' prior knowledge and experiences (Borun & Dristas 1997, cited in Crowley et al. 2001).

We have discussed so far on-site visits to interactive science centres and science museums. However, museums increasingly come with a 'digital counterpart', a web-based online place that provide visitors with opportunities for creative play, guided tours, role-play, simulations, etc.; or with an online presence only, as is the case for the 24 Hour Museum (http://www.24hourmuseum.org.uk/). Hawkey (2004) summarises the potential of on-line museums:

"Museum websites may have begun as digital brochures and developed subsequently into online representations of the physical museum but they have not stopped there. Generally resisting the temptation to use the latest special effects for their own sake, they show considerable diversity – of content, design, philosophy and navigational practice. The best are among the best sites for learning anywhere on the internet. While not professing to play the same kind of role as commercially produced games, many museum websites provide enjoyable and meaningful experiences in which the representation of objects and artefacts and the motivation and active engagement of learners are clearly paramount." (p. 37)

As with the distinction between formal and informal learning, it is hard to distinguish the contribution to learning from on-site versus on-line museum visits. Hawkey (op. cit.) argues that here, too, the boundaries are blurring, and suggests that *"the integration of real and virtual will provide further powerful learning opportunities"* (p. 38). And the same is true for school versus family visits (for example, in cases where a child participates in a school visit to a science centre, and as a direct result requests a follow up family visit).

In whatever form (virtual or real), and in whatever setting (in school or family visits for children, and individual or group visits for adults), the target of interactive science centres and science museums should be to enable visitors to participate in a culture of learning about science. Especially for children, as Crowley et al. (2001) note, the objective is to develop an interest in science, to value science as a cultural practice, and to form an identity as someone who is competent in science (p. 731).

2.5.2 Organised hobby and interests clubs

Other common sites for informal science learning are organised hobby and interests clubs. Jarman (2005), for example, examines science learning through Scouting, and asserts that this is an environment that has gone largely ignored as an informal science learning site. In examining scouting, Jarman (2005) admits that it is a setting that would, at first sight, be placed towards the formal end of a formal-informal continuum. However, a closer look reveals that in terms of 'curriculum' and 'assessment', it is more informal than it looks. Jarman (2005) suggests that four key features of learning environments and experiences can be used to build a 'profile' of the learning process (free-choice, curriculum, pedagogy and assessment) in the course of characterising it with regard to the formal-informal distinction. As discussed in section 2.2, Colley et al. (2003) suggest a similar way of characterising learning in terms of formality/informality (the suggested learning experience attributes to examine are process, location/setting, purposes and content).

Such approaches to distinguishing between formal and informal learning, allow for the identification of mixed-settings that can foster both formal and informal learning. For example, the Royal Yachting Association (www.rya.org) provides a structured training scheme for both professional and hobby sailors that includes navigation and meteorology. The aim is to enable people to sail competently and safely. The particular relevance to informal science learning is that the scheme merges experiential learning, curriculum-based teaching, assessment of practical skill and assessment of theoretical knowledge, leading to a recognised qualification. Typically, a beginning sailor will initially draw on general or school knowledge of navigation, extend this through informal practical activities on a boat (such as taking a position fix), formalise it in shore and sea-based classes, then apply it again in practice. This process is generally driven by the learner, through a combination of intrinsic and extrinsic motivation: to become a better sailor and to achieve a certificate of competence.

Another example of support for hobbies is the RSPB (Royal Society for Protection of Birds)'s project, "BirdTrack" (http://www.bto.org/birdtrack/). This project is studying the migration of birds and the distribution of scarce birds in Britain and Ireland, through collecting records from bird watchers. The web site states that the project:

"provides facilities for observers to store and manage their own records and for forwarding records to County Bird Recorders. The results will contribute to knowledge of birds and to their conservation at national, regional and local scales".

So this project both uses the contributions and observations of amateur bird watchers to a national project, and at the same time supports informal learners in organising their learning findings and information.

2.5.3 Learning in the family and in the community

Although the value of early learning experiences has long been recognised in subjects like maths (e.g. while shopping) and reading (e.g. through story books), little research can be found in informal, early science learning in the family and the community (Hall & Scheverien 2001). Two such studies are reviewed in this section.

Cumming (2002) found that informal experiences in the family were mentioned by children more often than school as a context for learning about the origins of certain food items. In a follow-up study, Cumming (2003) presents findings of a study involving the parents of 4-7 year old children, regarding children's informal experiences that contribute to their learning about food and reports that first hand experience (such as eating, preparing food, gardening and trips to the countryside), often accompanied by conversations with family and friends, contribute to learning about food. As in the family museum visit context, parents were found to answer children's questions, often providing additional information to what was requested. However, while in the museum setting Crowley et al. (2001) found that parents initiated discussion/interaction about some aspect of an exhibit more often than children, Cumming (2003) reports that most of the reported conversations in her study were *initiated by the child* rather than the adult.

Hall & Schaverien (2001) studied science and technology learning in the family, following stimuli (in the form of topics, science kits, etc.) provided at school. They focused on kindergarten and year 1 pupils, and followed a 'cognitive anthropology' approach, where the researcher became *part* of the child's informal environment for a period of 6 months and was thus able to record naturally occurring, casual informal encounters (rather than intrusively asking questions about the children's experiences or relying on parents retrospective accounts). They, too, found that family and friends offer a rich environment for interactions, joint investigations, testing and forming of theories and ideas about science and technology. Although parents' encouragement and prompting is important, Hall & Schaverien observed that "despite a parent's best intentions, children's interest was only sustained for as long as they considered the topic worth pursuing" (op cit, p. 476).

Adult science learning in the community has been studied by Alsop and Watts (1997), who report a study on the informal learning on radiation of the residents of a village in Somerset, an area of high background radiation due to the (naturally occurring) gas radon. All of the participants had received a leaflet shortly before the study, issued by the radon publicity campaign, and giving detailed information on the problem. The study analysed four case studies based on a conceptual change framework, and concluded that informal science learning in everyday life can bring substantial conceptual change in the cognitive, the affective, the conative and the self-esteem domains. In concluding, Alsop and Watts (1997) suggest that the more personally relevant the science is, the more effective and meaningful the (informal) learning will be:

"it is public need that should drive 'public understanding of science' rather than scientists and science educators simply patching up perceived deficiencies in public knowledge" (p. 648-9).

2.5.4 Conclusion to section 2.5

The more informal the setting the harder it is to study and analyse: looking at the body of literature on informal science learning, one can see a larger part dedicated to learning in science museums and interactive science centres and smaller parts dedicated to more unstructured types of informal science learning, like learning in hobby and interests clubs or in the family. No matter what the setting is, however, the fact remains that informal science learning builds on and is integrated with prior knowledge and experience, and is driven by personal interest, curiosity and motivation, making the learning experience meaningful and personally relevant (Dierking et al, 2003).

Dierking et al. (op cit, p.110) suggest that the following aspects of informal science learning need to be considered when framing related research:

1. *Learner initiated:* Such learning is self-motivated, voluntary, and guided by learners' needs and interests, so certain aspects of learning are critical to investigate (e.g., the role of motivation, choice and control, interest, and expectations in the learning process). This view is reinforced by Hall & Schaverien's (2001) conclusion quoted above, that children's interest is only sustained for as long as they consider the topic worth pursuing.

2. *Physical context:* The physical setting in which such learning takes place is extremely important, so this learning needs to be investigated in authentic contexts. Cumming (2003) also stressed the importance of first-hand, contextualised experience in children's learning about science, while the physical setting was the focus of the informal learning in Alsop and Watt's (1997) study.

3. *Sociocultural context:* Such learning is strongly socioculturally mediated, so research designs need to offer opportunities to explore social and cultural mediating factors including the role of conversations, social learning networks, cultural dimensions and the use of groups, as well as individuals, as the unit of analysis.

4. *Cumulative, Integrated:* Learning is a cumulative process involving connections and reinforcement among the variety of learning experiences people encounter in their lives: at home, during schooling, and out in the community and workplace. Research designs need to offer opportunities to investigate all dimensions of learning and their connections in a variety of settings across a span of time which will allow us to understand how these experiences are used and connected to subsequent experiences longitudinally. Hall & Schaverien (2001) also note that when observing a single experience (e.g. a single, isolated museum visit) one misses out important information on how scientific ideas and theories evolve in young children (or adults) over time.

5. *Process and Product:* Learning is both a process and a product, so we need to investigate the processes of learning as well as the products of learning. In fact, Hall & Schaverien (2001) argue that observing learning behaviours is not necessarily observing learning itself, and that clear theoretical frameworks are needed to guide the interpretation of learning behaviours as actual learning.

6. *Assessment:* The very nature of such learning requires multiple, creative methods for assessing it in a variety of ways under a variety of circumstances. Thus, innovative research designs, methods, and analyses are critical (e.g. conversation/discourse analysis, constructivist tools such as concept mapping and personal meaning mapping, social learning network analysis, and hierarchical linear modelling).

2.6 Mobile science learning

Certain features of mobile learning could address some contemporary concerns about the need to extend the opportunities for science learning outside the classroom. Sefton-Green (2004) argues:

"*Teachers and other educators just simply need to know more about children's experiences 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.* (p. 32)

We identified two trends in our earlier consideration of science learning:

- an increased interest in science for citizenship
- an interest in bringing science out of the classroom into the world.

We identify two particular developments in the use of mobile technology which contribute to these. The first of these is the enhancement of science communication and the second is enabling collaboration in practical activities or field work in science.

2.6.1 Science for Citizenship

In relation to the first area, a key curriculum trend has been to engage learners with the prospect and problems of modern science. One component of this is engaging with science as it appears in the news media as it is communicated in public. The idea of science education as a sort of pre-vocational foundation for future scientists underpins the UK Science National Curriculum (now under review), which some would argue has concentrated on teaching a body of scientific fact, as opposed to providing an understanding of scientific practice and scientific thinking. More recently curriculum trends especially at school level have becoming more geared towards science for citizenship and less towards science as an apprenticeship for future professional life as scientists. See e.g. Fensham (2004), Jenkins (2000)

Science as it is reported in the news media or science which emerges from museum visits are part of this. Reports of evaluations taking place in museums (e.g. Proctor and Tellis, 2003, Waycott, 2004) and science museums e.g. the Exploratorium, (Fleck *et al*., 2002) show the potential of handhelds which are wireless connected to provide both relevant multimedia adjuncts to the objects on display and the possibility of interacting with others during such visits. There is a smaller amount of work on accessing news reports and other public information on science on PDAs (Waycott, 2004).

2.6.2 Bringing science out of the classroom into the world

The involvement of students in practical work and what role it plays in learning science has been much discussed. Two critiques of school laboratory work are that there is a mismatch i) between the idea of laboratory based inquiry and the practice of cookbook style work, and ii) the activity in school science laboratories compared to what happens in 'real'science laboratories (Wallace et al., 2004). Desautels and Larochelle (1998) contrast the epistemological perspectives of school students and scientists and this has implications for the difficulty of achieving the ideal of authenticity. Often, the concerns about authenticity focus on whether the tasks set are authentic i.e. do they reflect the real work of scientists? or whether the settings are authentic i.e. does the location or the resourcing of the activity reflect the real work of scientists? Scientists sometimes do experiments in laboratories with dedicated equipment but they also can be found in naturalistic settings, and conducting experiments using computers, and also using computers to collaborate with other scientists.

Mobile technologies have a particularly important role to play when practical work is done in fieldwork settings. Using mobile technologies on field work transforms the possibilities for science learning. Cottingham et al. (2002) have produced a literature review describing some studies in biology and earth sciences settings. There have been a number of studies tracking what happened when school pupils gathered scientific data in the field, using mobile technology in many cases, (e.g. Rieger and Gay, 1997, Rochelle and Pea, 2002, Staudt and Hsi, 1999, Soloway et al., 2001; Rogers et al., 2004, Stanton Fraser et al., 2005) and for other purposes (Tinker and Krajcik, 2001).

A particular feature of science learning settings for fieldwork in particular is that such settings are often collaborative. Literature on computer supported collaborative learning (CSCL) stresses the positive role that technology can play in providing support for collaborative learning. Both Zurita and Nussbaum (2004) and Rochelle and Pea (2002) have discussed the ways in which the use of mobile technology offer support for collaborative learning.

Roschelle and Pea describe this as follows:

*"The different physical capabilities of personal, palm sized computers and either wireless local-area networks and either wireless local area networks or mobile ad hoc networks create differing application lever affordances which creates quite different potential for CSCL. (*p.25)"

Rochelle and Pea reviewing such projects describe the ways that wireless internet learning devices (WILD) used in computer supported collaborative learning augment physical space, and allow the aggregation of information across all individuals in a group working together. This is further elaborated in Roschelle (2003) together with the view that much work in this area often is based on a complex view of the technology and a simplistic view of social practice.

Zurita and Nussbaum (2004) describe the conditions for successful collaborative learning as:

"the interactivity required to achieve shared goals; the enablement of discussions about the goals; the support of both individual and group outcome achievement; the coordination of participant roles and rules; and the synchronisation and sharing of tasks.' (p.289)"

The key features of mobility, portability and the potential for collaboration via the use of handheld devices offer the possibility of interacting naturally in a mobile collaboration environment with face to face interactions (Danesh et al. 2001; Inkpen 1999 Hennessy et al., 1997) There is also the added advantage that each student has control of their own hardware, unlike students sitting together at a desktop PC.

Indeed, there have been suggestions that mobile technologies may enable a transition from occasional, supplemental use of desktop computers to frequent and integral use of personal mobile technologies (Soloway, Norris, Blumenfeld, Fishman, Marx, 2001) and that they can be used to augment physical and situated learning (Roschelle and Pea, 2002; Roschelle, 2003).

Other features of handhelds which have been highlighted in reports of their use include permanence, accessibility and immediacy as well as portability. This means that:

'whether students are at home, in the classroom or beside a river, they can get what they need when they need it. They can get access to documents, data animations and software tools. They have access to work from earlier weeks.' (Staudt and Hsi, 1999).

The Environmental Detectives project (Klopfer and Squire, under review) involves a participatory simulation that let learners use mobile devices to take a virtual field readings based on the scenario of an environmental incident. This provides a game-like, informal activity, with authentic, scientific practice which may be worth investigating further.

Table 4 below summarises the correspondence between mobility dimensions as they were identified earlier and the objectives of science learning as discussed in this section.

	Objectives of Science Learning	
Mobility Dimension	*Enhance science communication*	*Enable collaboration in field work*
Portability of tools/resources	Access news reports on PDAs	Scientific data gathering in the field
Peripatetic learner (spatial mobility)	Visit science centres	Field work
Learner alternates between tools/resources (tool variance)		Synchronisation
Learner alternates between topics/areas (thematic variance)		Synchronisation and sharing of tasks
Learning is dispersed in time (not always clear-cut start/finish)	Access to work from previous lessons/weeks	

Table 4: Mobility of learning and objectives of science learning

2.7 Mobile informal learning

Mobile learning in itself suggests informality. The image evoked by a scenario describing a learner engaged in a learning activity using a mobile device generally features the learner outside a ‘normal’ learning environment, making the most of the ‘mobility’ of their mobile device. They might be looking at revision questions on the bus home (BBC Bitesize; 2003, 2004), or listening to a Podcast of the lecture (Duke University, 2004) from that afternoon. However their current activity hooks into their wider learning, whatever it is they are doing with the mobile device tends to be less formal than being in a classroom.

What do we mean by 'mobile'? The learner, the device, and the learning itself can all be mobile. We can deliver 'mobile' content using any combination of these. Appropriate technologies can therefore include 'classic' mobile devices such as phones and PDAs, but also ambient technologies that enable information access in distributed spaces, as well as context awareness. Fixed delivery points such as kiosks must also be considered: if the learner is moving from one fixed point to another on a continuing learning trail, their learning is mobile, even if the delivery technology isn't. We must distinguish between mobility of content and mobility of the delivery device.

It is true that mobile devices such as PDAs have been used in more formal ways within more typical classroom or other institutional settings, as well as in professional environments, but when mobile devices are used outside these environments the learning tends to be of a more informal nature.

A review of the current research suggests that there are 3 primary ways in which mobile technologies can be used to provide informal learning activities.

1. Mobile learning in non-classroom learning spaces
2. Supporting distributed learning communities
3. Facilitating multi-player learning games

2.7.1 Mobile learning in non-classroom learning spaces

Mobile technologies such as PDAs and mobile phones have been used to provide learning opportunities in a variety of non-classroom environments. There is a clear distinction to be made between using mobile devices as simply another way to deliver content, and using them as the means to offer qualitatively different learning experiences. We also need to differentiate mobile learning that is tied to specific learning activities, such as exam revision, and learning that is far less structured and more serendipitous in nature.

A recent example of the use of mobile devices to provide an adjunct to structured, classroom learning is the BBC ByteSize Mobile project (BBC 2003, 2004), which used a Java application to let children do basic GCSE revision using their mobile phones. Given the limited amount of information that can be displayed on-screen and sent via text, the revision materials really are 'bite-sized'. This initiative has been running since 2003, and has proved to be very popular, especially with the growing number of phones with Java capabilities. The main impact of the BBC Bitesize programme comes from the size of its audience - over 650,000 GCSE students (as well as a number of curious adult learners). Some implementation problems highlighted include:

- Problem of localised content: some questions were not relevant to what a particular student had studied.
- Lack of detailed feedback for learners: the small screen size and memory capacity of the mobile phones meant that no detailed feedback about question responses could be given. This was highlighted as a key issue that learners wanted to see addressed.
- Compatibility across devices: despite Java being promoted as a crossplatform environment, it was difficult to get the Java game running on all phones.
- Costs: the SMS service was originally free, but excessive demand forced the BBC to charge for messages, leading to a significant decline in popularity.

Mobile devices can also be used to provide learning content that is not tied to a particular course or programme of study. One particular area where mobile devices are becoming popular for this type of content delivery is as mobile tour guides, which may be used in museums, galleries, or out on the street as a guide to a town or city. Some successful examples include (Abowd et al, 1997; Davies et al, 2001; His, 2002; Kusunoki et al, 2002; Williams et al, 2002).

2.7.2 Mobile Learning Games

Single player games on mobile devices such as phones and PDAs are becoming quite popular, but they are inherently limited by the capabilities of the mobile device (especially screen size). However, mobile devices can offer more engaging gaming experiences by acting as facilitators for multiplayer games, by offering a portable media device that can both monitor a player's position in the game and also keep the player themselves up-to-date on what is happening. By also exploiting the portability and connectivity of mobile devices, we can build multi-player games that also rely on physical movement, either in a learning space or another environment, to drive the game forward. The adoption of movement as an interaction technique for mobile games has recently been recognised (Cheok, 2004; Flintham, 2003).

Many different types of games can be produced using this method. Recently, one type in particular, *participatory simulations*, has attracted a lot of attention from researchers and educators. The idea behind participatory simulations is to engage learners in a game where they are actively playing a part in a simulation of a physical, social, biological or other complex system.

For example, in Colella's (2000) seminal work using wearable computers called Think Tags, children played a role in the simulation of the spread of a virus. The players had to physically move around the room, meeting other players. As they did this, their Think Tags communicated via infra-red, and a virtual virus spread from player to player, indicated by flashing LEDs on each tag. The challenge for the children was to determine the rules underlying the spread of the virus: why did some people get sick, and others didn't? The students were able to directly observe the spread of the virus in the game, and form hypotheses about it. They could then play again, testing their hypotheses against how the game actually worked.

Colella's original virus game has been reproduced using off-the-shelf PDA devices (Klopfer and Squire, 2004). This clearly demonstrates the potential for PDA devices, and even phones, to offer new and engaging learning experiences.

A key finding from Colella's study was that the use of mobile technology seemed to facilitate face-to-face interactions between students, rather than hindering them. Traditional computer technologies in the classroom have tended to hinder such interactions, by requiring students to sit in the corner with a PC rather than be engaged in interactions with other students.

Learning games like participatory simulations have strong links to constructivist approaches to learning emphasising the central role of the learner as an active constructor of their own knowledge. These types of learning experiences also sit well with recent initiatives to transform learning science into something more akin to actually 'doing science'. Learning activities that take place outside classrooms and within authentic learning environments also draw on the situated learning approach (Brown et al, 1989), which emphasises the need for learners to be learning within an authentic context and to be able to perform realistic activities relevant to the domain.

2.7.2.1 Environmental detectives

The MIT Games-to-Teach project seeks to further explore the development of 'augmented reality educational gaming' (Klopfer and Squire, under review). Augmented reality educational gaming builds on recent developments in handheld gaming, where context sensitive data and social interactions are used to supplement real world interactions.

The goal of the Environmental Detectives game was to teach secondary school and first year undergraduate students the skills of environmental inquiry, using a simulated environmental problem. Through collaborations with environmental engineers, a scenario was built around a spill of a toxin called Tri-Chloro-Ethelene, which is a ground water contaminant with moderate long-term health effects. The game included functionality to support the collection of both primary data (raw data on contamination levels acquired by sampling) and secondary data (interviews with 'virtual' experts).

The game was location-based, with the 'virtual' activities only being available in certain 'physical' locations, as detected by a GPS module attached to the Pocket PC. The interface was primarily map-based and students worked in pairs to navigate through the physical space to get to the virtual information. The goal of the game was to discover the source of the contamination and prepare a suitable remediation plan. The students were required to make trade-offs between soliciting interviews and drilling a well to sample ground water, mimicking the real challenges encountered in environmental investigations.

Five trials were conducted with game play lasting for between 90 minutes and 2 hours. Most groups were able to either locate the general area of the toxin or some basic remediation strategies, but few groups had fully coherent solutions. The secondary school students had particular difficulties with the subtlety of the investigation, indicating the need for additional scaffolding. Students responded very favourably to both the investigative experience and the experience of interacting with the technology.

As Environmental Detectives is easy to learn, but difficult to fully master, it can support an iterative approach to teaching investigative skills, with students having the ability to try new strategies on new maps with different contaminants.

2.7.2.2 Savannah

Savannah (Facer et al, 2004) was a pilot study exploring the use of mobile devices to enable a rich, interactive learning experience where students got to play the role of, and hence learn about, lions.

The Savannah study builds on Colella's work by taking the simulation out of the classroom and situating it in an appropriate environment for the topic. Students in Savannah got to play the role of lions roaming in the wild in an area 100m x 50m. Each student carried a PDA that gave them a window into the game-world, displaying content and actions that were appropriate to their current location and what was going on in the rest of the game. Each PDA could be tracked using GPS, and allowed the students to 'see', 'hear', and 'smell' the virtual Savannah they were exploring. The PDA screen displayed visual content and indications of scents, and the children wore headphones for an auditory experience. The PDAs also displayed informative and instructional messages such as "You're hungry", "You're too hot", "Return to the den". They also had a den area, to which they could retreat for a more reflective period after being out in the field.

As in Colella's Virus game, the children were more than willing to suspend their disbelief, and reported that they felt they had really experienced what it was like to be a lion on the savannah. During the game, they often talked as if they were directly experiencing the simulation (i.e. "I'm hungry", "I'm too hot"). They had the opportunity to explore multiple aspects of lion behaviour, and reported that the game had increased their understanding.

Several findings are important to note:

1. This study highlights the changing role of teachers and facilitators in the mobile learning experience. While in the den, children were encouraged to reflect on the success of their activities, but this was mainly teacher-led. When this reflection was led by the children themselves, they were highly engaged and motivated. When the teacher took control, the students became more passive and resistant to engagement. To be successful as a learning experience, the game needs to allow the students to control their own learning.

2. Students occupied multiple roles, including the role of the lion itself, the role of the child acting as a lion and the role of a child reflecting on his or her actions an the rules of the game in order to play better, and needed support in transitioning between these roles.

3. Despite suspending their disbelief, children had high expectations of the system, and were disappointed that they didn't have access to more lion-like powers and expected a more rich and interactive experience than current technology can provide.

2.7.3 Informal learning communities

Mobile devices have successfully been used to support informal communities that allow members to exchange information, and hence learn, about particular topics that are relevant to them. The recent popularity of web logs or blogs has to some extent been repeated with mobile technologies – people are able to post content to mobile blogs (moblogs) in the same way as they can to ordinary blogs using their mobile devices.

The International Centre for Digital Content at Liverpool John Moores University, UK, designed a PDA application for personalised education of breast cancer patients (Wood et al, 2003). The project started in 2002 and involved the delivery of text, images and audio-visual material to the patients' PDAs via the internet and the hospital's intranet for the duration of their course of treatment. The information delivered is selected based on the individual patient's needs. The user can query specific subject knowledge bases through a content specialist, to gain the information they need. This feature provides an answer to the problem of gathering information that is valid, reliable, specific and personal. The user can also make personal notes linked to a diary application. This provides them with key points for discussion at hospital meetings, allowing the patient to annotate content and receive timely reminders from the diary. Patient communication is enabled via SMS, allowing a patient community to share valuable insights and experiences.

2.8 Mobile, informal, science learning

There are numerous examples of mobile technologies such as PDAs being used in science learning environments such as museums and other spaces, but it is difficult to see an immediate differentiation of these into formal and informal learning. Handhelds are usually used to support a specific activity that takes place within a larger context of learning, and for this reason their use could easily be classified as more formal in nature. For example, handhelds have successfully been used to provide support for data gathering activities in science museums (for example Roschelle et al, 2003). However, this data gathering is a task that has been explicitly provided to the students, and their performance at the task is assessed (again using the handhelds).

But what adds a degree of informality to the learning is that it takes place within informal learning environments, such as science museums, and not within the confines and usual protocols of the classroom. There is growing support for actively promoting informal learning of this sort, found in institutions such as the Exploratorium (Hsi, 2002) and the Center for Informal Learning and Schools.

2.8.1 Collaboration

Supporting collaborations between visitors, specifically between companions who are visiting together, is a recurrent theme in currently reported projects going on at various science learning institutions. Lack of collaboration between visitors has been identified as a common malady of most visits to museums, galleries and other learning spaces – visits can be a lonely experience, and the use of mobile technologies to provide accessible means of communicating with other visitors is seen as an important direction.

Collaboration between visitors can take one of 3 forms:

1. being able to inspect or eavesdrop on another's experience
2. being able to communicate, using voice or (more commonly) text messages
3. being able to actively collaborate to perform a specific learning task

A 'chat' facility provided for visitors to the Uffizi Gallery in Florence as part of the MOBIlearn system trials (Sharples et al, under review) was enthusiastically used by younger visitors, who found it a way of short-circuiting the 'sacred space' of the gallery. They also wanted to print out their chat conversations, thereby providing themselves with a 'textual photograph' of their interaction.

A challenge for giving people the chance to share their experiences is that of 'sound pollution', i.e. if several pairs or groups of visitors are all sharing their guidebooks it quickly becomes difficult to hear the audio from your own device because you can hear everyone else's as well. The notion of being able to eavesdrop on someone else's audio using personal headphones was developed within the Sotto Voce project from Xerox PARC, and has been tested at the Filoli historic site.

Other successful example of using mobile devices to enable collaboration is the Kid Club Communicator, which featured email facilities and also a 2-way pager. Children using this system responded extremely well to the communication facilities provided.

HP's Cooltown project is a demonstration of a different kind of collaboration, one that uses the idea of virtual graffiti to let users leave messages tied to physical locations that other visitors can only pick up from that location.

2.8.2 Reflection

Giving students the means to reflect on what they have done (and hopefully learned!) during a museum visit is a powerful tool for enhancing their learning experience. The WHIRL project has explored the use of handhelds to provide just this kind of support. The software allowed students to track the kinds of questions they were asking about what they were seeing, increasing their awareness of how their understanding was developing and what areas they were struggling with. Teachers were also able to use the system to track students questions as well, which meant that the enhanced reflection was also a tool for monitoring student progression.

2.8.3 Building collections

A number of recent and current projects are exploring ways to allow learners to have more control over their own visit by letting them construct their own trails of learning by collecting bookmarks or objects along the way. For example, in the ArtScape project visitors bookmarked items of interest during their visit and could then view their collections afterwards. The system also used fuzzy logic to determine connections between items in the collections and gave learners a way of re-exploring their own visit. This concept combines well with the idea of extending visits beyond the museum itself, discussed below. The idea of bookmarking objects has become quite popular, but in many cases the actual act of bookmarking itself is quite mundane. More recent projects, including some not yet deployed, are focusing on enhancing the bookmarking process to increase visitor engagement. For example, the principle of kinaesthetic learning (Thomas & Diem, 1994) can be applied to movements within a museum space – using the act of bookmarking as a way to increase physical engagement with the space will lead to a more memorable visit.

2.8.4 Extending the visit beyond the museum

Initiatives such as the CoolTown technologies being used at the Exploratorium are an example of how there is recognition of the need to extend the visit beyond the time that visitor spend within the museum itself. This means they need to be able to access content when they are physically away from the museum, and also some time afterwards as well. Visitors also need something meaningful to take away with them as well, and the idea of having them create their own collections of objects (as discussed above) works well for this.

Key messages: looking for ways to transform the learning experience, but not revolutionise it. Informal learning environments such as science museums already contain large numbers of 'learning artefacts' and the aim is to use mobile technologies to augment and enhance visitor interactions with these artefacts. The question is 'what can we let people do with these mobile devices that could not be done before?' Among the answers to this question are:

1. Support for remote inspection of others' experiences
2. Support for 2-way communication
3. Support for task-focused collaboration
4. Support for enhance reflection, for both students and teachers
5. Giving learners increased ownership over their own learning

An important requirement that has arisen from evaluations of the use of handhelds in some museums is the need to make sure the technology does not distract from the experience itself. Initial versions of the software used at the Exploratorium included suggestions about how to interact with exhibits, but this proved too distracting for users and so the system was trimmed down to provide only the means to 'remember' items of interest.

However, this is not a universal problem – it depends on what the museum or gallery is already offering the learner. In the case of the Uffizi, for example, very little is presented in the way of information about the paintings, and Brugnoli, Bo and Murelli (in preparation) discuss the opportunities for learners to prepare for their visit beforehand, to plan a deeply organised visit, and to use their mobile devices whilst in the gallery to support it.

3 Review of Empirical and Field Studies by Partners

This section comprises a review of recently completed and ongoing work at the partner institutions that is relevant to the theme of mobile learning in informal science settings. Where multiple studies have been carried out, only the ones that are immediately relevant to the current theme are considered.

3.1 Appropriation of PDAs as tools for learning

Waycott (formerly at the Open University) has conducted a series of studies (Waycott, 2004) looking at how users of mobile devices such as PDAs appropriate these technologies for their everyday working lives. Tool appropriation is defined as "the integration of a new technology into the user's activities" (Waycott in press). Waycott et al (2005) have then used an activity theory framework to analyse these studies, offering a range of insights and conclusions into how i) mobile devices and their function can be adapted to everyday working practices, and ii) how the use of mobile devices can impact on the activities themselves.

The use of activity theory in these studies is particularly salient because it represents an important shift away from considering the user interacting with the device and towards a view that sees the user interacting with other artefacts through the device. The focus of any study thus becomes the activity that a user is involved in, rather than the devices, tools, or methods that he or she might be employing. Computers and other devices are part of the analysis, but they are present as mediators for the activity, not the focus of it.

One of Waycott's studies of particular relevance to this review was of visitors to the Tate Modern museum making use of a mobile guide on PDAs.

Waycott et al (2005) cite the view that PDAs as informal learning tools have received the most attention in the context of museums and art galleries (this view is supported in Fleck et al, 2002 and Hsi, 2003). However, the paradox is that in this context, PDAs are not themselves a personal tool, because they are usually loaned out to visitors by the museum or gallery.

Another important point made by Waycott et al is that although the use of PDAs as learning tools can enable many beneficial activities and resources for learners, the use of these devices as learning tools is not a panacea, and they bring with them their own set of limitations and constraints that in turn impact on the learner's experience with them. The characteristics and hence limitations of PDAs have been reviewed in several places, but a useful overview is that they have small screens, hence limited display capabilities; they have a limited range of input and output options, which have arisen mostly from the need to overcome the small screen size and lack of a keyboard. Waycott et al. note that although PDAs have not been designed with learning applications in mind, learners will use whatever tools are available, and hence the focus of these studies on how existing PDA tools are appropriated for learning activities.

3.1.1 Tate Multimedia Trial

PDAs were piloted as a platform for multimedia guides at the Tate Modern museum during September 2002 and then a second trial ran in the latter half of 2003. Technical problems meant that the system did not functional entirely as planned, but several insights were gained into how people reacted to the presence of the PDAs in the gallery learning space.

One very pragmatic issue that arose was the actual physical integration of the PDA with other tools the visitor was using, such a guidebook, notepad, paper, pencil etc. Many visitors make use of traditional tools during their visit, and if a PDA is to serve as an adjunct to these tools rather than as a replacement, then the issue of how to carry and work with all of these tools together becomes a real issue of concern.

A related problem is how to offer users the means to effectively manipulate information, take notes etc but simultaneously keep the interface simple. This problem has also been found in studies in the Exploratorium (Fleck et al) and also in the CAGE studies described below. A successful strategy for offering a simple yet effective interface seemed to be offering only a single method for interacting with the exhibits, so that users got to do something but were not given multiple options which could confuse and hinder their experience in the gallery/museum.

Making it possible for visitors to make their own notes as they went along was one of the main aims for the Tate system, and problems with the limited input methods on the device seemed to cause problems for many users. Waycott [in press] also reports on difficulties of note-taking from another industry-based case study, which is relevant for our discussion. Feedback from company employees using PDAs in their everyday work indicated that they were unhappy not just the available input methods but also with the inherent rigidity of how the PDA worked, likening it to being told that all notes must be taken on specific paper, and kept in a specific binder. This issue seems highly relevant to the design of learning technologies, given what we know about the variety of individual learning styles and user preferences.

In summary, whilst the PDAs offered much promise and the multimedia content delivery enhanced visitors experiences, the technical and physical limitations of the device actually constrained learners. Difficulties in having to learn a novel interface, problems carrying the PDA with everything else, and technical failures all contributed to breakdowns in the visitor experience and shifts of focus away from the activity and on to the tool itself. Again, this shift is relevant to the use of activity theory, and also to our theme: the challenge is to give users a device that allows them to be engaged in an activity that is mediated and supported by appropriate tools such as a PDA, but does not hinder their experience or force their attention on to the device itself away from the activity that should be being supported.

3.2 Developing Systems to Support informal learning in museums and other heritage sites

3.2.1 MOBIlearn/CAGE (UoB)

The University of Birmingham carried out trials to evaluate the provision of a context-aware guide for a museum gallery site. This guide, CAGE (Context Aware Gallery Exploration) (Lonsdale et al, 2005) made use of a context-awareness architecture developed for the EU project MOBIlearn, deployed as a Web Service and connected to other system components developed specifically for the CAGE project. Visitors to Nottingham Castle Museum's gallery were given the chance to try out the guide running on a PDA.

The PDA's location within the gallery was tracked using a bespoke ultrasound tracking system which could determine which painting the visitor was currently in front of. This was the primary feature of the visitor's context used by the system. Content appeared automatically on the screen, and audio was played through the speaker/headphones as soon as a visitor stopped in front of a painting. If they remained there, they would hear content with more detail about that painting. Furthermore, if they returned to a painting that they had previously visited, the content would pick-up from where they left off, and they were also given the chance to review content they had already seen.

A controlled study to compare the use of the PDA guide with a corresponding paper guide, and with no guide at all, suggested that visitors overall saw the potential of the system, but were put off by its complexity. Paradoxically, visitors seemed to simultaneously want more functionality from the system, but less complexity.

A primary aim of the study was to determine whether people's pattern of movement within the gallery space would change as a result of using the PDA. It had previously been identified (through baseline studies) that visitors would tend to follow a linear path through the gallery. When reviewing the content that was made available by the museum for the PDA guide, it was found that there were links between several of the paintings that were not visible to the visitors. The content was designed on the PDA to highlight these links, suggesting that visitors might want to visit the associated painting after viewing the first in a linked pair. However, it was found that although visitors were clearly made aware of related paintings (video footage shows scanning behaviour following a prompt from the PDA) no visitors deviated from their linear path. However, the Uffizi trial of the MOBIlearn system (Brugnoli et al, in preparation) found that visitors in that case developed an 'augmented itinerary' , deviating greatly from the usual linear route.

During initial trials of the CAGE system it was also found that, given the choice between using onscreen navigation to change the displayed content and actual physical movement (hence triggering the context-aware delivery), some users would use physical movement. This novel way of overcoming the input limitations of the PDA was an intriguing way of navigating content, but this behaviour was not seen to be repeated during actual system trials. This was believed to be because of the lack of any task-focused behaviour during the visits, as compared to the initial prototype trials where users were given a set of questions to answer. In the actual visits, users did not have any specific reason to navigate through the content and so chose not to.

3.2.2 CAERUS (UoB)

CAERUS is a complete context aware educational resource system for outdoor use. A generalised extension of the GardenGuide system described in (Naismith and Smith, 2004), CAERUS provides learning opportunities by presenting location-based multimedia content to learners on Pocket PC handheld computers. The learner's location is acquired through a GPS receiver attached to the device, with a view to extend this to support both indoor and outdoor positioning. As illustrated in Figure 3, the learner can view his or her location on the map-based interface. Audio content is presented automatically exactly where it is relevant. Learners can then select to view additional multimedia content for that particular location or continue with their exploration or tour.

Figure 3: CAERUS handheld application

CAERUS also includes a desktop application, illustrated in Figure 4, to administer the location-based content. Maps in any image format can be imported into the desktop application and calibrated. Once calibrated, the administrator can define regions of interest and associate them with thematically-organised multimedia content. The system supports both free exploration and 'guided' tours, where the next region of interest is suggested to the visitor. The handheld and desktop applications communicate through a standard synchronisation procedure.

Figure 4: CAERUS desktop application

Work to date has provided a foundation to more fully explore the lifecycle of a visit, including preparation for the visit, the visit itself and follow-up on the visit. Currently, the learner can use the handheld application to retrace his or her path through the site and review the content received. Extending this to a web-based delivery application would allow the content to be both previewed before the visit and reviewed from any location. GPS data is currently logged and synchronised back to the desktop application. Formatting this graphically would allow help learners to follow-up on their visit and provide a means for site administrators to evaluate the effectiveness of their exhibits. Additional planned extensions include providing the ability for learners to add information in the field and support for alerts and messaging.

CAERUS includes a 'Themes' option whereby specific locations and artefacts can be chosen to support a particular purpose for a visit. Using the 'Theme' mode is rather like having a guided tour, as opposed to just exploring on your own.

Evaluations of the CAERUS system at the Winterbourne Botanic Gardens in Birmingham produced a number of results. Overall, visitors found CAERUS easy to use, but did not feel in control of the system. This lack of perceived control did not seem to dampen their positive regard for the guide however, and participants mostly reported that they would recommend it to other visitors. When comparing age groups (over and under 50), it was found that the older visitors tended to think that learning to use the system needed more training than the younger visitors. Younger visitors also reported that the onscreen display was easier to read at a glance.

Specific problems arose with the perception of the GPS system for location tracking, which visitors found to be too slow and imprecise. Visitors also reported that using the map built-in to CAERUS required too much mental effort, and did not welcome this intrusion. This led to too much 'heads down' time, meaning that the guide was not seamlessly integrated into the visitor experience.

The use of the 'Theme' mode did not appear to have any significant effects on how visitors moved around the gardens, with most simply following the natural paths of the garden and not the 'Themed' suggestions from the guide. However, several participants did express a desire for more specific guidance when in 'Theme' mode, suggesting that perhaps the cues for movements in particular direction were not strong enough.

3.2.3 Bletchley Park SMS (OU)

The Bletchley Park SMS project (Mulholland, in press) at the Open University is an example of a system that has been purposely built to support learners in a museum setting. Or rather, the system is intended to support visitors to a museum in learning beyond the museum, ie after their visit they can access personalised learning resources relevant to their time in the museum. This addresses one of the key problems that has been identified for museum engagement: the lack of follow-up activities.

Using the Bletchley Park SMS system, visitors to the Bletchley Park Museum were able to 'tag' specific exhibits and locations by sending a short code from their own mobile phone. After the visit, they can view a website that features content assembled specifically for them based on the associations between the items they have tagged. Content is stored with appropriate metadata to allow the system to present meaningful paths through the content that relate directly to visitor's choices of items. An evaluation of the system with schoolchildren showed that they were able to make use of the multiple sources of information presented through the post-visit web-site, and the students appeared to actively enjoy using the system. Comparisons of the system to more traditional content-presentation methods will feature in the next stage of the work.

3.2.4 Fliers in the Wild (OULU)

Fliers in the wild –project (Laru et al, 2004, 2005) at the University of Oulu is a project where learning value of Smartphones and self-configuring Bluetooth networks was explored with real participants in real context. The project was a part of MOSIL KAL-JEIRP where mobile support for integrated learning was explored. The 22 participants were 12-year old primary school students visiting a nature school in Northern Finland. Their program included collaborative inquiry learning augmented with mobile tools conducted outdoors on a nature trail. The students were assigned to inquiry learning groups (eight triads and two dyads). The instruction focused on biology, specifically, examples and traces of animate and inanimate nature observed in the wild.

Each dyad/triad participated in the study used a Nokia S60 series phone equipped with Nokia Flier

Figure 5: Nokia Flier Software

software (Figure 5). The Nokia Flier application allowed participants to create and locally distribute short messages containing text and a picture. Nokia Flier used Bluetooth technology for communicating with other phones. The software used was not designed for learning purposes, thus the design of the interface was modified and improved for this collaborative learning scenario. Specifically, it was adapted by creating template fliers, which included sentence openers for phases where participants' when creating and evaluating fliers.

Fliers were also used to deliver a storyboard of directions and instructions to participants at appropriate phases along the nature trail. Collaborative inquiry learning activities were embedded into the story as tasks. The storyboard had a linear sequence of story phases, where scientists from a distant country informed students, gave feedback, or asked them to do inquiry tasks in the wild at that location. The story was based on the idea that the scientists were preparing a book of Finnish nature and needed help from local assistants for their inquiry activities.

Results were collected by three methods: (a) pre- and post questionnaires given before and after the nature trail experience which involved general questions and a mind-map task, (b) the fliers that were published by the triads/dyads during the nature trail experience, and (c) audio recordings of dyad/triad discussions during the nature trail experience.

Initial analysis of the pre- and post mind-map data indicates that there were substantial differences in biology content knowledge between the dyads/triads. The recorded verbal discussions and mind-map tasks gave evidence of distinctly different roles and approaches within dyads/triads in the collaborative inquiry by the low-achievers' compared to the high-achievers'. Further analyses will provide more information about the quality of collaboration among and within participants.

3.3 Ambient support for learning

Ambient computing is part of the wider paradigm of ubiquitous computing, which an emphasis on placing intelligent computing support in the environment as well in the user's hands. Ambient computing may rely entirely on computing support from embedded devices and technologies, but more commonly it relies on a combination of embedded and handheld technologies to give users support within a specific environment of use.

The potential advantages of ambient computing include the possibility to reduce distractions for users by embedding the supporting technology within the environment.

3.3.1 Ambient Wood (Nottingham)

The Ambient Wood (Rogers et al, 2002) was part of the six-year, EPSRC-supported Equator project focusing on the integration of physical and digital interaction. The project built upon the benefits of incorporating physicality and tangibility into learning. Digital information was coupled with novel arrangements of electronically embedded physical objects, providing alternative forms of interactions that were more intuitive; but also allowing the juxtaposition of familiar actions with unfamiliar effects, thus encouraging children to reflect and think beyond the present of their actions to higher levels of abstraction.

The experience was designed for 10-12 year-olds. A series of activities were designed around the topic of habitats, focusing on the plants and animals in the different habitats of woodland and the relationships between them. An open clearing and a wooded area were chosen as they have different distributions of organisms and interdependencies among them.

The learning experience had 3 stages:

Stage 1: **Exploring and Discovering**. Pairs of children equipped with a PDA explored the two habitats. In addition to what was observable around them, they could find out additional information about growing processes, feeding behaviours and organism dependencies. The PDA provided information either in response to probe readings on moisture and light at a specific location; or was triggered by the children's physical presence in a certain location in the habitat, using a combination of pinging and GPS location tracking. In the second case, the children first heard a relevant sound transmitted through wireless speakers hidden in the habitat, followed by a voice-over and the display of relevant images and information on the PDA. A special-purpose periscope was located in the wood, where children could go for additional information on 'hidden' processes, such as the behaviour of tiny insects.

Stage 2: Reflecting, Consolidating, and Hypothesising. After exploration, the children gathered in a den with a classroom-like setup, where they could use an interactive display to share their readings from the exploration and collaboratively reflect on their findings and experiences. An area was also available where the children could reconstruct the habitat they just encountered, using paper 'tokens' to represent different entities and a computer to provide appropriate feedback to their testing of their hypotheses on different combinations of the organisms.

Stage 3: Hypothesising and Experimenting. The children were sent back into the wood to observe experiments where either new organisms were introduced into the habitat, or changing moisture and light levels. The children tried to predict the outcomes, and they could use the periscope to get feedback and answers to their hypothesis in the form of animations.

The Ambient Wood was trialled with 16 11-year-olds, who worked in pairs. They would spend 30 minutes in stage 1, 15-20 minutes in stage 2, and 30 minutes in stage 3. During stage 1 the children made successful use of the probe and PDA, which proved an engaging, collaborative activity. It was easy for the children to understand the connection between the digital readings and the activity. The coupling of the exploration with the periscope provided an intuitive and explicit way of integrating different kinds of knowledge, where the periscope was providing information about hidden aspects of the environment. The triggering of information display on the PDA based on the children's bodily presence was less successful, as often the kids were too engrossed with their activities to notice sounds, voice-over and PDA display. Stage 2 enabled children to consolidate knowledge from their activity in the wood. The reconstruction activity based on information delivered on the PDA during exploration was not as successful, possibly because the coupling between the physical activity and the digital feedback was not close enough. Stage 3 was engaging and fun, and verified that children were able to make accurate hypotheses.

3.4 Building mobile tools

3.4.1 Bayesian Keys (OU)

An EduServ funded project at the Open University is investigating the provision of a biological classification system on mobile devices.

This project is an example of current mobile technologies are allowing technologies previously confined to the lab to be taken out into the field and hence put to more effective use, in the context for which they were specifically designed.

The system allows the use of a multi-access key, an improvement over classical dichotomous keys, for the purpose of biological identification. The software was originally developed in the 1980s for desktop computers, and now has been implemented on mobile devices. The system allows users to specific multiple identifying characteristics of an organism in any order, and uses Bayesian methods to increase the likelihood of finding an accurate match.

The project is evaluating the use of this software on mobile devices for students at the Open University, but this work is not scheduled until next year.

3.5 Emerging themes and issues

3.5.1 Movement – CAGE & CAERUS

With learners relying on mobile devices that can be carried and moved from one place to another, the role of movement is an important consideration for the use of mobile tools to promote learning. In all of the examples described in this section, learners are moving around in a physical learning space, interacting with artefacts located therein, with mobile devices in some way mediating those interactions.

This movement of learners in the learning space raises questions about the very physical, tangible, and enactive nature of this kind of learning. There seem to be 2 salient questions:

- Can learners make use of movement to interact with the learning environment, either directly (e.g. movement triggers content change) or indirectly (patterns of movement indicate specific learner states to the system)?

- Can we use the mobile devices to influence learners' movements in a learning space, with the aim being to optimise their experiences?

These questions arose in both the CAGE and CAERUS trials, and we can also see that this issue maps directly on to the perspective from activity theory introduced by Waycott (op.cit): mobile tools being acted upon by learners, and learners being acted upon by mobile tools.

3.5.2 PDAs as adjunctive tools

There is a general recognition that PDAs and any other mobile technology cannot replace or subvert the functionality of other established tools. In all of the current case studies, PDAs have been introduced as adjuncts, intended to provide support where none was previously given, rather than replace existing tools. There seem to be real social, psychological, and physical barriers when introducing these technologies to users, and this is an area of future research.

3.5.3 PDAs as a way of taking lab tools into the field

Ambient Wood and Bayesian Keys are both examples of how mobile technologies are allowing learners to take tools that have historically been confined to a lab space out into the field so that interactions with those tools becomes more meaningful and productive. A promising research direction is to explore what other tools, which are currently confined to the lab, might successfully be migrated into other settings such as museums, galleries and other public spaces.

3.5.4 Need for tools to mediate and support, and not be focus

There seems to be a common research focus among the project partners to provide support for mobile learners that means they can spend more time heads-up, looking at artefacts and interacting with others, and less time 'heads-down', paying attention to a badly-designed interface or malfunctioning system.

3.5.5 New ways to explore content

It seems that in many cases there is already a large amount of content available in the museums, galleries etc featured in the studies reported above, and the mobile systems developed for visitors are offering genuinely new ways for people to access that content. It may not be true of all galleries and museums, but it is probably largely the case that a great deal of content is available, with no obvious means of making it available to visitors in a useful and non-distracting way. Mobile devices seem to offer a great deal of promise in this area.

4 Contextual Learning and Context Awareness

This section offers a review of research and perspectives on:

1. contextual learning, that is learning that takes place within a specific context relevant to the learning topic and the learner's aims

2. context-awareness, that is the application of context-aware computing to enhancing learning activities

This review is presented primarily as two distinct sections, Learning in Context considers contextual learning, and Learning through Context considers context awareness. There are thus two different but complementary perspectives on context and its relation to learning being presented here.

These two areas could each be subject to an extensive review beyond the scope of this document. For our purposes the review offered here is framed by our focus on mobile learning in informal science settings.

As well as learning through context and learning in context, uses of mobile technology to support learning activities can also be described as providing learning out of context. In this case, the learning activities being supported take place outside of the normal context of learning (eg a classroom) but do not directly provide any benefits derived from the new context within which they are pursued. For example, the BBC Bytesize revision materials, delivered to mobile phones via a downloadable Java application, provide the means for learners to be engaged in learning activities outside of the classroom or other places where they might normally revise. Although there are pragmatic gains in allowing learners to use these materials outside the classroom or other learning spaces, the activity does not gain anything specific from the context in which it is situated. Several of these examples of learning out of context have already been covered in previous sections, and since these cases do not exploit context as a way of enhancing the learning experience, they are not discussed in this section.

4.1 *Learning in context – using mobile tools to get away from the classroom*

This section considers how mobile technologies can be used to enable contextual or situated learning. Mobile devices can be used to allow learners to take part in learning experiences that are situated outside of their normal learning environment (such as a classroom). In contrast to the learning out of context category (described above), examples of learning in context demonstrate how the context in which the learning activity takes place can itself augment the learning experience, without paying any special regard to obtaining information about that context or tailoring the behaviour of the learning technology in response to the context. It is the ability to take the learning technology out of the classroom and into more authentic contexts that provides us with benefits. In principle, any learning technology could physically be moved from one location to another, but the specific design of mobile computing devices and the learning software now available for them gives rise to a specific set of affordances that are worth reviewing.

We begin with an overview of situated learning and associated approaches, as relevant to mobile learning in informal science settings, and then consider some exemplary uses of mobile technologies to enable these forms of learning.

4.1.1 What is context for 'learning in context'?

The 'context' in 'learning in context' refers to the environment and situation in which the learner is engaged in some learning activity. This includes the physical environment, its locality, the surroundings, and the people nearby. It also includes situational elements that describe the roles that are taken on by learners, their peers, and teachers.

4.1.2 What do mobile devices offer for learning in context?

Mobile devices enable learning in context by allowing learners to move out of the classroom and out into the field. The devices act as enabling tools that let people do things outside the classroom in more authentic settings. The benefit to learners is that they get to take part in a learning experience that takes place in a more authentic context.

4.1.3 Situated Learning

The situated learning paradigm, as originally propounded by Lave et al (1991) holds that learning is not merely the acquisition of knowledge by individuals, but instead a process of social participation.

The situation where the learning takes place has a great impact on this process. Brown et al (1989), also emphasise the idea of cognitive apprenticeship , where teachers (the experts) work alongside students (the apprentices) to create situations where the students can begin to work on problems even before they fully understand them.

Situated learning requires knowledge to be presented in authentic contexts (settings and applications that would normally involve that knowledge) and learners to participate within a community of practice. By developing appropriate context-based teaching strategies with mobile technologies, we can fulfil both of these requirements.

Two strands that are especially relevant to the use of mobile devices can be considered in relation to the situated learning paradigm. They are problem-based learning, and case-based learning.

4.1.3.1 Problem-based learning

Problem-based learning (PBL) (Koschmann et al, 1996) aims to develop students' critical thinking skills by giving them an ill-defined problem that is reflective of what they would encounter as a practising professional. The problem is used as a basis for "*learning by analogy and abstraction via reflection"* (O'Malley et al, 2003).

The distinct characteristics of PBL (Stepian and Gallagher, 1993) include the following:

- Problems do not test skills; they assist in the development of skills, and are used to drive the curriculum.
- Problems are ill-structured, with minimal presenting information. Gathering information, perceiving the problem and developing the solution becomes an iterative process.
- Students (usually in groups of 5-6) solve the problems; teachers and coaches act as facilitators and give guidelines as to how the problem may be approached.

Assessment is authentic and performance based.

Throughout the process of exploring a problem, students are encouraged to identify the areas of knowledge they will require to understand the problem. The group then collects these learning issues, along with data, hypotheses and plans for future inquiry in a structured manner, which can be facilitated by shared information resources (e.g. physical or electronic whiteboard), and uses the collected information to develop a plan for the next iteration of problem formulation, solution, reflection and abstraction.

Applications of PBL include medical education (Albanese and Mitchell, 1993), business administration (Merchant, 1995; Stinson and Milter, 1995) and nursing (Higgins, 1994).

4.1.3.2 Case-based learning

Case-based learning (CBL) (Kolodner and Guzdial, 2000) is similar to PBL, but relies on more well-defined problems, that may or may not be representative of what students might encounter in the real world. CBL is more flexible than PBL in that it can be used in small or large classes and can be used as either an assessment exercise or as a catalyst for class discussions and lectures.

4.1.4 Types of Applications

4.1.4.1 Data logging and "Probeware"

Data logging is probably the most popular way to use to mobile devices to enable learning in context. Palm and PocketPC PDAs are small, easily carried, and can be fitted with various sensors and measuring devices that allow them to act as scientific instruments.

4.1.4.1.1 COSHH (Control of Substances Hazardous to Health)

There is no need for any non-standard equipment or upgrades in order to use mobile devices for data logging. The fact that every PDA (whether Palm or PocketPC) comes with the requisite software for entering and organising data means that any such device can be effectively used in the field as a way to gather data. Moreover, because the data can be gathered in a standardised way (eg through the use of templates) the data can easily be collated and shared among class members. The advantages to using the mobile devices are that the learners are able to gather data from a meaningful context, using an effective template that can guide their observations, and then are able to submit this data to the class pool for later use.

An example of this kind of use of mobile devices for data collection can be found at Bishop Burton College (JISC, 2005), where Palm devices have successfully been used to gather data relating to a COSHH assessment exercise. Students were provided with a spreadsheet template and then used the devices to gather data in an authentic context. Subsequent pooling of the data provided a useful learning resource that could easily be used in the classroom. The benefits to the learners came from the opportunity to go out into a real-world context, and be supported by the mobile devices.

4.1.4.1.2 Butterfly Watching

If we can increase the coupling between the physical environment the learner is in and their current learning topic we can provide powerful learning experiences. One such example is a system that allows children to identify butterflies in the field using PDAs that are connected to a content server. A butterfly-watching system was implemented and tested at an elementary school in Taiwan (Chen et al, 2003). This example, already described in detail in Section 2.7.1, shows how the use of mobile technologies to allow learning activities to be moved outside the classroom can have positive effects for learners.

4.1.4.2 Learning support in context

Traditional learning is for the most part based on *just-in-case learning* – learners are expected to acquire knowledge and skills on the supposition that at some point they may require them. In contrast, the use of portable computing technologies can help us exploit the benefits of *just-in-time learning*, where learners can view content and practice skills relevant to the specific situation in which they find themselves.

A number of examples of this can be found in the medical profession, where learners have been able to use mobile devices to review content and guidance notes as they are engaged in on the job training. Brandt et al (Brandt et al, 2003) describe a system where trainees in an intensive care unit are able to easily access video materials via a barcode scanner and a PDA. They discuss Schon's concepts of reflection-in-action and reflection-on-action in relation to the use of mobile technologies to enable learning in a meaningful context, and their research suggests strong benefits from enabling practical, on-the-job learning with appropriate support. This work is significant in that it focuses on the role of peer-to-peer learning, with learners able to produce their own video materials for others to benefit from. This demonstrates the role of mobile devices as informal tools that can provide essential scaffolding to learning experiences embedded in real contexts.

4.2 Learning through context – context aware applications for learning

In the section above, focusing on learning in context, we have deliberately ignored learning applications where benefits could be gained not just from being in a particular situation or context but also through responding to the context as well. This response to the user's situation is the central premise behind context-aware computing, a paradigm of user-centred computing that aims to provide applications that can adapt their behaviour to suit what is going on around them, the tasks their user is currently engaged in, and what they know about how their users like to do things. Many examples of context-aware computing for learning are also examples of learning in context, since to make the most of a system that responds to context we need to use it in a rich context and not confine it to somewhere like a classroom. For the purposes of discussion, this report has tried to keep these two perspectives distinct, but the distinction is not always so clear when reviewing the literature.

4.2.1 What is context for "learning through context"?

As we shall see, context-aware computing aims to obtain and use information about the user, their activity, and their environment, to tailor the behaviour of an application or device to better suit the current situation. There is no consensus on a definition of context for context-aware computing, but s (2001) offer the following catch-all summary, describing context as:

"…any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application".

This definition is actually quite useful simply because it is so general – there is no easy way of determining exactly what elements of a situation will be relevant before designing an application, and even then some elements will not be apparently useful until the application is actually used. Dey and Mankoff (2005) highlight the interaction that must take place between a user and an application, and it is useful to note that this interaction can be bi-directional in that it need not be the user who initiates an interaction, as is the case with traditional computer use. Rather it is more likely that a context-aware application will initiate an interaction by responding to a change in the user's situation and offering a set of appropriate choices based on that change.

4.2.2 Benefits to learners

Using mobile devices to deliver content and options that are relevant to the user's specific situation means that learners see information in a specific context. According to Nyriri (2002), knowledge is just this: information in context. Most traditional teaching practice relies on what can be termed just-in-case learning – learners are expected to acquire knowledge regardless of whether they require it for a specific purpose or not. In contrast, just-in-time learning advocates a much more pragmatic approach, where learners acquire knowledge that is specifically related to the task in which they are currently engaged. The benefits of this kind of just-in-time, situated learning have been explored, for example in (Goodyear, 2000). We can also exploit the power of coupling the informatic spaces (provided by mobile computing devices) with the social network of users and the physical environment in which they are acting. Zurita and Nussbaum (2004) have identified learning gains associated with this kind of coupling, and Roschelle (2002) cites coupling as the key way of harnessing the true power of mobile devices for learning.

4.2.3 Context aware computing

Context-aware computing is a paradigm in the field of mobile computing that focuses on the ability of applications to discover and, crucially, take advantage of, contextual information. Such information includes things like what time of day it is (in both absolute and relative form), the user's environment (including location, surroundings, and conditions), who the user is (including preferences, habits, and experience), what the user is doing (including goals, activities, and objects), and what is nearby (including other users and usable resources).

The reason for wanting to take advantage of contextual information is simple: we want to make our lives easier, by making our computers more capable of sensing what is going on in our world, enabling them to act appropriately, and therefore supporting our own appropriate actions. This would not only simplify the interaction between user and computer, but also enable the computer's activity to become seamlessly embedded in the actions of the user and the environment in which these actions are performed.

The advent of powerful computers that can be held in the hand and made to perform a variety of functions has meant that there is a need to make sure these devices can do and will do everything that is expected of them. However, no matter how powerful they can be made, or how flexible their operation, handheld devices may still suffer from design limitations and constraints that mean they probably cannot offer the same kind of interaction as afforded by a desktop or even laptop machine.

By the same token, delivery of services and content to mobile devices is increasingly supported by high bandwidth communications. While the pricing of such communications is still a moot point it is clear that much could be gained through the effective management of content delivery; users would be far more willing to pay for content that is directly of interest to them and directly relevant to their current needs.

Context-awareness has come to be seen as the way to address the need for devices that offer intelligent, adaptable operation whilst at the same time overcoming their own design limitations. Furthermore, human-computer interaction with a desktop personal computer can always be assumed to rely upon the user giving full attention to the computer. For mobile devices, attention will often be shared between the computer and the environment. Context-awareness could allow the user to interact with the computer whilst performing other activities in the environment.

Context-awareness can be implemented in a number of different ways, and at a number of different levels. It might be an application that is aware of the context of its user, or the device that it runs on, or the service that provides the application over a wireless network, or any combination of these and other factors. The nature of mobile computing means that the lines are becoming increasingly blurred between the traditional ideas of “computer”, “application”, and “device”. There has a considerable amount of research into what have variously been called pervasive, ubiquitous, embedded, wearable, and disappearing computers. What can be seen as a central idea behind all of these initiatives and concepts is that of computer systems and services that can deliver more appropriate interactions to their users by being aware of what is going in their users’ world.

Users themselves can also form part of this context. Having access to information about the user themselves, in the form of user profiles that detail preferences and interaction histories, can also deliver significant benefits in terms of tailoring the system according to the user’s requirements and expectations.

Context aware artefacts therefore include devices, applications, and systems, as well as services provided through these things. In this report we aim to address the wider issue of context-awareness for a variety of mobile computing devices, ranging from laptops to phones and PDAs, all of which offer their users a variety of interactive services suitable for implementing a context-aware architecture.

Context-aware computing has been something of a buzzword in computing research for about the last ten years. The most commonly cited seminal work in this area is the Active Badge project at Olivetti and the PARCTab project at Xerox PARC (Schilit, 1994). In this work, people would wear small transponders in badges, which would signal a unique identification to the system network. When the wearer of a badge entered a particular room, the network could be altered to reflect this change of location, e.g., the room's telephone could be configured to receive calls for that person, the computer in the room could display the person's desktop etc.

The central premise underlying context-aware computing is the implementation of an automated method of gathering information that can help direct a computer service's behaviour. Giving them access to contextual information that guides their interactions with us is seen as a potential revolutionary step in interface and service design.

Advances in sensing devices and the abilities of perception systems (i.e. software) means that we are increasingly able to have computing devices gather, interpret, and therefore make good use of contextual information.

4.2.4 Context and mobile devices

A common business model for next generation mobile networks and services is that users of mobile computing devices (PDAs, Smartphones etc) want access to multimedia content such as the web. It is not clear how well substantiated this model is in terms of user requirements, and it is likely that the demand for multimedia content might well be dependent on a host of factors. However, it is clear that current attempts to provide multimedia content have demonstrated that this is not easy. For instance, WAP phones offered access to a 'web' but it was not possible to surf the World Wide Web (rather users could access specific 'pages' created for WAP browsers). Furthermore, limitations of the delivery device place severe constraints on the display of such information. For example, the small screen size of a PDA means that an ordinary web page cannot be rendered effectively on the display, and the limited interface options mean that complex interaction options are rendered useless. This explains why WAP phones used WML to create specific pages. An alternative solution to these problems of multimedia on limited devices is *content adaptation* – altering the layout and formatting of content so as to render it usable on, for example, devices with small screens (Lum and Lau, 2002). Determining exactly how and when to adapt content is a challenge in itself, and one possible method is to use *contextual information* to govern what information is displayed and how.

4.2.5 Technical review: what elements of 'context' can we detect?

In this section we consider the range of contextual data that we can obtain through technological means. This means that we are focusing on those aspects of context that are accessible to computer devices relying on sensors to provide measurements of context-related factors or software to provide relevant inferences from other sources. We can usefully distinguish between explicit and implicit context (Beale and Lonsdale, 2004). Explicit context refers to those elements of context that are immediately observable and detectable, such as location or body posture. Implicit context refers to factors that are not immediately observable but can be inferred from other means. For example, an individual's availability for communication may be assessed by collating information from their physical location, their diary entries, and their current activity.

A comprehensive review of all technical means available to sample contextual data is beyond the scope of this report, but we offer an indication of the range of data that may be collected, with reference to some of the more important factors that need to be considered when choosing between alternatives.

4.2.5.1 Location

Location of the device/user remains the mainstay of the majority of context-aware applications (e.g. Abowd et al, 1997; Berderson, 1995; Fels, 1998; Jose and Davies, 1999; Oppermann and Specht, 1999). Location can be either absolute, specifying position in relation to an established frame of reference such as a grid reference, or relative, where position is described only in terms relating to the immediate surroundings. Relative positions are not necessarily less accurate, and can make use of coordinate systems and other ways of precisely describing location, but they do not refer to an external frame of reference and so relative location information is useful only in the context in which it is obtained. Absolute location information on the other hand can be re-used in a variety of contexts.

There is a range of solutions available to suit a variety of requirements. We review four of the more commonly used systems and consider the merits of each.

4.2.5.1.1 GPS

GPS is probably the best known of these, offering absolute positioning data based on global grid references. GPS systems comprise a small radio receiver that uses signals from geostationary satellites to derive position on the Earth's surface. These systems are accurate to approximately 3 metres. The receivers themselves have become significantly smaller and cheaper in the last few years, and now there are PDAs available that feature built-in GPS capabilities (such PDAs have successfully been used in the CAERUS context aware guide at Birmingham). GPS upgrades are available for most PDA devices. Network connectivity is also providing for a new generation of what is known as Assisted GPS, or simply A-GPS. Using network connections to distributed computing resources, the calculations required to derive location information from satellite signals can be offloaded to remote computers, instead of having to perform all the calculations on the device itself. This saves battery power, computing resources, and means the receiving device can remain small and compact without sacrificing accuracy. It is likely that GPS will increasingly be found in mobile phone technologies in the next couple of years. Some 3G handsets already incorporate this technology.

The primary advantage of GPS is that it is a standardised system with a large range of equipment available. GPS works worldwide and can be integrated with local tracking systems. The biggest disadvantage is that because of its reliance on line-of-sight communications with satellites, GPS does not work well (if at all) for indoor applications.

Successful examples of projects that have used GPS to provide context-aware applications are the CAERUS project (Naismith and Smith, 2004) and Abowd et al's CyberGuide system (1997).

4.2.5.1.2 Wireless Network positioning

In contrast to GPS systems, wireless network positioning solutions can provide excellent tracking within enclosed spaces, but are difficult to deploy outdoors. A number of variants exist, but the essential mechanism for tracking on wireless networks is the use of signal strengths from a number of wireless base stations or access points to triangulate a device's position. However, signal strengths can be affected by a range of factors, including nearby electrical equipment, placement of people and furniture, and transient interference. Because of the reliance on relative signal strengths, WLAN tracking works very well in determining which room a device is in (because the signal strength profiles in that room are likely to differ significantly from those in adjacent rooms) but does not work well for positioning within rooms or other enclosed spaces. In larger spaces the signal strength variance from one position to another cannot be distinguished from variance due to other interference.

A number of off-the-shelf solutions exist for wireless tracking, with the most popular being the Ekahau system (http://www.ekahau.com/?id=2100). Ekahau requires no special hardware and requires software only on the client devices. Other solutions rely on specific hardware or on software that runs on both client devices and the wireless infrastructure. There are advantages to each kind of system but the primary deciding factor is whether wireless tracking can provide data that is suitable for an application, given the limitations relating to tracking within and between rooms.

Examples of projects that have successfully used wireless LAN tracking to provide context awareness include Schwabe and Goth (2005).

4.2.5.1.3 Bluetooth

Bluetooth is a short-range radio-frequency technology to provide point-to-point and point-to-multipoint communications between Bluetooth equipped devices. Most newer mobile phones are Bluetooth capable, and the system is gaining popularity for wirelessly connecting computer components such as keyboards, mice, and printers. Bluetooth signals can be used to derive position information in a similar fashion to the use of wireless network signals, albeit over small ranges and usually only in terms of proximal and relative positioning. In other words, Bluetooth networks do not cover large spaces and so cannot be used to provide tracking over greater distances. However, Bluetooth can be very effective in providing simple, beacon-based location information. Bluetooth transmitters positioned at key points can indicate to a device its approximate location (in terms of what room it is in) simply through being visible to the receiving device.

More precise data can be obtained through making use of Bluetooth's point-to-multipoint connectivity. Just wireless network tracking takes signals from multiple basestations, Bluetooth tracking systems can also use multiple connection points to acquire more points to use for triangulation.

An official positioning solution for the Bluetooth platform is currently being developed.

4.2.5.1.4 Infrared Beacons

Infrared beacons can be used to provide proximal location information in the same way as Bluetooth beacons, as described above. Infrared is popular and easy to use because most devices have the ability to send and receive infrared signals. Making use of infrared signals to indicate proximity to an object or place is therefore relatively simple. Off-the-shelf solutions such as Hypertag are now offering very simple ways to provide basic location-based applications with little development cost. The main disadvantage of infrared is that it requires line of sight communication, and the range is limited to about 5 metres. Because of these limitations, infrared typically requires some specific action on the part of the user to ensure that their device has picked up a signal from a nearby beacon.

4.2.5.1.5 Ultrasound positioning systems

For high accuracy positioning within enclosed spaces, alternative solutions such as ultrasound tracking systems may be used. These systems use a set of fixed ultrasound transmitters combined with a single receiver on the tracked device to yield positioning data with a high degree of accuracy (approaching <10cm). Such systems are extremely useful when accuracy is needed but they can be more difficult to develop and deploy. Off-the-shelf solutions are available, such as the Pyxis system (Randell and Muller, 2001).

4.2.5.2 User State

The physical state of the user, such as whether they are standing, sitting, or walking, can provide useful means of determining what content and options it is appropriate to offer them. (Bristow et al, 2002) has demonstrated a system using accelerometers that can accurately detect whether a user is sitting, standing still, or walking, and delivers content relevant to these states on a head-up display. Users who are sitting and can pay most attention see the most detail, whilst users who are walking and can pay least attention see only brief information.

Other states can be measured, albeit crudely, using a range of other sensor mechanisms. For example, Sykes and Brown (2003) describe the measure of arousal during gameplay using the force-feedback measurement built-in to the controller of a games console. Galvanic skin response (GSR) sensors can also be used to measure similar physiological states in a similar way.

Determining what activity a user is engaged in through the use of explicit context data is difficult. Implicit data is required in order to infer possible activities. Implicit data relevant to this type of contextual information include diary entries, geographic location combined with knowledge of what a specific location can offer in the way of activities, and stored data about what a particular user tends to do at particular times and places (e.g. Khalil and Connelly, 2005).

4.2.5.3 User Model

Student or *learner modelling* aims to add user-adaptivity to the component(s) of a learning environment by adapting i) the selection and form of information to be presented; ii) the content of problems and tasks; and iii) the content and timing of hints and feedback (Jameson, 2003). In this way learner modelling seeks to use information about the user and their experiences to guide content delivery. This approach to context awareness was relevant to MOBIlearn, and we anticipate a use for models of this sort within the context awareness subsystem.

Aspects of the learner to which a learner model can respond include the following:

- The learner's knowledge of the current topic area, including knowledge acquired before use of the current system
- The learner's learning style, their motivation, and their general way of looking at the topic area
- Details of the learner's current processing of a particular problem

The underlying assumption to the use of learner modelling is that the use of this kind of information can help make the learner's experience more effective and enjoyable, and this assumption appears to be borne out by the research in this area (Corbett, 2001 cited in Jameson, 2003).

4.2.6 What can we usefully do with context-awareness?

This section offers a set of categories for the different types of context-aware applications that are available.

Before considering the range of activities we can support through context-awareness, it is useful to look at classifications of context-aware applications that have been previously developed in the literature. There is no single, comprehensive classification scheme, but by drawing on several sources we can derive useful categories for talking about different types of context awareness.

The categories identified are:

1. Capturing and replaying context
2. Content selection and adaptation
3. Sharing experiences
4. Games and interactive experiences
5. Streamlining interactions

Chen and Kotz (2000) express dissatisfaction with available definitions of context and context awareness, and suggest that these definitions fail to differentiate between contextual information that is necessary to actually drive context-aware applications and that which is merely interesting enough to capture, store, and make available to the user. Chen and Kotz refer to these two types of context awareness as *active* and *passive* awareness – there is a difference between applications that are context-aware in the sense that they can capture and store some aspect of the user's context, and *context driven* applications that can capture and respond to aspects of the same context. This gives us a useful high-level distinction between two different kinds of context-awareness. Other categorisations are offered in Schilit (1994), Pascoe (1998) and Brown et al (2000a). However, none of these categorisations really tell us what we can do that is relevant to mobile learning for informal science. What follows is a review of the kinds of applications that have been developed that have been used (or have the potential to be used) in this context. Where previously identified categories of context-aware applications are relevant, they are referenced.

4.2.6.1 Capturing and Replaying Context

Passive context awareness (as described by Chen and Kotz) is primarily about storing of contextual data in some reusable form. Brown et al (2000b) also talk about "memory for past events" as one of six compelling applications for context awareness.

It seems that passive context awareness has attracted less attention in the field of ubiquitous computing, but for learning applications there are some obvious benefits in giving users the chance to store elements of their context. Passive applications can also later become active applications, responding to the stored context data at some later point.

If we can build applications that can somehow respond to the context in which they are used, then it is possible to keep a record of that context. If we keep a record, we can use that context in variety of ways at the time of capture, or we can store it for later use. There are two obvious benefits to this:

Learners can view a more meaningful, contextualised recording of their experiences, that may map directly on to their memories of the behaviour of the context-aware application they used

Where the recorded context includes elements of the learner's own activity, they are given a chance to reflect on their own learning process, and may identify areas of difficulty or interest which they were not aware of.

The Bletchley Park SMS Project at the OU and the ArtScape project are examples of how we can obtain recordings of the learner's interest during the visit through non-complex means and then use this information to present a coherent resource from seemingly incoherent parts. Learners are offered the chance to record their interests by submitting 'tags' which then drive the presentation of content on a website that they can view after their visit. This too is a recording of context, when we see that a user's interests during the visit are part of their context at that time. In 'replaying' that context by way of structured content, we are effectively combining the capture and replay of context with content selection and adaptation (see below). This highlights that any categories of context-aware applications are not mutually exclusive, since context-awareness typically forms part of a multi-faceted interactive experience that can comprise multiple phases.

4.2.6.2 Content Selection/Adaptation

Content selection and adaptation is derived from Brown's *pro-active triggering*, and Schilit's *context-triggered actions*.

Using information about the user's context to select appropriate items of content to deliver is the current mainstay of context-aware applications. Typically, the onscreen display changes in response to a change in the user's context, while moving around a gallery or interacting with specific exhibits.

There are many examples of this type of application being used to provide context/location aware guides and other interactive systems for learning in museum spaces.

As well as simply determining what items of content should be displayed, contextual information can also be used to adapt or customise the content. The order of display of items within a single block of content may be re-arranged, some items may be selected over others, or entire sections may be transformed to fit the learners current situation. There is a current focus on producing reusable learning objects that support this kind of adaptability, whereby learning content is assembled from a store of smaller chunks.

4.2.6.3 Sharing experiences

Sharing experiences is another category identified by Brown et al (2000b).

Visiting a gallery, museum or other public exhibition space is often a lonely experience. However, the museum experience is very much influenced by its social content (Falk and Dierking, 1992). Several studies have indicated that promoting interactions with exhibits and with other visitors can form the key points of a successful learning experience (Hindmarsch et al, 2002; Leinhardt and Crowley, 2002). By using information about a visitor's current interests, activities, and location, and by providing suitable communication channels, we can enable them to share their visit with others.

As identified in Aoki et al (Aoki et al, 2002), there are primarily 3 types of shared visiting that we can enable:

1. shared listening: where visitors can eavesdrop on content that another visitor is viewing/hearing by means of a remote link to their device

2. following: visitors can shadow another visitors entire visit remotely, offering a vicarious visiting experience

3. checking in: visitors can exchange brief messages during their visits

Shared visiting may also be extended to include visitors who are not currently present within the exhibition space, but who are connected to its online equivalent. (Brown et al, 2003) describe their experiences deploying a mixed-reality system within a museum space that allowed both physical and online visitors to share their experiences. This system appeared to encourage interactions between visitors, also encouraged 'rich interactions' with the exhibits in the museum.

Whilst context-awareness is not currently common in shared visiting applications, it is easy to see its potential, and even a need for it in many cases. Laurillau and Paterno (2004), Hindmarsh et al, (2002) and Aoki et al (2002) all assert the importance of group awareness, that is knowing what other members of your group (including 2 person groups) are doing and what their availability is. This is also reflected in the MOBIlearn Uffizi study, discussed earlier. This is context-awareness, and crucially it highlights the importance of being aware not just one's own context, but also the context of others as well. This notion of being visible to others and others also being visible to you is also emphasised by Bellotti & Edwards (2001) who propose accountability as one of two primary requirements for context-aware systems that fit into social contexts (see Section 4.3.1).

4.2.6.4 Games and Interactive Simulations

There is a range of games and other interactive entertainment experiences that currently use elements of context as some driving force for the gameplay. Primarily, these games use location tracking as a way of coupling the virtual world of the game with a real physical space, giving players the chance to take part in a mixed-reality experience. Other factors may come into play as well, such as the state of other players within the game directly affecting a player's own state.

Participatory Simulations are a good example of how mobile devices can be combined with context-awareness to couple real, physical learning spaces with virtual ones to enable fun and engaging learning experiences. In participatory simulations, the learners themselves act out key parts in an immersive recreation of a dynamic system. Each learner carries a networked device which allows them to become part of the dynamic system they are learning about. The aim of this approach is to move the simulation away from the computer screen and more into the tangible world that students can interact with. By making them part of the simulation itself, they are engaged in the learning process, and get to immediately see the effect their actions can have on the system as a whole. They do not just watch the simulation, they *are* the simulation. Colella et al (1998) describe a participatory simulation where learners play the role of hosts in the spread of a virus: small wearable computers keep a track of who they meet and the transmission of the disease. Additional descriptions of participatory simulations enabled through the use of mobile technologies can be found in (Facer et al, 2004;Klopfer and Squire, 2004) (already covered in a previous section).

These studies report positive responses from the learners involved, but the main issue of concern is whether learning that takes place within simulations like this transfer across to other situations and settings. Despite the initial enthusiasm and the groundbreaking nature of Papert's (1980) work, there have been questions about the transferability of the skills that students develop in a microworld such as Papert's LOGO. These same questions remain unanswered for the microworlds within participatory simulations.

However, there are many reasons why researchers should be interested in games as a learning platform. Modern educational theories hold that learning should be a self-motivated and rewarding activity (cited in Amory et al, 1998, for example Kolesnik, 1970). Play is observed as a learning activity in any animal that is capable of learning, and 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 play has been considered for use in institutionalised education.

The power of games comes from their capacity to generate intrinsic motivation in the players. People take part because they want to, because the game is fun, not because they are told to do so. 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 – children love modern computer games, and will spend hours playing them. If we can harness these activities for educational purposes we will have a powerful tool to enhance teaching and learning.

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). 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 less than 36 learning principles that are embodied within games, all of which contribute to encouraging the player/learner to experience with different ways of learning and thinking.

The use of games in educational settings can help learners who for a variety of reasons may be disengaged from the learning process, through perhaps lack of interest or confidence (Klawe, 1994) or self esteem (cited in Mitchell and Savill-Smith, 2004; Ritchie and Dodge, 1992). 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 maths and science, can be represented through being embedded in gameplay. Creative and critical thought can also be promoted through the use of games (Doolittle, 1995 cited in Mitchell and Savill-Smith, 2004).

Also, we can see that many items on the current agenda for change in education can be addressed through exploring more game-like activities. There is a current call, in science education at least, to make the learning more like the doing. For science, this means that learners should be able to take part in activities that mirror real-life scientific activities. What better way to do this than through the medium of a simulation game. Klopfer et al (2004) describe a recent project that provided just this sort of learning, through the medium of a participatory simulation that allowed learners to take on the role of *Environmental Detectives* and perform scientific analyses based on the scenario of an environmental incident.

Participatory simulations are a recent concept to have come out of the use of mobile technologies for learning and teaching. Before we continue with an exploration of this new type of learning activity, let us briefly review the available mobile technologies that are driving innovation in this area.

Mobile devices have become a popular personal technology, and offer new ways not just for people to communicate but also to interact with a range of multimedia content, in real-world contexts, not just classrooms. Mobile devices include items such as mobile phones, personal digital assistants (PDAs), and portable computers such as laptops and tablet PCs. Wireless networks and cheaper, faster connections over telephone links means that increasingly these devices are connected to the internet. These devices can also easily connect to one another, through easy to use methods such as infra-red beaming and Bluetooth short-range radio. This author has contributed to the production of an activity centred review of the use of mobile technologies in learning which explores the different uses of these technologies in more detail – see Naismith *et al* (2004). In essence, the advent of mobile computing devices has led to new breed of 'mixed games' where computer technology is used to facilitate or enable more traditional forms of games played not on or through computers but with and around them. Mobile devices are easily embedded in activities that take place away from a computer screen.

The primary way in which context-awareness can be used to drive games for mobile learning is through the coupling of the physical world with the virtual game world. For example, movement in physical space can be used to trigger events in the game, and interactions with game objects can be mediated through real, physical objects.

4.2.6.5 Streamlining interactions

Brown et al (2000b) offers *streamlining interaction* as one category for context-aware applications. Schilit (1994) also describes related categories, namely *proximate selection*, *automatic reconfiguration*, and *contextual information & commands.* These categories are all summarised as providing support for interactions between user and device (Human Computer Interaction HCI), and also between users of different devices (Human Human Interaction HHI).

Applications of this type use contextual information to offer appropriate assistance and prompts to help make the interaction process as easy as possible. As well as simply offering help, a device may also reconfigure itself so as to be best suited to the current task, or in response to a user's particular problem. An example of this can be found in the Satchel project (Lamming et al, 2000) where a device reconfigures itself to support sharing of information. This has obvious benefits for learners who are trying to work collaboratively with materials.

Other examples also suggest that context-aware applications can take a more active role in the learning process. Ogata and Yano (2004) describe a system that supports learners of Japanese phrases by offering appropriate prompts based on their situation and location. This is an excellent example of how different types of context-aware applications can be combined: Ogata's system offers situated learning through streamlined interactions.

Similarly, Rudman's Conversational Helper (Rudman and Sharples, 2002) provides users with prompts based on the contents of their current conversation, using voice recognition technology.

Given the acknowledged importance of collaboration for mobile learning applications, tools which can support both HCI and HHI are of significant importance for future developments.

4.2.7 Open Issues

This section presents a selection of the salient issues that are yet to be addressed by research into the use of context-awareness for learning applications.

The two primary modes in which a context-aware application can operate are content *pull* and content *push*. In content pull, users are responsible for invoking a change in content display, an action from the device, or other response to contextual data. When the users indicate that they wish the device to react, they activate it (by pressing a button or other interface element) and the device will then respond. This method of operation is familiar to users of everyday computing systems – most applications remain quiescent until their user initiates some activity. In particular, the model of web browsing is that of information pull – the browser typically remains inactive until the user requests some a page.

By contrast, systems that rely on the push method of interaction respond directly to a change in context or other such trigger without intervention from the user. If the system is working correctly, then the actions of the device should seem helpful and appropriate to the user. However, there is a chance that the user may find that the system presents them with content, options, or actions without such presentations being expected or appropriate.

The challenge for designers is to build systems that respond appropriately to contextual factors but which also adhere to the established principle of 'least astonishment' (Thimbleby, 1990).

Cheverst et al (2001) have directly compared pull and push interaction methods for a context-aware guide. As they identified, *multiple contextual inputs* and *dynamic content* can compound the design problem even further. Where a system is responding to more than element of context, it soon becomes unclear which element should signify a change in context and hence an update on the display. Similarly, if content itself can be dynamic (e.g. changes to opening times of attractions), this becomes part of the context, but can lead to a dissonance with the user's expectation of static content.

The main disadvantage of using a pull model is that information displayed on the screen may become inconsistent with information held by the system, because of the asynchronous nature of the interaction. If content changes, and the user does not request an update, they are left with 'old' content on the screen.

However, because the user focuses their attention on the device in order to initiate a 'pull' event, they are not distracted by content changes.

By using a push model, we can maintain up-to-date content, but at the expense of possibly updating the display when the user does not expect or desire an update. Solutions to this include the addition of a Hold feature, so that users can maintain the current content on the screen, but the issue then becomes how to notify the user that new content is available, and under what circumstances the system should over-ride the Hold.

All of these factors centre on one central issue: where is the locus of control in a context-aware application? In pull-based applications, the locus of control is with the user, but in push-based systems it is with the system itself. It seems that much more research is required to determine how to design systems that make the most sense to users and to offer them appropriate control whilst still providing the benefits of automatic context-aware content delivery that occurs in the background.

Locus of control can also be shared between different components of the system. Mobile applications will typically comprise a client-side application running on a user's device which connects to a server-side application that provides content and perhaps processes contextual data. The responsibility for actually performing context-awareness must be appropriately shared between these system components.

4.2.7.1 Dealing with ambiguity

It has to be assumed that any context-aware application will at some point need to deal with ambiguous data, have no way of deciding between options, or will perhaps simply get it wrong. In this case, being able to include the user in the construction of context is important. This process has been referred to as *mediation* (Dey and Mankoff, 2005). This process of querying the user clearly has dependencies on the user understanding what is being requested and why, and so far this process is poorly understood and has historically been largely ignored (Dey and Mankoff, 2005).

4.2.7.2 Seamless vs Seamful interactions

In considering push vs pull application models, we have touched upon the issue of seamless vs seamful interaction. Usually we wish the system to present a seamless experience to the user, not distracting their attention by jarring delivery of new content and not preventing them from engaging in whatever activity they are currently involved in. However, seamful interaction, where an application is deliberately designed to make the most of the 'gaps' between components or specific limitations of the system, offer interesting opportunities for learning, at the very least learning about context-aware applications themselves can work. One notable example is found in Chalmers et al (2004) where an interactive, multiplayer game taking place on the streets of Bristol exploited areas where there was no network coverage for the system to provide hiding places for the players. These hiding places were part of the fabric of the game itself, and hence seamful interaction became a necessary and engaging part of the experience.

4.2.7.3 Long-term context-awareness

An area that has not been addressed so far in this research field is the use of context-aware applications over long periods of time, as opposed to single one-off uses in one particular scenario. It is likely that long-term context-awareness will allow the use of more comprehensive user models that the system itself can build-up over time, and the accumulation of user preferences that can be used to tailor the configuration of the device and/or application. The notion of dwelling with technology, discussed by Weiser (1999), also has philosophical roots in the work of Heidegger. Brown and Randell (2004) also call for attention to long term use of context-aware technologies.

4.3 Guidelines for representing context in software systems

Guidelines for representing context in software systems can encompass two aspects of representing context, namely:

1. how we represent context within the software system itself, using structured data and mechanisms for manipulating those data;

2. how we represent the context described by those data to the actual user of the system.

The focus of (1) is the implementation and use of standardised schemas for contextual data, such as schemas defined using XML and XSD. These schemas should ideally be human-readable as well as machine-readable, providing for maximum interoperability between systems and developers. However, the use of standardised schemas for the representation of contextual data is primarily an issue related to the technical implementation of software systems, which is not an intended focus for this report. Any discussion of the use of structured data for representing context would quickly diverge into a general discussion of standardised data formats for sharing information between software systems, and as such would not serve our purpose of considering context-awareness specifically for learning applications.

Our focus in this section is on the user interface aspects of context-aware applications, and so this section on guidelines for representing context in software systems will concentrate on how we might best represent contextual data not to the system itself or to other developers, but to the end user themselves. To date there has been very little consideration of this in the research literature. To produce guidelines relevant to representing context to users we offer the following 2 approaches

1. review the key papers in this field
2. work forwards from first principles, applying usability heuristics to context-aware application

We use these sources to derive essential guidelines that relate directly to the design, implementation, and deployment of context-aware systems for mobile learning in informal science settings. These derived guidelines are presented in bold in the text, and are summarised at the end of this section.

4.3.1 Key papers: Representing context to the user – user interface issues

The user interface issues relating to the gathering and display of contextual information have received little attention in the literature. This is perhaps because of a widespread feeling that enough work already exists on the design of user interfaces that can simply be re-applied to the design of context-aware applications. In some cases this may be true, but in many others it would seem that new guidelines are required.

Brown and Randell (2004) consider the use of software applications in medical settings and offer some thoughts about how we might design context-aware tools to be support in this environment. They propose three guidelines relating to the general design of context aware applications (not just representing context), and some of their arguments can be summarised as be predictable. They recall classic design problems in HCI where users have struggled with complex systems simply because they are complex. Our first guideline embodies this call to ensure that users can understand what is going on with a context-aware application.

Guideline 1: Be predictable. Complexity is likely to be confusing.

Bellotti & Edwards (2001) highlight one of the key problems of context-aware applications by stating their belief that there are many aspects of context which we as humans can be aware of and respond to, but which cannot be sensed or inferred through current technological means. This, they say, means that context-aware systems must always be able to defer to their users in an efficient and unobtrusive fashion. This paper is a good touchstone for a discussion of guidelines for representing context to users of context-aware systems because the authors identify firstly the main limitation of context-aware applications, one that is likely to persist for a good many years if not permanently; and secondly the paper goes on to identify a design framework for addressing this limitation, proposing four design principles that are intended to support intelligibility of the behaviour of the context-aware system and accountability of users and human-salient details of context that are described as being important for context-aware system design.

Bellotti and Edwards express the view that because of the limitations of context-aware systems, human users must be able to reason about the state and behaviour of any context-aware system they are using, and also the environment in which they are using it. To do this, it seems clear that the context-aware system must be able to present its current state in a way that is intelligible to the user, and it must behave in a way that makes sense so that the user is not left feeling puzzled by the responses from the system. Furthermore, if users themselves are to reason about their environment, it will be useful (and perhaps in some cases essential) for the context-aware system itself to support this reasoning, by presenting information that is not immediately available to the user or by offering some new way of representing and/or interpreting that information.

The issue of accountability relates to both the system and its users. Bellotti and Edwards maintain that context-aware systems mediate between people, suggesting, supporting, and even initiating actions that impact on others. Context-aware systems also make an individual's actions more visible to others. For example, Cohen (1994) cites the discomfort of users who install a tool that indicates when other users are accessing their shared folders through audible signals. There is a great potential for context-aware systems and their users to cause discomfort, offence, or irritation through inconsiderate behaviours, and so both the applications must be designed to incorporate accountability for both the software itself and its users.

Bellotti and Edwards offer the following summary of the core of their design framework:

"Intelligibility: context-aware systems… must be able to represent to their users what they know, how they know it, and what they are doing about it.

Accountability: context-aware systems must enforce user accountability when… they seek to mediate user actions that impact others" (p. 201)

Bellotti and Edwards set out their design framework using four principles. These principles are discussed below.

4.3.1.1 Informing the user of system capabilities and understandings

Goffman (1959, 1963, cited in Bellotti and Edwards, 2001) shows us how sensitive people can be to their social context. People will modify their own behaviour in order to present an acceptable 'front' to other people around them. To understand the behaviour of others, people need to be able to understand the context they share with others, and when using context-aware applications this means they must know what the system can do, who else has access to it, and what impact it will have on their actions and behaviour, and what impact the presence of the system will have on the actions and behaviours of others.

Furthermore, users need information not just about the social aspects of their context, but also the technical capabilities of the system in relation to this. For example, where users can indicate their availability to others, they need to understand the categories of availability that they can use, and what each signifies.

Guideline 2: Inform the user of the capabilities of the context-aware system they are using

4.3.1.2 Provide feedback

Providing feedback to users is a well-established guideline for the design of interactive systems. However, many context-aware applications have failed to address this requirement to date (as stated in e.g. Want 1999). The variety of feedback mechanisms that we see in desktop computer systems today arose from the need to overcome usability problems with those systems, providing users with information about system states so that they can choose appropriate actions. In addition to basic feedback mechanisms indicating current system state and potential states should certain actions be taken, users of context-aware systems need further information about what data the system is gathering and how it is using it to provide its context aware services.

Guideline 3: Provide feedback to the user, through:

Guideline 3a: Provide feedback information to the user – what is happening? What did I just do? What have I done before now?

Guideline 3b: Provide feedforward information to the user – what will happen if I do this?

Guideline 4: Inform the user about what information is being gathered, and to what use it is being put/will be put

4.3.1.3 Enforce identity and action disclosure

When people use computer-mediated communication of the sort afforded by context-aware applications, they can become disembodied in the sense that the system provides no guarantee that their actions will be attributable to them in any definite way (Heath and Luff, 1991).

Bellotti & Sellen (1993) have further developed this argument to propose dissociation, where actors' identities within a CMC system may not be discernible at all. Context-aware systems, being forms of computer-mediated communication, must provide mechanisms that force the disclosure of actions and identity.

Guideline 5: Prevent anonymity of users, through:

Guideline 5a: Enforce disclosure of identity

Guideline 5b: Enforce disclosure of actions

4.3.1.4 Provide and defer control to the user

In detecting what the user is trying to do and offering appropriate help, context-aware systems can too often become unusable or, worse, plain irritating by simply getting things wrong, and also by providing no means for the user to correct them or even just stop them continuing to provide inappropriate recommendations. Bellotti and Edwards describe 3 design strategies that can help minimise the effects of these problems:

- In cases where there is a small degree of error, the user must be offered a means to correct or undo the action(s) taken by the system
- If there is a large chance for error, the user must be consulted before the action is taken to confirm its appropriateness
- If there is no way of determining the likelihood of error, the user must be given a set of choices before the system takes any action.

Guideline 6: Provide for deferment of control

Guideline 6a: To the user, over his system and actions/behaviours from other systems/users that may impact on him

Guideline 6b: Involve the user when there is room for doubt

4.3.2 Application of established usability heuristics to context-aware applications

Nielsen's 10 heuristics[3] for user interface design are an often cited and adapted source of guidelines for designing interactive systems. In considering usability heuristics for representing context, our basis is an adaptation of Nielsen's heuristics provided by Sharples & Beale (2002). We review each heuristic in turn and relate it to our review of context-aware technologies for mobile learning, and the guidelines identified in the previous section.

4.3.2.1 Visibility of system status

The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

It is essential to make the current status of the system visible to the user, through clear displays and feedback mechanisms, as discussed above in Section 4.3.1, Guideline 3. A particular problem relates to the presence of dynamic content within a context-awareness system, and whether the system relies on a push or pull model of content delivery. A context-aware system is not a static system in the sense that a desktop PC is static, because the user and their environment is not static.

4.3.2.2 Match between system and the real world

The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

Context-awareness is a difficult concept for most end-users to grasp. Even if the behaviour of the system makes sense to them and is supportive of the user's activity, the actual method of interacting with a context-aware system and the reactive nature of the system is alien to the majority of users. It is essential to find appropriate models and metaphors for representing the state of context-aware systems that make sense to users. These models and metaphors are likely in many cases to be different to the models and metaphors used for desktop PCs, because the mode of operation is fundamentally different.

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[3] http://www.useit.com/papers/heurisics/heuristic_list/html

4.3.2.3 User control and freedom

Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

As discussed in Section 5.1, users need to be able to take control of the system where appropriate, and because context-aware applications are likely to be unfamiliar the methods for taking control need to be made very obvious to the user.

4.3.2.4 Consistency and standards

Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.

At present there is little agreement on how to represent context and how to build interfaces for context-aware applications. This usability heuristic is therefore less applicable to the design of context-aware systems, but it does emphasise the need to rely on internal consistency as well as external consistency. This also relates to the use of appropriate models and metaphors and the match between the system and the real world.

4.3.2.5 Error prevention

Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.

As already identified, providing adequate feedforward information to allow users to determine the results of possible actions is an important feature for context-aware systems. Because of a lack of familiarity with context-aware applications, users are more likely to make errors in choosing between different options. Good use of feedforward information, sensible models, and making the system status visible can all help prevent errors occurring, but there needs to be a wider recognition of how users might struggle with context-aware systems.

4.3.2.6 Recognition rather than recall

Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

Recognition means putting knowledge in the world, rather than expecting it to be in the user's head. This is hard when designing for mobile devices because of limited screen size and because of the many and varied distractions in the environment where such a device may be used. Context-aware applications that use mobile devices therefore need to ensure that their design is kept as simple as possible, so that the user is not required to remember too much information. Standardised ways of getting things done are required: most people are familiar with web browsing and the idea of moving backwards and forwards between pages. We can exploit people's familiarity with well-known concepts, but the trade-off is with the flexibility and complexity of the system.

4.3.2.7 Flexibility and efficiency of use

Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

Probably the most important way of providing accelerators for mobile devices is to allow users to perform tasks in different sequences, once they are familiar with the dependencies between different settings and actions. Novice users will require handholding and a specific order in which to perform actions, but experienced users will be able to perform tasks in an order of their choice once they are confident with the results of each action.

4.3.2.8 Aesthetic and minimalist design

Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

This is never more true than when designing for mobile devices. There is not space on the screen for design flourishes, and so minimalist design is the only answer.

4.3.2.9 Help users recognize, diagnose, and recover from errors

Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

As discussed above, users are likely to be unfamiliar with how a context-aware application operates, especially since there are no agreed standards for their operation. It is therefore even more essential than ever to make sure users can recognise errors and recover from them. This heuristic is related to the concept of intelligibility discussed in Section 5.1.

4.3.2.10 Help and documentation

Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Users of mobile devices have less opportunity to turn to printed documentation, so built-in help that offers appropriate support when needed is essential. Human support should also not be overlooked, with many users finding that they have questions about how a context-aware system works the first time they use it.

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